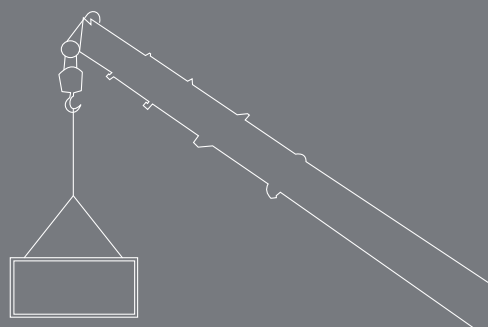
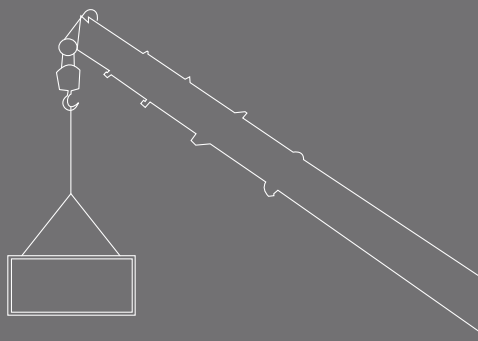


Concrete Home

Precast Concrete to Improve Efficiency in the Design and Construction of Social Housing for Antioquia

Universidad Pontificia Bolivariana



Concrete Home

Precast Concrete to Improve Efficiency in the Design and Construction of Social Housing for Antioquia



Concrete **Home**

Precast Concrete to Improve Efficiency in the Design and Construction of Social Housing for Antioquia

721.04454
R436

Restrepo-Montoya, Alejandro, author
Concrete home / Alejandro Restrepo-Montoya, autor -- Medellín : UPB, 2020.
400 pages, 21 x 29,7 cm.
ISBN: 978-958-764-901-7 (versión digital en español)
ISBN: 978-958-764-722-8 (versión digital en inglés)

1. Precast concrete – 2. Social Housing - design and construction – 3. Building materials – I. Title

CO-MdUPB / spa / rda
SCDD 21 / Cutter-Sanborn

© Alejandro Restrepo-Montoya
© Editorial Universidad Pontificia Bolivariana
Vigilada Mineducación

Concrete home. Precast Concrete to Improve Efficiency in the Design and Construction of Social Housing for Antioquia
ISBN: 978-958-764-901-7 (versión digital en español)
DOI: http://doi.org/10.18566/978-958-764-901-7
ISBN: 978-958-764-722-8 (versión digital en inglés)
DOI: http://doi.org/10.18566/978-958-764-722-8
Primera edición, 2020
Escuela de Arquitectura y Diseño
Facultad de Arquitectura

Gran Canciller UPB y Arzobispo de Medellín: Mons. Ricardo Tobón Restrepo
Rector General: Pbro. Julio Jairo Ceballos Sepúlveda
Vicerrector Académico: Álvaro Gómez Fernández
Decana de la Escuela de Arquitectura y Diseño: Juliana Restrepo Jaramillo
Editor: Juan Carlos Rodas Montoya
Coordinación de Producción: Ana Milena Gómez Correa
Corrección de Estilo: Cristian Suárez

Dirección Editorial:
Editorial Universidad Pontificia Bolivariana, 2020
Correo electrónico: editorial@upb.edu.co
www.upb.edu.co
Telefax: (57)(4) 354 4565
A.A. 56006 - Medellín - Colombia

Radicado: 1948-11-02-20

Reservados todos los derechos. Salvo excepción prevista por la ley, no se permite la reproducción total o parcial de esta obra, ni su incorporación a un sistema informático, ni su transmisión en cualquier forma o por cualquier medio (electrónico, mecánico, fotocopia, grabación u otros) sin la autorización previa de la Editorial Universidad Pontificia Bolivariana y por escrito de los titulares del copyright. La infracción de dichos derechos conlleva sanciones legales y puede constituir un delito contra la propiedad intelectual.

TECHNISCHE UNIVERSITÄT MÜNCHEN

Fakultät für Architektur
Lehrstuhl für Baukonstruktion und Baustoffkunde

Concrete Home
Precast Concrete to improve Efficiency in the Design and Construction of Social Housing for Antioquia

Omar Alejandro Restrepo Montoya

Vollständiger Abdruck der von der Fakultät für Architektur der Technischen Universität München zur Erlangung des akademischen Grades eines Doktor-Ingenieurs (Dr.-Ing.) genehmigten Dissertation.

Vorsitzender:	Prof. Dr.-Ing. Thomas Bock
Prüfer der Dissertation:	1. Prof. Dipl.-Ing. Florian Musso
	2. Prof. Hubert Klumpner

Die Dissertation wurde am 16.05.2018 bei der Technischen Universität München eingereicht und durch die Fakultät für Architektur am 07.06.2018 angenommen.

Anhang I

Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich die bei der promotionsführenden Einrichtung
Fakultät für Architektur / Lehrstuhl für Baukonstruktion und Baustoffkunde - EBB

der TUM zur Promotionsprüfung vorgelegte Arbeit mit dem Titel:
Concrete Home: Betonfertigteile als Weg, die Effizienz in Entwurf und Konstruktion sozialer Wohnbauprojekte in Antioquia zu verbessern

Concrete Home: Precast Concrete to improve Efficiency in the Design and Construction of Social Housing for Antioquia

in Fakultät für Architektur / Lehrstuhl für Baukonstruktion und Baustoffkunde - EBB
Fakultät, Institut, Lehrstuhl, Klinik, Krankenhaus, Abteilung

unter der Anleitung und Betreuung durch: Prof. Dipl.-Ing. Florian Musso ohne sonstige Hilfe erstellt und bei der Abfassung nur die gemäß § 6 Ab. 6 und 7 Satz 2 angebotenen Hilfsmittel benutzt habe.

☒ Ich habe keine Organisation eingeschaltet, die gegen Entgelt Betreuerinnen und Betreuer für die Anfertigung von Dissertationen sucht, oder die mir obliegenden Pflichten hinsichtlich der Prüfungsleistungen für mich ganz oder teilweise erledigt.

☒ Ich habe die Dissertation in dieser oder ähnlicher Form in keinem anderen Prüfungsverfahren als Prüfungsleistung vorgelegt.

☐ Die vollständige Dissertation wurde in _____ veröffentlicht. Die promotionsführende Einrichtung

_____

hat der Veröffentlichung zugestimmt.

☒ Ich habe den angestrebten Doktorgrad noch nicht erworben und bin nicht in einem früheren Promotionsverfahren für den angestrebten Doktorgrad endgültig gescheitert.

☐ Ich habe bereits am _____ bei der Fakultät für _____

_____

der Hochschule _____

unter Vorlage einer Dissertation mit dem Thema _____

_____

die Zulassung zur Promotion beantragt mit dem Ergebnis: _____

_____

Die öffentlich zugängliche Promotionsordnung der TUM ist mir bekannt, insbesondere habe ich die Bedeutung von § 28 (Nichtigkeit der Promotion) und § 29 (Entzug des Doktorgrades) zur Kenntnis genommen. Ich bin mir der Konsequenzen einer falschen Eidesstattlichen Erklärung bewusst.

Mit der Aufnahme meiner personenbezogenen Daten in die Alumni-Datei bei der TUM bin ich

☒ einverstanden, ☐ nicht einverstanden.

Alejandro Restrepo M. .

Medellín (Kolumbien), 30.04.2018, Unterschrift

Concrete Home

Precast concrete to improve efficiency in the design and construction of social housing for Antioquia

Author

Alejandro Restrepo-Montoya
Architect, Professor at *Universidad Pontificia Bolivariana* (UPB), Faculty of Architecture. Medellín, Colombia.
Director of Strategic Urban Projects for Medellín, Colombia, 2016 – 2020
Scientific Ambassador for the German Academic Exchange Service (*Deutscher Akademischer Austauschdienst,* DAAD) in Colombia.

Director

Professor Florian Musso
Dissertation Chairman. Professor at *Technische Universität Munchen* (TUM). Faculty of Architecture.
Lehrstuhl für Entwerfen, Baukonstruktion und Baustoffkunde (EBB). Munich, Germany.

Advisor

Professor Hubert Klumpner
Advisor. Professor at Department of Architecture D-ARCH, *Eidgenössische Technische Hochschule* (ETH).
Chair of Architecture and Urban Design. Zürich, Switzerland.

Abstract

Technische Universität München

Meldung des Dissertationsthemas

zur Vorlage beim Promotionsamt

Identifikationsnummer	1432784

Titel der Arbeit
Concrete Home

Concrete Home

Untertitel
Betonfertigteile als Weg, die Effizienz in Entwurf und Konstruktion sozialer Wohnbauprojekte in Antioquia zu verbessern

Precast Concrete to improve Efficiency in the Design and Construction of Social Housing for Antioquia

Doktorand/-in

Restrepo Montoya	Omar Alejandro
Nachname	Vorname

Fakultät
Fakultät für Architektur

Zusammenfassung (Abstract)

Die Forschungsarbeit untersucht konstruktive Möglichkeiten, die Effizienz sozialer Wohnbauprojekte im Allgemeinen und besonders in Antioquia / Kolumbien zu steigern. Die theoretischen Ergebnisse werden durch praktische Experimente mit Prototypen und Anwendungen in kolumbianischen Wohnbauprojekten verifiziert. Es wird dargestellt, dass durch Betonfertigteile Zeit- und Geldersparnis ermöglicht wird.

This study investigates constructive possibilities to improve the efficiency of social housing in general and in the Department of Antioquia / Colombia in particular. The theoretical results have been proven and verified by practical applications in prototypes and in housing projects in Colombia. The results show that by using precast concrete, time and money can be saved by the application of the theoretical framework.

Einverstanden:

TUM FAKULTÄT FÜR ARCHITEKTUR
BAUKONSTRUKTION & BAUSTOFFKUNDE
PROFESSOR FLORIAN MUSSO
D - 80333 MÜNCHEN, ARCISSTRASSE 21
TEL. 0049 (0) 89 / 289 -22302 FAX. -22355

Unterschrift des 1. Prüfers (Doktorvater/-mutter) mit Namensstempel

Alejandro Restrepo M.

Unterschrift (Doktorand/-in)

TUM Universitätsbibliothek Formular Nr. 0031-DIR-ALL Stand: 16.07.2014

To those who have kept the hope.

"All Colombians are entitled to decent housing.
The State will set the conditions to make this right effective and will promote affordable housing,
adequate systems of long-term financing and associative forms of execution for these housing programs".

The 1991 Political Constitution of Colombia (*Constitución Política de Colombia,*1991).
Chapter 2. "Of the Social, Economic and Cultural Rights".

Preface

Some years ago, while walking in lower New York City, a young man approached me to talk about how my music had a positive effect on his life. I asked him for his name, where he was from and what he did, to which he answered: Alejandro, from Medellín, Colombia, and I am about to graduate as a Doctor of Architecture in a German university. His last words awoke my curiosity and we started a conversation about the need for creating new social housing proposals; accessible to the less economically favored populations yet with designs that prompted quality of life. Something unlike a matchbox —with only a window and a door— which are closer to prison cells than to homes, and that fail to create a positive existential environment or even provide ideal privacy.

Since our first encounter we have not lost contact. I spoke about my wishes to adapt and possibly apply, in Panama, the social housing proposal developed in his doctoral dissertation. And as many of my songs' lyrics, which seek to document the experience of life in a city, his work will also help create an answer that will produce positive effects, beyond his beloved Medellín, beyond the borders between our countries, to be shared and used by those who desperately need and seek attention.

Perhaps some will deem the inclusion of this prologue in a doctoral dissertation an odd decision.

I believe Alejandro and I think differently.

To prevent the Apocalypse caused by the disappearance of human solidarity, our suicidal selfishness and the predominance of materialism over spiritual consideration, we need an aid that will justify the triumph of our best instincts. And this collaboration will come from many sources, by people of all ages and trades, of all nations, gender and religions. Nothing framed inside the thought of a better future for us all can seem strange or out of place. I congratulate you, Alejandro, for accomplishing with discipline what you started so long ago, away from your homeland but with her always present, motivating and justifying your academic efforts.

I long for the opportunity to study your work, publish it in our website and, God willing, combine it with a social project that I hope will result beneficial, not only to my dear Panama but to our Latin America.

A big hug,



Rubén Blades
New York, June 2018

Content

Introduction
1 Problem
2 Context
3 Social Housing
4 Precast Concrete Technology
5 Case Studies
6 Efficiency
7 Conclusion
8 Experimental research
9 Perspectives
10 Bibliography
Annexes

Introduction

Precast concrete and social housing. An alternative to improve efficiency and reduce the social housing deficit in Antioquia, Colombia

Social housing has been under study for several decades. The spaces that comprise it, the technical systems with which it has been built, the costs, the housing quality and their contributions to urban and regional developments are permanently considered in the project that tries to satisfy the wishes of communities while improving their quality of life.

In a context in which traditional constructive systems and massive, totalitarian industrializations have still not completely resolved the quantitative and qualitative deficit of social housing, this research proposes the partial industrialization of social housing through the prefabrication in concrete of the support structure, as a strategy to increase efficiency, qualify local construction processes, improve their quality, increase their quantity, and reduce the costs and time that are conventionally used for their construction. To bring industrialization closer to local constructive traditions reaffirms cultural traditions, responds to the conditions of the environmental, social and economic settings, and proposes spaces and solutions from constructive techniques that contribute to the well-being of the population.

The industrialization of social housing can help solve the deficit through, continuous production and the low costs of some of the elements that make it up. The challenge for architecture and engineering consists of proposing spaces that respond to the contemporary needs of the family groups that inhabit them, considering the highest conditions of housing quality possible and preserving conditions of identity and individuality in the communities.

This text focuses on the technical model of prefabrication in concrete of the support structure, to propose solutions to the problems related to the quality of housing, the production time, the efficient use of materials and the industrialization processes associated with traditional processes. Grouped in ten chapters, this seven-year research process was conducted in the Technical University of Munich (*Technische Universität München*, TUM) and in the *Universidad Pontificia Bolivariana* (UPB) in Medellín, Colombia.

In the first part, made up of Chapters 1 and 2, the problem of the housing deficit is analyzed, together with the national and regional contexts through their geographic, social, economic, industrial, political, legal, historic, urban and architectural dimensions.

The second part, made up of Chapters 3 and 4, studies the technical principles of precast concrete and solves three fundamental questions: *What is prefabrication? What are its characteristics? How is this technique contextualized in social housing?* Projects built in Western Europe and America since 1948, were analyzed from each of their components to understand in detail the technical, housing and aesthetic essence of prefabrication in concrete.

The third part, made up of Chapters 5 and 6, presents the central ideas on which the project is structured, considering three fundamental aspects to increase efficiency in the construction of social housing: *quantity* and *quality* in relation to the *resources* necessary.

In the fourth part, made up of Chapters 7 and 8, the results of the research are presented: the architectural and constructive typologies of the dwellings, conceived in three moments: industrialization of the support structure, individualization of the architectural designs and transformation of the living space. Two prototypes, built on a 1:1 scale at the end of the research process, detail the components, technical processes and achievements, which determine the impact of this project in the context of social housing in Colombia and the Department (State) of Antioquia, considering the future of this constructive technique and its subsequent developments, which will be part of new research processes.

The fifth part of this investigation is made up of Chapters 9 and 10, and the Annexes. Chapter 9 proposes future structural, urban and architectural developments for this constructive system through the variation of tis geometry, the substitution of some of its components and the use of lighter industrialized elements, which allow reducing the housing deficit in rural and urban areas with difficult accessibility. Chapter 10 lists the bibliographic sources used in the development of the research. The annexes complement the information analyzed and the proposals made in the previous chapters.

This research aims to put criteria at the service of engineering, architecture and the community for the industrialization of a social housing that considers traditional techniques of construction, which allows the preservation and reaffirmation of the value of cultural traditions, the environmental setting, the identity and quality of life in efficient, economic projects and with measurable criteria of quality.

On April 28, 2015, an application for a scientific invention patent was filed in Colombia for the industrialized modular construction system that was developed in this doctoral research. On April 28, 2016, this application ascended to the category of an international patent application. On December 8, 2017, the Colombian Superintendency of Industry and Commerce (SIC) granted National Scientific Patent Number (11): 15096687 to the Prefabricated Modular Building System developed in this doctoral dissertation.

The results of this research will be placed at the service of the community with the aim of expanding the supply of housing solutions in our context and replicating them elsewhere, improving the living conditions of the families that make up our society, and providing new solutions to solve the housing deficit with quality housing.

I

Problem



Figure 1
A view of Medellín from the northwestern mountains. In the foreground, lots available for construction and the social housing buildings built by the local Government. In the background, housing built by families classified as belonging to the quantitative deficit.

The accumulated social housing deficit in Colombia and in the Department of Antioquia is caused, among other factors, by economic, technical and social conditions, which are classified in quantitative and qualitative deficiencies.

1.1. The problem in quantitative terms

The number of homes built has not been sufficient to offer a housing solution to existing families in Colombia and Antioquia. This problem is related to the costs and time of traditionally used systems, such as *in-situ* cast concrete and structural and non-structural masonry, in the construction of social housing. These same techniques, which come from the construction of housing in medium- and high-socioeconomic strata, have been replicated in sectors where social housing is built. Therefore, no obvious technical difference exists between the construction methods of high-socioeconomic strata and social housing. According to the Colombian Chamber of Construction (CAMACOL[1]), the costs of the support structure can account for up to 65% of the direct costs of construction (Forero, 2011, pp. 6-7). To adapt to available budgets, architectural designs must seek ways to reduce costs in the remaining 35% of the operation. The social-housing cost surpasses the purchasing possibilities of families with fewer economic resources, even when the availability of subsidies or loans has paved the way to purchase new and used housing. Therefore, these families must appeal to other strategies, such as renting, sharing their home with others or beginning self-construction processes with the structural and housing risks that this activity entails. In addition to the cost, the construction time of traditional systems does not balance the speed of growth of the deficit, which makes the amount of solutions built be insufficient to satisfy the demand that exists and that increases steadily. From the social point of view, migration from the countryside to the cities and internal displacement, caused by the violence or the search to improve living conditions, has caused the population growth in certain areas to exceed the supply of housing available, which makes the deficit increase (Figure 1).

1.2. The problem in qualitative terms

Some social houses that have already been built do not meet the minimum living conditions or the quality conditions established in existing regulations. Some of their elements, such as floors, walls and roofs, do not exist or present serious physical deterioration. Other houses do not have adequate ventilation, lighting or the health and safety conditions necessary; others do not have a kitchen or public utilities, such as water and electricity.

1 For its acronym in Spanish



Figure 2
A view of Medellín toward the northeastern mountains. Houses in the qualitative deficit that do not meet the safety and living conditions established by existing regulations. Photo: M. Vásquez.

Some have overcrowding, with four or more people per room. According to the National Administrative Department of Statistics (DANE[2]), these houses require the provision of public utilities, improvements in their physical structure and expansion of the living space (Freire et al., 2009, p. 15). Despite the existence of these homes, usually built by the families themselves, they have not generated the desired welfare conditions nor the ones established in existing regulations (Figure 2).

1.3. Current policy of social housing

Article 90 of the National Development Plan, contained in Law 1753 of 2015, defines Social Housing as the housing unit that meets the quality standards in urban, architectural and construction design. According to its market value, social housing is classified into two types: Priority Social-Interest Housing (*Vivienda de Interés Social Prioritario,* VIP[3]) and Social-Interest Housing (*Vivienda de Interés Social,* VIS[4]) (Law 1753, 2015, Art. 90).

1.3.1. Priority Social-Interest Housing (*vivienda de interés social prioritario, VIP*)

This type of housing must meet two conditions, according to the National Development Plan for 2014-2018: a maximum selling price of 70 minimum monthly wages (*Salario Mínimo Mensual Legal Vigente,* SMMLV[5]) in Colombia[6], and a minimum constructed area of 45 m². Its average selling price per square meter is COP 1,215,265 (approximately Euros (€) 347) (Law 1753 of 2015, Art. 90). In addition to these requirements, and according to CAMACOL and the Antioquia Regional Office Manager, Eduardo Loaiza, the market offer proposes these other conditions for Priority Social-Interest Housing (*Viviendas Sociales de Interés Prioritario,* VIP): a kitchen, a laundry area, a bathroom, a social area composed of a living room and a dining room, two bedrooms, a main door and a door for the bathroom, installations for water, electricity and telephone. These homes are not provided with finished floors or walls, except in the bathroom, kitchen and laundry area (E. Loaiza, personal communication, January 20, 2016) (Table 1).

2 For its acronym in Spanish
3 For its acronym in Spanish
4 For its acronym in Spanish
5 For its acronym in Spanish
6 In January of 2018, equal to COP 781,242 (approximately € 223.52)

Components	VIP	VIS
Maximum selling price in monthly wages (Colombia)	70	135
Maximum selling price in COP	54,686,940	105,467,670
Maximum selling price in €	15,646	30,175
Minimum constructed area (m²)	45	From 45 to 80
Average selling cost in COP per square meter (COP/ m²)	1,215,265	1,318,346
Average selling cost in Euros per square meter (€/ m²)	347	377
Kitchen	1	1
Laundry area	1	1
Bathroom	1	1 or 2
Living room	1	1
Dinning room	1	1
Study	0	1
Balcony	0 or 1	0 or 1
Bedrooms	2	2 or 3
Main door	1	1
Door in the bedrooms	0	2 or 3
Door for the bathrooms	1	1 or 2
Finished floors	10% to 30%	75% to 100%
Finished walls	10% to 30%	75% to 100%
Installations for water, energy and telephone	Yes	Yes
General accessibility to housing units	On the first floor	On the first floor
Natural ventilation and lighting	Yes	Yes
Vehicular access and public-transport routs	Yes	Yes
Proximity of the project to sources of pollution	No	No
Home garbage collection	Yes	Yes
Continuous pedestrian circulations in nearby environments	Yes	Yes
Elevator	No	No

Table 1
Regulatory requirements and commercial offerings for Priority Social-Interest Housing (VIP) and Social-Interest Housing (VIS) in the real-estate market in Colombia and Antioquia.

1.3.2. Social-Interest Housing (*Vivienda de Interés Social, VIS*)

Colombia's National Development Plan for 2014-2018 proposes that Social-Interest Housing (VIS) must meet two conditions: a maximum selling price of 135 minimum monthly wages in Colombia and a minimum constructed area of 45 m². In the local real estate market, Social-Interest Housing (VIS) with up to 80 m² has been built. The average commercial cost for social housing, 80 m² in area, is COP 1,318,346 per square meter (approximately € 377) (Law 1753 of 2015, Art. 90). According to CAMACOL, in addition to these requirements, the VIS social-housing market offers: a kitchen, a laundry area, one or two bathrooms, and a social area composed of a living room, a dining room and sometimes a study. It may eventually have a balcony, two or three bedrooms, a main door, a door in each bathroom, a door in each bedroom, installations for water, electricity and telephone, finishings in the bathroom, the kitchen and the laundry area.

According to the commercial offer, some homes are delivered with finished floors and walls throughout the house (E. Loaiza, personal communication, January 20, 2016) (Table 1).

1.4. The deficit

According to DANE, the housing deficit is classified as quantitative and qualitative. The quantitative deficit indicates the number of houses necessary for every family to have a home. The qualitative deficit indicates the number of homes that do not meet the minimum standards to provide an adequate quality of life for its inhabitants (Freire et al., 2009, pp. 14-16).

1.4.1. The quantitative deficit

This is the difference between the number of families and existing homes (Freire et al., 2009, pp. 14-16). In Table 2, the indicators used by DANE to measure the quantitative housing deficit in Colombia are presented:

Indicators to measure the quantitative deficit
Total lack of housing
Cohabitation: two households in a single house
Immitigable overcrowding: *Homes with five or more persons per room* *Homes in which each person has less than four square meters for his or her use*
Homes built with temporary or precarious materials
Family groups of any size that share the home with others *There is a lack of housing since they do not have a home for their own use*
Homes located in high risk-areas and with conditions of evident deterioration

Table 2
Indicators used by DANE to measure the quantitative housing deficit.

The causes of the quantitative deficit are analyzed from two aspects: the costs of social housing and the speed of its construction in relation to the growth of the population.

1.4.1.1. Construction cost

While social housing is one of the least costly goods in the real-estate market in Colombia and Antioquia, the limited financial resources available to homeless families, the conditions of financial credits and the instability of the costs of materials have increased the magnitude of the housing deficit. Until now, the number of houses built and the investment made by the Government and the private construction industry have not balanced the deficit numbers. Architect Alejandro Aravena and Engineer Andrés Iacobelli propose that these strategies have been used to reduce costs in the construction of social housing in the local context, which have deteriorated its quality: location of the projects in remote areas, where land costs less that in urban centers and the reduction of living areas (Aravena & Iacobelli, 2012, p. 14). To these two strategies the elimination of some non-structural elements (walls, windows, doors), and most of the finishing materials would have to be added. When construction processes are not formalized, inhabitants generally resort to self-construction by squatting on land, with environmental and stability risks that become a threat and a new security problem.

1.4.1.2. Construction time

Generally, in social-housing projects, the architectural designs are not intended to be constructed through standardized processes and the serialized production of their parts. Failure to meet deadlines or budgets is occasionally resolved by eliminating non-structural elements and finishes to reduce construction costs and time, which affects the architectural and technical quality of the project. The traditional techniques selected to build social housing make time periods uncertain. Construction time has a significant impact on the final cost, since failure to meet the deadlines originally established increases costs and delays the return on investment. Sales are deferred and some fixed costs, such as public services, labor, security and the use of equipment, must still be paid. Architectural designs, in some cases made without the principles of dimensional coordination, generate waste and rework in the construction, which increase the time and direct costs. According to CAMACOL, the overruns in materials, labor and the extension of construction time due to waste or rework in constructions may reach between 3% and 5% of the total cost in the social-interest housing projects (E. Loaiza, personal communication, December 20, 2010).

1.4.2. The qualitative deficit

This is the number of homes that do not meet minimum standards of quality and do not provide suitable living spaces for its inhabitants (Freire et al., 2009, pp. 15-16). The indicators used by DANE to measure this deficit are presented in Table 3:

Indicators to measure the qualitative housing deficit
Deterioration in floors, walls and ceilings
Mitigable overcrowding: homes that have four persons per room
The absence of a kitchen or deficiencies in the functioning of this space
Homes with no provision of public services
Homes that need to be improved or have their area increased
Deficiencies in lighting and ventilation

Table 3
Indicators used by DANE to measure the qualitative housing deficit.

The causes of the qualitative deficit are found in the failure to meet the minimum requirements for the design and construction of social housing and the informal planning and construction processes. Even when houses are already inhabited, the lack of financial resources does not allow families to complete them. Some homes, self-built in most cases, are located in geologically unstable areas with no access to public transport networks, spaces for education, health and recreation. Mass-housing solutions are built to resolve the quantitative deficit without guaranteeing the solution of the qualitative deficit. The unplanned growth of existing housing ignores urban regulations and generates problems related to high density, availability of public services and quality of life in domestic and urban spaces. These qualitative deficiencies are classified as objective and subjective criteria:

1.4.2.1. Objective criteria: Non-compliance of minimum social housing requirements

- Deterioration of the living space due to a lack of modularity, the absence of dimensional coordination and the elimination of finishes in floors, walls and ceilings.
- The processes used, generally associated with self-construction, prevent the replication of technical systems for the construction of social housing.
- Social housing in the qualitative deficit is generally located in places where public utilities, such as water and electricity, do not exist. This causes difficulties in transporting materials to the construction sites and generates urbanization processes in unstable areas with high geological risks.
- The adaptability of housing to inclined topographies is difficult due to the architectural typologies and the construction systems used. The load-bearing capacity of these areas makes it necessary that the foundations of the support structures be deep, which increases direct costs.
- Due to the characteristics of the topography and the characteristics of the houses, there are difficulties for accessibility by the disabled.

1.4.2.2. Subjective criteria: Informal processes of planning and building

- The complexity of some of the construction systems chosen increases costs and time, reduces the budgets available and the quality of the living space.
- The construction systems that use structural elements in the interior spaces reduce the flexibility of their use.
- Some houses show a lack of environmental quality and bioclimatic comfort in the living space.
- The placement of structural elements in the façades and their systematic repetition reduce the individual expression in the language of each home and generate responses removed from the aesthetic beauty desired by its occupants.
- The location of some structural elements restricts the transformation of the interior space after being occupied.

1.4.3. The accumulated deficit

The sources consulted to determine the accumulated housing deficit in Colombia and Antioquia are from the official census, conducted by DANE in 1993 and 2005.

1.4.3.1. The accumulated deficit in 1993

According to official figures, in 1993 Colombia had a total of 7,159,825 families. Of these, 3,841,300 (53.65% of the total) had some type of housing deficit. The quantitative deficit was 1,217,056 homes (equal to 17%) and the qualitative deficit was 2,624,244 homes (equal to 36.65%) (DANE, 1993). In 1993, the Department of Antioquia had a total of 981,004 families. Of these families, 372,288 (37.95% of its population) presented some type of deficit. Among them, 69,301 homes (7.06%) presented a quantitative deficit and 302,987 (30.89%) were classified as housing in the qualitative deficit (DANE, 1993) (Graphic 1).

1.4.3.2. The accumulated deficit in 2005

The most recent official housing census, conducted by DANE, indicated that Colombia had 10,570,899 families. The accumulated deficit in the country was 3,828,055 homes, 36.21% of the population. Of these homes, 1,307,757 (12.37%) presented a quantitative deficit, and 2520,298 homes (23.84%) were in a qualitative deficit (DANE, 2005). In the same year, the Department of Antioquia had 1,458,193 homes, of which 386,118 (26.48% of the total) were in deficit. Of these, 96.169 (6.6%) presented a quantitative deficit and 289,949 (19.88%) were classified as housing with a qualitative deficit (DANE, 2005) (Graphic 1).

1.4.4. Variations in the deficit

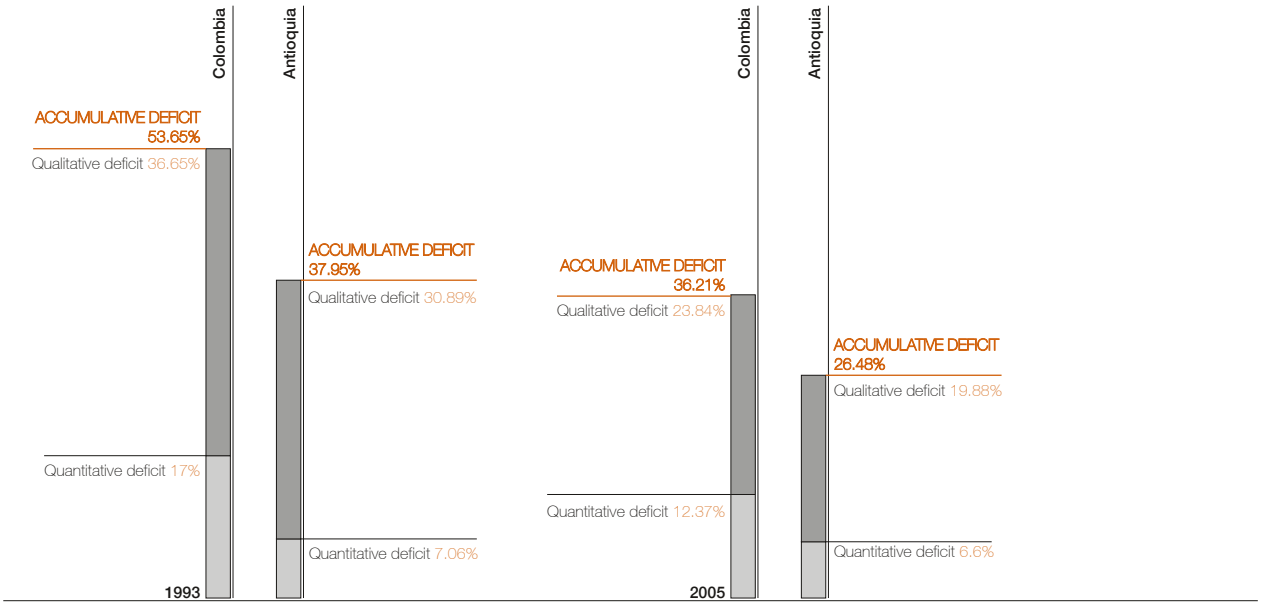
The official housing census in 2005 indicated that Colombia had 3,411,074 families more than in 1993. This explains why the average annual growth was 284,256 families in the country (equal to 2.69% per year of the total population). In the Department of Antioquia, the increase between 1993 and 2005 was 477,189 families, indicating an average annual growth of 39,765 households (equal to 2.73% per year of the state's population). The variations in the quantitative, qualitative and total deficit in this period presented the following results:

1.4.4.1. Quantitative

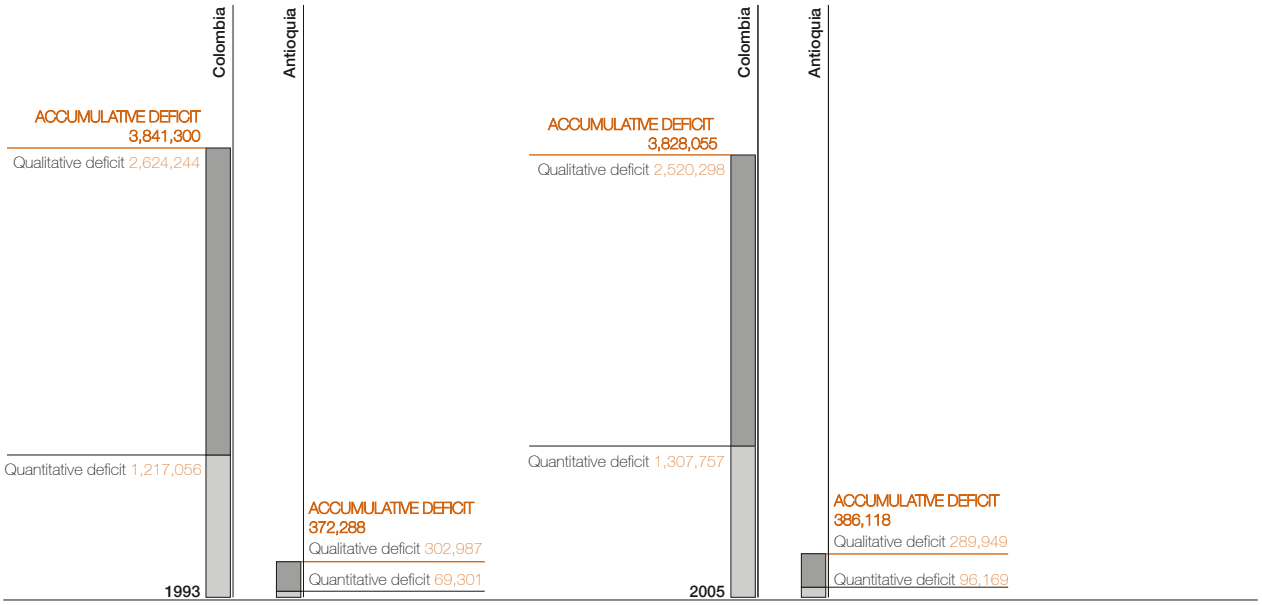
Between 1993 and 2005, the quantitative deficit in Colombia increased from 1,217,056 to 1,307,757 households, a total of 90,701 units, an average of 7,558 homes per year. In percentage terms, the deficit decreased 4.63%, from 17% in 1993 to 12.37% in 2005. In the Department of Antioquia, the quantitative deficit increased by 26,868 units, rising from 69,301 families in 1993 to 96,169 families in 2007, an average of 2,239 families per year. As a percentage, in considering the increase in the population, the quantitative deficit in Antioquia decreased by 0.46% (Graphic 2).

1.4.4.2. Qualitative

In this same period, the qualitative deficit in Colombia fell by 103,946 households (12.81%), from 2,624,244 in 1993 to 2,520,298 units in 2005. In Antioquia, the qualitative deficit was also reduced by 13,038 households, going from 302,987 units in 1993 to 289,949 in 2005. As a percentage, the qualitative deficit in Antioquia decreased by 11.01% (Graphic 2).



Graphic 1
The accumulated quantitative and qualitative deficit in Colombia and in Antioquia in 1993 and 2005, according to the official figures from DANE.



Graphic 2
Variations in the quantitative, qualitative and accumulated deficit in Colombia and Antioquia between 1993 and 2005, according to the official figures from DANE.

1.4.4.3. Accumulated

The accumulated deficit (understood as the sum of the quantitative and qualitative deficit) decreased in Colombia by 13,245 units (17.44%), from 3,841,300 families in 1993 to 3,828,055 in 2005. In Antioquia, the total housing deficit increased by 13,830 units (an average of 1,152 units per year), but as a percentage, it fell 11.47%, considering the increase in the population in this period (Graphic 2).

1.5. Hypothesis

While official sectors and private enterprises have built numerous social housing solutions, the quantitative and qualitative deficit has still not been resolved or drastically reduced. Therefore, it is necessary to build a greater number of homes in less time, with lower costs and with a detailed control of quality. To do this, it is necessary to increase efficiency in the construction, adapt the houses to different contexts and respond to the requirements of their inhabitants to generate well-being. The strategies that are proposed to do this are industrialization (serialized and standardized production of structural elements in less time), customization (individualization in the architectural design, in the production process and in the construction of the projects, to offer different responses and avoid undesired aspects generated by the massification of the architectural language) and transformation (modifications and improvements made by the families themselves, according to their needs and preferences, once they inhabit the space).

1.5.1. Industrialization: serial production of structural elements

To reduce the housing deficit, the industrial production of structural elements incorporates the advantages or standardization and mass production to increase the number of units, save time and reduce costs with detailed quality control. For social housing, it is necessary to produce the components that the population itself cannot produce (the support structure, roof and technical installations), with speed, quality, precision and security. The complementary non-structural elements, such as interior and exterior walls or the installation of the finishing materials, could be delivered later or could be built by the communities themselves.

With the industrialization of the structural component of the houses, an additional element is added: saving time, which could also lead to a reduction of costs. Social housing is supported and defined by its structure, which should be one of the fastest works to execute. Decreasing execution time without sacrificing quality construction and the safety of the housing reduces the financial costs and, therefore, the general costs of the operation. According to the conditions of the accumulated housing deficit, projects should be built as quickly as possible. The industrialization of housing, such as the prefabrication of all or some of its parts, is proposed. Aravena and Iacobelli (2012) argue that if there is one place where the industrialization or prefabrication of architecture makes sense, that place is in social housing. They propose that a precast structural system saves time because, instead of being built, it is only assembled. In prefabrication, the standardization of the pieces and the systematic repetition of the processes is the fundamental aspect of its own efficiency. In addition, precast constructions control the quality of their components in the production site, thus being able to certify the structural calculation, its manufacture and assembly. Reducing construction time in social housing is, therefore, economically and socially desirable.

In-situ cast concrete, which precedes the use of precast concrete, has been used in the construction of various architectural projects: homes, offices, institutional buildings and public spaces. Given the use that concrete has had as a structural material in the Colombian context and in the Department of Antioquia, precast concrete is a possibility to industrialize the construction of social housing. This system allows controlling its quality, knowing its costs beforehand, and saving time in construction. Knowledge of the material will provide the leap to its industrialization to improve efficiency in the construction of public housing. Precast concrete is a system considered and endorsed by the Colombian Earthquake-Resistant Construction Regulations (NSR-10). The raw materials for its production can be found in the Colombian market. According to Eduardo Loaiza, Colombia produces approximately 93% of the materials for construction, which means that, by increasing construction through a system that uses raw materials produced in the country, the economy and employment also grow (E. Loaiza, personal communication, December 12, 2010). The industrialization of concrete through prefabrication is proposed to achieve better quality, control of costs and time through the optimal use of the resources available: urban and architectural space, materials, labor activities and equipment necessary to assemble the precast elements.

1.5.2. Customization: individualization during design and construction

The standardization of social housing, desirable to construct a greater number of housing units and respond quickly at a low cost, has been criticized historically for the inability to accommodate the diversity of users that it serves. Ramón Araújo (1997, p. 8) proposes that there are many examples that confirm that homogeneous solutions are unable to respond to different family structures, each with different tastes and sensibilities and a natural ideal to identify or customize their home. Architectural-design efforts, that have attempted to break the repetitive pattern, have fallen into arbitrary aesthetic operations at the expense of the efficiency of the system itself.

In the configuration of social housing, the support structure is the standardized and industrialized element that ensures the safety of the building. With the non-structural elements, the language of the housing is individualized and the interior spaces are designed according to the conformation of the family. The non-structural elements may be designed in different ways, in the architectural design or modified by the families themselves. This is a process of "customizing" the housing, according to the context and the preferences of its inhabitants. It is an adaptation of architecture to the support structure with different aesthetics (Aravena & Iacobelli, 2012, p. 471).

Industrialization is the strategy for the mass, quick and low-cost production of structural elements. Customization of the non-structural elements is the strategy to generate

a diverse language from the architectural design, adapted to the environment and the preferences of its users in the social housing. To reduce the social housing deficit by using skilled labor in production factories and conventional labor in construction processes, a strategy is proposed that simultaneously considers the efficiency of industrialization and the diversity of customization.

1.5.3. Transformation: improvement and personal contribution after occupation

While it is possible to conceive different responses from the architectural design, to avoid the monotony of standardized solutions, it is the families themselves who tend to transform the space and the appearance of the place in which they live according to their needs or with their aesthetic preferences in search for conditions of identity. Some families enlarge their homes to the size desired or modify the living space to give it another use. Others vary the shapes and colors of the façades to personalize the language of the housing.

While the customization process generates a desirable individuality in architectural and design processes, the transformation or the personal contribution of the families who live in the houses adapt these spaces to their living needs and their preferences. The intervention on the living areas and the language of the home is the process of adapting the space to the family's needs, to the dreams of those who live there and to the environmental conditions. To the extent that the structure is designed in a standardized, repetitive manner, the non-structural elements will define the spaces for growth and the transformation of the homes with different shapes and appearances. According to Aravena and Iacobelli (2012), this spontaneous construction, without the presence of skilled labor, now operates as an adaptation of the structures to the preferences of each family, which gives vitality and diversity to urban housing complexes.

Partially industrialized housing resolves the limits of living space with a support structure made in an industrial plant and with all the technical standards that ensure its quality. The language of the façades, future growths and the adaptation of the interior space to the needs of the families are aspects that link the living space to their daily activities and to the quality of life each family seeks.

Summary

To increase the quantity and quality of social housing to reduce the housing deficit in Antioquia

The number of houses that has been built in the local context since the mid-XX Century has not been sufficient to meet the existing demand or to reduce the housing deficit. The few variations in the structural systems and in the construction processes to build social housing have caused the same formulas to be repeated without the problem being solved.

Housing with lower costs and construction time compared to traditional construction systems

In terms of quantity (quantitative deficit), this has not been solved because of two main factors. The *costs* and the *time* required by the construction processes with the conventionally used systems, such as cast-concrete structures and structural masonry walls. With the use of these systems, traditional construction processes have not resolved the housing deficit and the time required in the conventional construction processes are greater than those of the deficit growth. If the construction processes of social housing reduced their costs, a greater part of the population could access them. If construction deadlines were reduced, the speed of construction of new housing would expand the existing supply and with market conditions, sales costs could be reduced. Therefore, it is necessary to rethink the technique of the construction processes to reduce the costs and time required by these social-housing construction processes. The solution considered is the industrialization of part or all of the social-housing construction processes through the standardization and serial production of some of its components and of the installation processes, which should be studied from social, cultural, topographical, transport, economic and technical aspects, among others.

Housing with urban, spatial and technical quality control

In terms of the quality of social housing (qualitative deficit), this is associated with those that do not meet the minimum requirements required by current regulations for their design and construction. This problem is classified in the following aspects:

Objective criteria (non-compliance with the minimum quality requirements in social housing):

- The construction processes used in social housing in the local context do not consider criteria of modularity or dimensional coordination among the structural and non-structural elements. This condition increases costs, makes construction processes difficult and causes the non-installation of some of the housing components.
- Individual, informal and unskilled construction processes do not allow massive replication of industrialized technical solutions that could reduce costs and increase the quality of the processes.
- The location of new housing projects in territories far from urban centers and services hinders the transportation processes of materials, which causes the use of non-certified elements that put the stability of the constructions and, therefore, the life of people at risk.
- The informal occupation of territories means that housing is not adequately adapted to the land with topographical difficulties and soils with different mechanical resistances. The use of structures with point loads (such as skeletal system), formed by columns and beams or with linear loads (such as masonry load-bearing walls) cause foundations to be deeper and more expensive, to ensure the stability of the system; this reduces the budgets for the construction of the living space and the selection of finishings.
- The territories available, generally sloped and away from urban centers, reduce the possibilities of accessibility to housing by all types of people.

Subjective criteria (caused by informal planning and construction processes of social housing):

- The constructive processes used in social housing in the local context are complex, artisan, far from industrial developments, with uncertain periods of time and costs.
- Houses built with conventional structural systems (skeletal or load-bearing walls) minimize the possibilities of variation in the use of interior space and the individual expression in the language of their façades.
- The architectural designs and construction systems used do not consider criteria of bioclimatic and environmental quality and the comfort of the interior space.
- The technical systems used, with load-bearing structures that occupy considerable areas of the façade, cause the languages of the housing to lack individual expression, which distances the façades from the criteria of individuality and beauty desired by the communities.
- By having construction systems that reduce the flexibility of the spaces, the possibilities of transformation or adaptation of the houses to the future are reduced, generating responses that are far from the desires and the needs of the inhabitants.

Three strategies: rationality, identity and incrementality

To increase the number and quality of housing, control costs and time, meet the minimum requirements established by existing regulations and formalize the planning, design and construction processes, the design and construction of social housing is proposed in three moments:

Rationality: industrialize the essential (the support structure)

The production process carried out in industrial plants producing materials.

Controlling the industrialized or prefabricated production of the support structure from the industries allows having standardized productions, reducing costs in the scale productions, decreasing time in the manufacture of these

elements, while having verifiable quality standards and safety criteria controlled from the production plants. The support structure must be economical and have agile installation processes, which reduce costs and time of the structures conventionally used. It should be modular, replicable in different contexts, transportable, adaptable to different conditions, conforming affordable housing with simple and economical installation processes. It should allow flexibility in the use of the housing, improve the comfort of the interior space, permit different aesthetic responses in the façade according to the context and culture of its inhabitants, and make the future transformation of the living space possible.

Identity: personalize the necessary (the living space and the language of the dwellings)

The participatory design process carried out by professionals and the communities.

Social housing should allow the adaptability of its structural systems and its non-structural elements to the environmental characteristics of the surroundings, the cultural traditions of its inhabitants and the desires of individuality of families. To increase flexibility, the support structure must occupy perimeter spaces and define interior areas and façades with a minimal presence of structural elements. This allows adapting existing space to the needs of the families and the language of the building to the climatic, cultural and economic conditions of the context. A perimeter support structure, allowing the presence of free stories and façades, permits the interaction of architectural professionals with communities from the design processes, generates responses from users' wishes, improves bioclimatic conditions, defines criteria of beauty based on the local traditions and desires of the communities, and establishes freedoms for the transformation and growth of the interior space from the needs of families over time.

Incrementality: transforming the ideal (uses, areas and ways of living)

The process of occupation and appropriation of housing made by the communities.

Structural systems and the conventional conception of housing do not allow growth or transformation over time, activities to which communities generally resort in the local context. In popular housing, space can be transformed according to the increase of the members of the family group, with the implementation of new economic activities or with the desire to increase the areas or modify the appearance of their homes. Therefore, the structural systems of social housing must be articulated with urban and architectural designs that permit conceiving evolutionary and incremental spaces, transforming their use over time, modifying spatiality and transforming inhabited space according to the needs or desires of family groups.

2

Context

Geography, social and cultural characteristics of the population, economy, transport infrastructure and industrial developments have conditioned the process to design, construct and inhabit social housing. The urban group's characteristics, typological models, materiality and forms of living are the result of a relation between the context and the project that define the appropriation of space, its transformations, architectural language and quality of life.

2.1. Geography

The Department of Antioquia is located in the northwestern area of Colombia and occupies an area of 62,612 km², equal to 5.6% of the national territory (Graphic 3). It is composed of 125 municipalities, grouped in nine regions: Urabá, North, Lower Cauca, West, Aburrá Valley (where Medellín, its capital, is located), Northeast, Southeast, East, and Middle Magdalena. These combine different elements of Colombian geography: the sea, plains, mountains, plateaus, moors, rivers, marshes and forests (*Instituto Geográfico Agustín Codazzi,* IGAC, n. d.).

2.1.1. Topography

Two thirds of the territory in Antioquia is flat surfaces located to the north and west: the Magdalena River valley, the lower part of the Cauca River, the areas near the Department of Chocó, and the Urabá region; near the Caribbean coast. The other third of the surface is conformed of mountainous areas from the Colombian Central and Western mountain range, with elevations between 1,000m and 4,080m above sea level (MASL) (Graphic 4) (IGAC, n. d.).

2.1.2. Seismology

In 2006, the Colombian Institute of Engineering and Mining (*Instituto Colombiano de Ingeniería y Minería,* Ingeominas[7]), today known as the Colombian Geological Service (*Servicio Geológico Colombiano*), and the AIS 300 Committee of the Colombian Association of Seismic Engineering (*Asociación Colombiana de Ingeniería Sísmica,* AIS[8]), conducted studies to determine the degree of seismic threat in different regions of the country and in each one of its departments. These studies indicated that 14% of the land in Antioquia is located in areas of high seismic risk, while 86% is found in areas of intermediate seismic threat. To the west, the seismic threat is high. In the central and eastern areas, the seismic threat is intermediate (Graphic 5) (*Comisión Sismorresistente & Minambiente,* 2010, p. 11).

2.1.3. Hidrography

Antioquia has a hydrographic network for energy production and river transportation. To the northwest of the state, the coasts are bathed by the Caribbean Sea; its basin occupies 32% of the hydrographic network and is where the Atrato River sub-basin is found. The Cauca River's basin occupies 46% of the hydrographic network of Antioquia and includes the Nechí and San Juan River sub-basins. The Magdalena River basin covers 22% and reservoirs and locations with river ports are found on its banks. Annual rainfall averages between 1,000mm and 4,500mm (Graphic 6) (IGAC, n. d.).



Graphic 3
Colombia´s location in South America and Antioquia´s location in Colombia.



Graphic 4
Topographic zoning of the State of Antioquia.

7 For its abbreviation in Spanish
8 For its abbreviation in Spanish

2.1.4. Climate

Climate in Antioquia is tropical and is conditioned by the Andean Mountain system, which presents a climate determined by altitude and thermal levels ranging from 2 to 2,550 MASL. Average temperatures are between 13ºC in the highest areas to 28ºC in locations situated close to coastal regions.

- Forty municipalities (32% of the department) are located between 2 and 1,000 MASL. Their average temperature ranges from 22ºC to 28ºC.
- Sixty-four municipalities (51.2%) are located between 1,001 and 2,000 MASL, with average temperatures between 18ºC and 22ºC.
- Twenty-one municipalities (16.8%) are located between 2,001 and 2,550 MASL, with average temperatures between 13ºC and 18ºC (Graphic 7) (IDEAM, n. d.).

2.2. Society

In the social context, three aspects – population, culture and quality of life – are studied.

2.2.1. Population

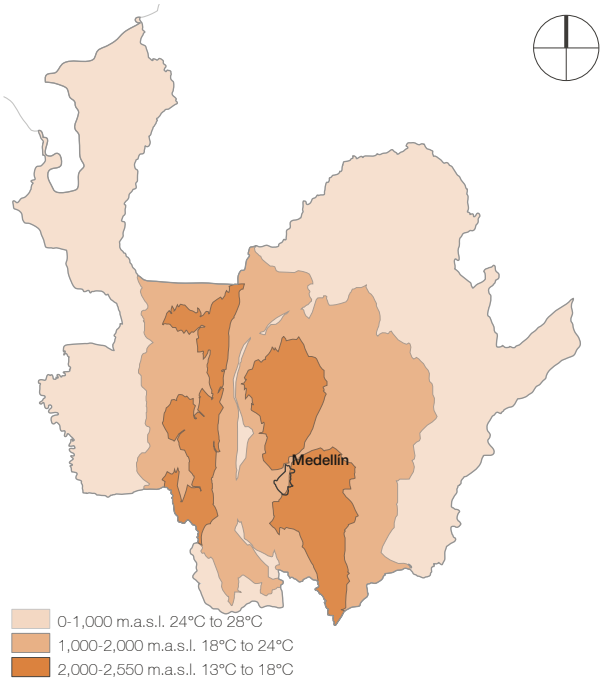
DANE's 2015 population projection indicated that Antioquia had 6,299,886 inhabitants. Of these, 4,906,327 (77.88% of the total population) were concentrated in the urban area of its municipalities, while 1,393,559 (22.12%) lived in rural areas. Migration (motivated by the search for new work, academic opportunities and displacements caused by violence) changed the initial rural vocation to an urban one (Graphic 8) (DANE, 2005), thus resulting in the unplanned growth of peripheral and metropolitan areas of (Hoyos, 2010, p. 94).



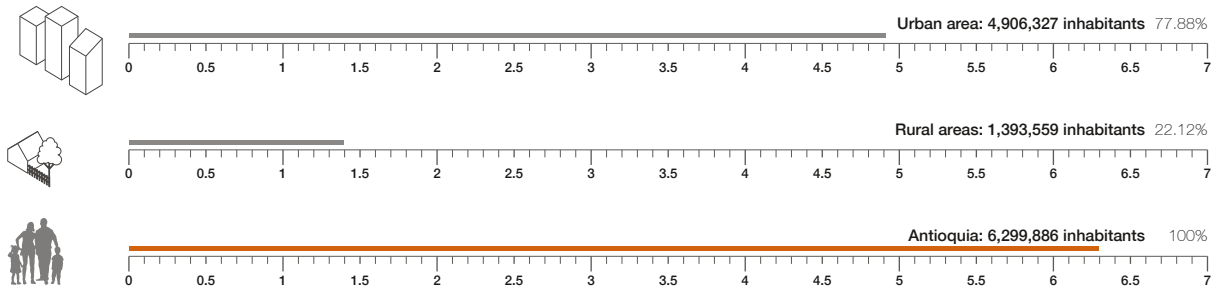
Graphic 6
Hydrographic maps of the State of Antioquia.



Graphic 5
Areas of seismic risk in Antioquia.



Graphic 7
Temperatures in the municipalities of Antioquia, according to the altitude above sea level (IGAC, 2009).



Graphic 8
The 2015 population projection in Antioquia (DANE, 2015).

According to DANE's 2015 population projection, 3,685,278 inhabitants (58.5% of the population in Antioquia) were concentrated in the Aburrá Valley region, comprised of Medellín and its surrounding municipalities: Barbosa, Girardota, Copacabana, Bello, Envigado, Itagüí, Sabaneta, La Estrella, and Caldas. In the department's other eight regions, there were 2,614,608 people, equivalent to 41.50% of the total population. These studies indicate that the ethnic composition of Antioquia's population, in 2015, was composed of 89% by mixed races, 10% by Afro-Colombians, and 1% by Indigenous people (DANE, 2013, as cited in *Empresa de Vivienda de Antioquia,* VIVA, 2015, p. 24). The displacement of population, due to violence occurred between March 2006 and March 2011, caused 174,088 people to come to Antioquia from other parts of the country. In the same period, 163,202 people left the department. Aburrá Valley and the East were the regions that received most of the displaced population. Aburrá Valley, and the Lower Cauca and Urabá regions saw the greatest exit of population due to forced displacement (DANE, 2013, as cited in VIVA, 2015, p. 26). The country's modernization and population concentration in urban centers has transformed social structures. Since the mid-XX Century, the number of working-class members and the number of low-income families in cities has increased. Some communities, with no possibility of acquiring a house, decided to build it themselves, which generated serious risks due to geological conditions and the structural instability of the homes (Echeverri & Orsini, 2010, p. 130).

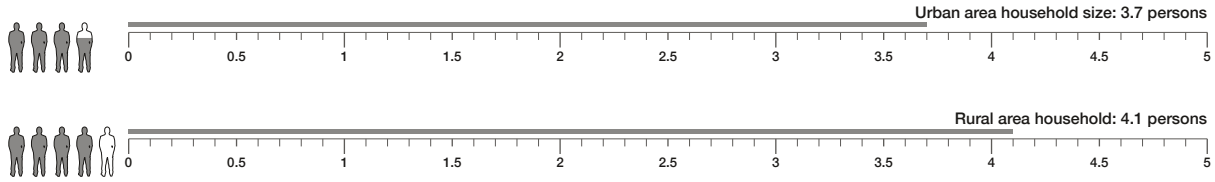
2.2.2. Culture

Cultural heritage has influenced urbanization patterns and ways of living. As cited by Saldarriaga (2009, p. 22), these traditions have been gradually changed to coexist with contemporary lifestyles. Present Pasts in Antioquia's domestic architecture have been manifested in the urban layout, in architectural typologies and in their language. Housing built in a local level has retained some urban, housing and technical traditions, but the modernization in ways of living and the influence of other cultural contexts have modified their original condition. Each geographic area has preserved specific ethnic traditions. Pre-Hispanic heritage has been the basis on which aspects from other cultures, such as Indigenous, African, West Indian, European and modern traditions, have been added (Saldarriaga, 2009, p. 18).

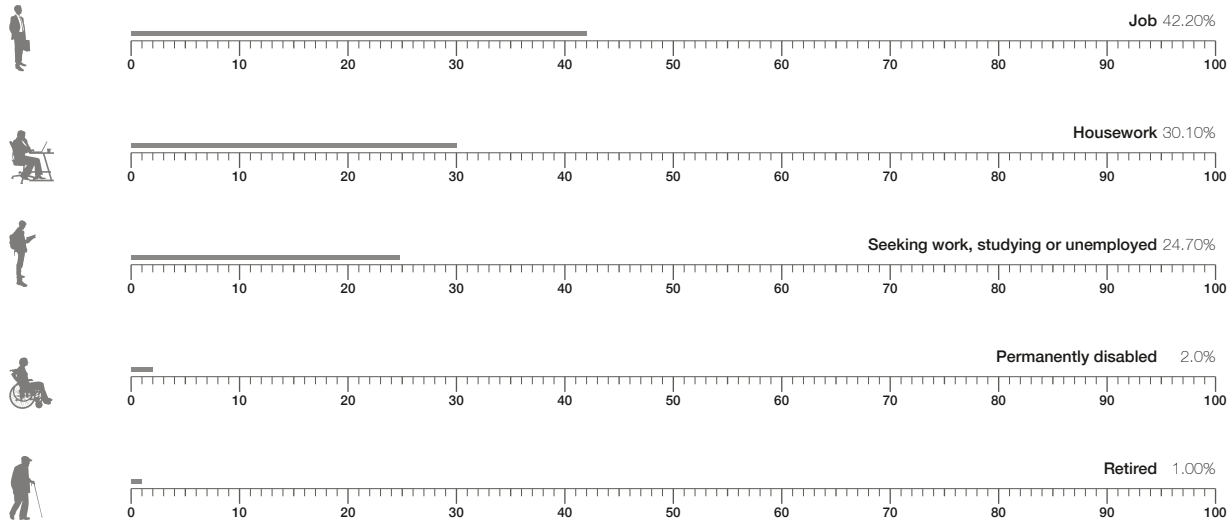
Contemporary urban environments have incorporated a sociocultural heterogeneity, reflected in ways of living. Real estate and construction industries have also had an impact on social housing since the mid-XX Century. Houses, apartments, gated housing complexes and lower-class neighborhoods have been mixed in urban areas, where the population's economic possibilities determine specific project characteristics. Popular housing occupies nearly 50% of the urbanized territories in Colombian cities. Its development is seen in different types of settlements, such as planned neighborhoods, urbanizations with progressive developments and informal neighborhoods. Contemporary residence variants have been set up in public and domestic spaces in popular neighborhoods, where cultural traditions have been combined with social, economic and urban aspects. In rural areas, traditional farming homes have been partially replaced by modern housing, with spatial and formal characteristics that aim to replicate experiences built in urban environments, but with limitations and precariousness similar to those of existing housing (Saldarriaga, 2009, p. 22).

2.2.3. Quality of life

Studies conducted by the 2013 Quality of Life and Principal Indicators Survey in Antioquia concluded that the Lower Cauca, Urabá and Middle Magdalena regions presented the highest percentages of homes with overcrowding (considered when there are five or more persons per room). The average household size was 3.7 persons in the urban area and 4.1 in the rural area (Graphic 9). Of the total number of homes, 15% presented unmet basic needs (lack of public utilities, inadequate ventilation and lighting, homes without floor finishes and kitchens, and with insufficient areas for occupation by inhabitants) (DANE, 2013, as cited in VIVA, 2015, p. 26). The detriment in families' quality of life in Antioquia is due to two main causes: the first was the armed conflict, which generated difficulties in accessing basic social services, prevented the free movement of people in inhabited areas and reduced the food supply. The second was a set of illegal economic activities, such as illicit crops and unregulated mining exploitation, which caused population displacement, insecurity, misuse of land and reduction of housing areas (*Departamento Administrativo de Planeación,* as cited in VIVA, 2015, p. 28). Additionally, the informal processes of self-construction in urban peripheries caused physical, environmental and social imbalances with negative implications on the quality of life of their inhabitants (VIVA, 2015, p. 131).



Graphic 9
Average household size in urban and rural areas in Antioquia (The Quality of Life and Principal Indicators in Antioquia Survey, 2013).



Graphic 10
Labor conditions in Antioquia's population (DANE, 2005).

2.3. Economy

According to the official 2005 DANE census, in Antioquia, 42.20% of the economically active population had a job; 30.1% did housework; 24.7% of the people were seeking work, were studying or were unemployed; 2% had been declared permanently disabled to work and 1% of the people were retired (Graphic 10) (DANE, 2013, as cited in VIVA, 2015, p. 30).

More than 65% of Antioquia's economy is classified in the service sector. It is the second most industrialized department in Colombia and its contribution to the national Gross Domestic Product (GDP) has a 15% average. Other contributions to economic development come from the rural and manufacturing sectors (DANE, 2013, as cited in VIVA, 2015, p. 30). In the XXI Century, Antioquia has focused its potential toward the economy of knowledge. In 2014, the average per capita income was COP 680,708, approximately EURO (€) 200 at that time (DANE, 2015).

2.4. Infraestructure

Two components, associated with the design and construction of social housing, are studied: transport and public utilities.

2.4.1. Transport

Antioquia has river, rail, air and land transportation networks.

In 2012, the river transportation system had 18 ports and seven rivers with navigable stretches for boats that transported less than 25 tons (CTA, 2013).

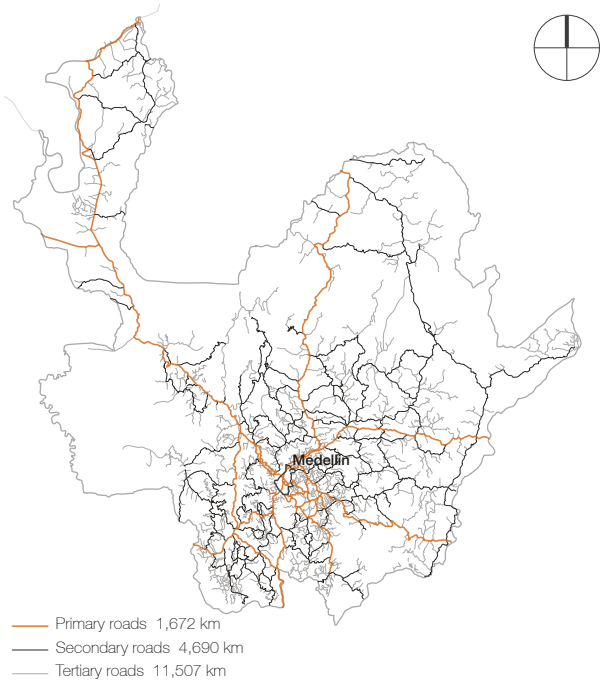
In the same year, railway transportation was 723km long (26% of them in operation) and air transportation had 32 active airports in its 125 municipalities (*Aerocivil,* n. d.).

Ground transportation has been the most widely used. In 2016, 99% of the cargo was moved by truck through primary, secondary and tertiary road networks that has a total of 17,869km (*Mintransporte,* as cited in VIVA, 2015, pp. 32-33).

The primary road network, with an extension of 1,672km (9.3% of the department's roads) (VIVA, 2015), is based on highways, which is the nation's responsibility (*Mintransporte,* as cited in *Alcaldía de Bogotá,* n. d.).

The secondary road network, with an area of 4,690km (equivalent to 26.2% of the roads in Antioquia) (*Mintransporte,* as cited in VIVA, 2015, p. 32) is administered by the departments and municipalities.

The tertiary road network, with an area of 11,507km (64.4% of Antioquia's roads) (*Mintransporte,* as cited in VIVA, 2015, p. 32), is the responsibility of the municipalities and is based on highways or roads that connect municipal centers with hamlets or connect several villages together (Graphic 11).



Graphic 11
Land transportation networks in Antioquia (Colombian Ministry of Transport, 2015).

2.4.2. Public utilities

In 2016, 97.8% of the houses located in urban areas had aqueduct coverage; while in rural areas, coverage was 57.8%. In urban areas, 93.7% of the households had sewer network availability, while in rural areas it was 25%. More than 95% of the homes in Antioquia have power grid connections (Graphic 12) (*Encuesta de Calidad de Vida,* 2013, as cited in VIVA, 2015, p. 32).

2.5. Industry

Nearly 95% of the raw materials needed to build urban infrastructures, roads and buildings may be found in Antioquia's market (E. Loaiza, personal communication, 2016). The *in-situ* concrete cast structural systems or structural masonry in concrete blocks or bricks has been used for the construction of high-socioeconomic strata projects and for social housing projects. Since 2008, some regional prefabrication companies came together to form CAMACOL's Concrete Prefabricated Committee (*Comité de Prefabricados en Concreto de la Cámara Colombiana de la Construcción*), under the coordination of the Cement Producers Institute (*Instituto de Productores de Cemento,* ICPC[9]). In October 2016, it had 14 affiliated companies. This committee was formed to study and investigate topics associated with the design, production and construction of elements in precast concrete, develop new products with it, enter the market of the construction of buildings and develop new processes to improve their marketing channels.

2.6. Political context

The Ministry of Housing, City and Territory was created through Article 14 of Law 1444 of 2011. It was defined as a national public entity that, according to housing access and financing conditions, is responsible for formulating, adopting, directing, coordinating and executing public policies, plans and projects regarding urban housing and basic sanitation (*Minvivienda,* n. d. b). In 2010, the National Government and its Ministry of Housing, City and Territory developed a program for the mass construction of housing, in order to reduce the existing deficit. In 2012, the construction of 100,000 free-of-charge housing units, for Colombian families with limited economic resources, began (*Minvivienda,* n. d. a). Between 2012 and 2015, the Housing Company of Antioquia (*Empresa de Vivienda de Antioquia,* VIVA) formed strategic alliances to formulate and manage the construction of new housing. This entity, of a commercial and industrial nature, and dependent to the Office of the Governor of Antioquia, was formed to develop – from architectural, technical and legal requirements – new housing in urban and rural areas, legalize lots of land and improve existing housing (VIVA, n. d.). Between 2012 and 2015, VIVA led the construction of 38,340 new homes and the improvement of 7,700 existing homes in Antioquia (VIVA, n. d.).

2.7. Precast concrete: technical regulations

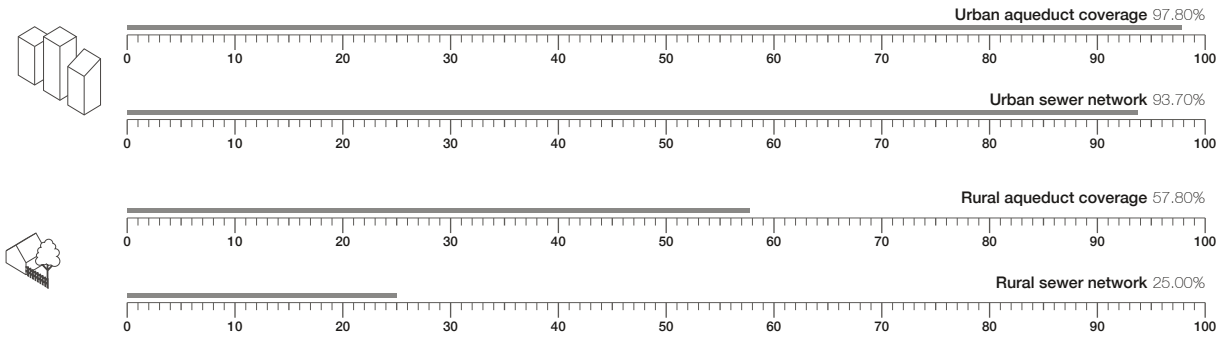
Since March 2010, the technical regulation for housing construction has been governed by the Colombian Earthquake–Resistant Standard, NSR-10 (Reglamento Colombiano de Construcción Sismo-Resistente NSR-10). Chapter C.16, "Precast Concrete" of Title C, entitled "Structural Concrete," considers and regulates structural and non–structural elements for construction with precast concrete. This document defines the minimum standards that must be met in the structural design of precast elements, and proposes technical conditions such as:

Distribution of stress in the design of structural and non–structural elements
Structural integrity
Design of connections and supports
Elements embedded after the placement of concrete
Identification marks, management and evaluation of the precast structures' resistances

Table 4
Minimum standards and technical conditions for precast elements (NSR 10).

Title C has other chapters that must be consulted before designing precast concrete elements. Subsection C.1.1.1 of NSR-10 indicates that the specified compressive strength of structural concrete should not be less than 17 MegaPascal (MPa). Section C.7.7.3 of Chapter C.7, entitled "Reinforcement Details", indicates the regulations that govern reinforcements for precast concrete.

9 For its acronym in Spanish



Graphic 12
Public utilities available in homes located in urban and rural areas (Quality of Life Survey, 2013).

Chapter C.9 indicates the resistance and operation requirements of each of the structural elements that could be part of a building (*Comisión Sismorresistente & Minambiente,* 2010, p. C-1). For each dosage, NSR-10 proposes testing concrete according to the requirements defined from Chapter C.5.6.2 through Chapter C.5.6.5 (*Comisión Sismorresistente & Minambiente,* 2010, p. C-75).

Chapter C.18, "Pre-stressed Concrete," regulates the technical requirements of precast and pre-stressed elements for structure construction. Pre-stressed concrete is defined, in NSR-10, as structural concrete with internally introduced stresses that help reduce potential traction stresses caused by loads (*Comisión Sismorresistente & Minambiente,* 2010, p. C-311).

The country's industrial context has entered the market of additives and additions for concrete mixtures, elements that can reduce costs while maintaining or improving the mixtures' resistance. All of the structural and non–structural elements in precast concrete, that are specified for the design and construction of social housing projects in Colombia, must comply with NSR-10's requirements, the official document that has regulated the design and seismic–resistant construction in the country since 2010.

Summary

The context and industrialization of social housing

The conditions of the local context insinuate diverse aspects to be taken into account in the design and construction of social housing.

In geographic terms

Dwellings must be designed to adapt to the different topographic profiles of the Department. Sloping lands make up a third of the area, while flat lands occupy two-thirds of the territory. The conformation of the support structure must also be adapted to the mechanical resistance of the soils available. Generally, social housing has been conceived in remote areas, where the cost of land is lower. These peripheries are located on sloping lots, with mechanical resistances lower that those of soils in urbanized land. In order to solve the stability of the housing units in relation to the soil, the foundations of the traditional construction systems concentrate the loads on specific elements (such as columns) or longitudinal elements (such as load-bearing walls). This concentration of the loads in walls or in columns increases the depth of the foundations and, therefore, costs and time. In addition to configuring geometries in the dwellings so that projects can occupy flat or sloped terrain, the support structures must have foundations that distribute the loads to the ground in a uniform, superficial manner, ideally with continuous structural slabs for areas with high and intermediate seismic risks, which are those that make up the territories of the Department. The dwellings must be conceived from a structural system that, in addition to adapting to different terrain profiles with different load-bearing capacities, provide conditions of well-being and comfort in different climates, which vary according to the altitude above sea level, due to the context in which they are placed.

In social terms

The traditions and ways of living of local communities should be considered in versatile, customizable, comfortable dwellings and with a beauty linked to their cultures. Although the industrialization of housing construction systems can reduce costs and time, they must maintain conditions of individuality or adaptability to different surroundings in terms of environment, culture and language, which express the tastes and traditions of the communities according to the context. Culturally, social housing in the local context has been conditioned by its structural elements using traditional materials, such as *in-situ* cast concrete and structural masonry in concrete or brick blocks.

In economic terms

The economy of the cement and brick industries has been strengthened by these local traditions in urban contexts. Therefore, innovations that use this type of materials could have the cement industry as an ally in the research, production and installation processes of these elements. It is argued that the industrialization of the elements that make up social housing can occur through the prefabrication of the concrete. This material is known and has been used in the construction of numerous housing solutions in the country since the early years of the XX Century, where it has been specified as a material cast *in situ* for the conformation of the structural elements of the projects.

Infrastructure

If the support structure or the non-structural elements are prefabricated in industrial plants located at a distance from the projects, they must respond to the constraints, such as dimensions, volumes and weights of each one, posed by their transport. Therefore, the proposals for the industrialization of the housing structure are conceived for territories with terrestrial accessibility (in come cases, rail or river), which allow the loading of elements with these dimensions and weights, and that are ideally not located more than 150km from the production site so that the distances can be covered without losing efficiency in the time and costs of the transport. For this case, an industrial presence of prefabricating plants in various parts of the Departmental and National territory, each with a radius of up to 150km, is necessary to meet the demand for possible precast-concrete houses in other municipalities and Departments. Another industrialization possibility is the production of precast-concrete elements on the work site. This is known as field factores, which can reduce transport costs, but increase logistics costs by moving specialized machinery and tools to the project site. In each case, according to the distances between the plants and the projects, transport costs, and the accessibility to the lots, it should be considered whether the production of the structural elements in the industry or at the construction site is more efficient.

In industrial terms

The industrial context in precast-concrete processes has been strengthened since the last ten years of the XX Century and with the permanent desire of industries to innovate and produce new knowledge. The presence of cement-factory points and the number of concrete prefabricators in Antioquia has increased since the beginning of the XXI Century, serving various sectors of the Departmental and National territory. The precast-concrete industry in the local context has a union called the Committee of Prefabricators of Antioquia (*Comité de Prefabricadores de Antioquia*), with the presence of the Colombian Institute of Cement Producers (*Instituto Colombiano de Productores de Cemento,* ICPC), the Colombian Chamber of Construction (*Cámara Colombiana de la Construcción,* CAMACOL) and prefabrication companies that have their headquarters in the Department. The prefabrication of social housing counts on the industrial sector as one of its strongest potential allies, given the historical presence of the cement industry in the construction of housing in the country and the union of prefabricators, increasingly positioned and stronger in the physical-infrastructure market, with serious intentions of being part of the housing market.

In political terms

The delivery of new housing units to communities with major economic problems has been a program of local Governments and the National Government since the middle of the XX Century. In 2010, the Colombian Government launched a program to build 100,000 free homes for

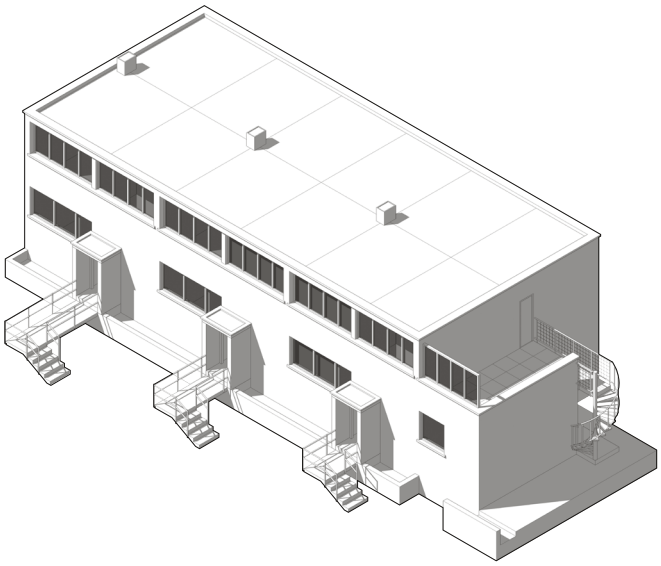
communities distributed throughout the National territory, while the Government of Antioquia, through the Housing Company of Antioquia (*Empresa de Vivienda de Antioquia,* VIVA) has built tens of thousands of housing units in each period of governorship. Medellín's Development Plan has proposed the construction of 20,000 new housing units between 2016 and 2020, a situation that shows the interest of governments in the construction of affordable, quality housing for communities. This political commitment would benefit from industrialized systems that reduce time, lower costs and increase the quantity and quality of the social housing offered, a situation that makes the industrialized-housing system attractive for official subsidy programs or the construction of new homes for economically disadvantages communities. Private industry – in conjunction with the official sector – if it finds budgets and schedules that improve the efficiency of the structural systems, can generate industry and construction sponsorship programs for new housing units using this technique.

In regulatory terms

For the regulation of the use of precast concrete in the construction of houses and other buildings, the Colombian Earthquake-Resistant Construction Regulations NSR-10 (*Código Colombiano de Construcción Sismo Resistente NSR-10*) has Chapter C.16. (Precast Concrete), which forms part of Title C (Structural Concrete). Construction with precast concrete in the country is regulated and permits housing developments through the use of this system. Dosages, minimum resistances required, structural reinforcements, hoisting mechanisms and types of joints of the prefabricated elements are explained in detail in the current regulations for the use of this structural and constructive system.



Social Housing



Graphic 13
Housing proposed through the *Existenzminimum* housing model. *Weißenhofsiedlung,* Stuttgart. Architect: Mart Stam

3.1. History and evolution of the concept of social housing

In both international and local contexts, the development of social housing has some similar aspects. Conceptual principles, developed in Western Europe, were subsequently replicated in Latin America. In a regional context, these developments have been accompanied by urban, social, economic and technical models, with which different projects have been proposed.

3.1.1. In Western Europe

In the second half of the XX Century, three models or actions were used for in-series housing production: speculative, cooperative and state. The speculative action was primarily based on the construction of neighborhoods with basic legal requirements for renting purposes. The cooperative action was based on worker and employee associations of large industrial companies, whose main purpose was obtaining a house with their own resources and with the available State subsidies. The State action included legislation on urban and housing problems, establishment of chains of credit, subsidies and entities responsible for conceiving, designing and building the neighborhoods (Saldarriaga & Carrascal, 2006, pp. 11-12). In the early years of the XX Century, housing programs and their needs were reviewed; strategies were studied to reduce construction costs, other technical systems were experimented with, the standardization of designs was proposed, and the industrialization of construction was implemented. The attempt to establish a new urban model prompted reflection on the characteristics of housing projects; theories on public spaces, transportation policies, equipment and regional urban plans were raised (Sambricio, 2012, p. 7).

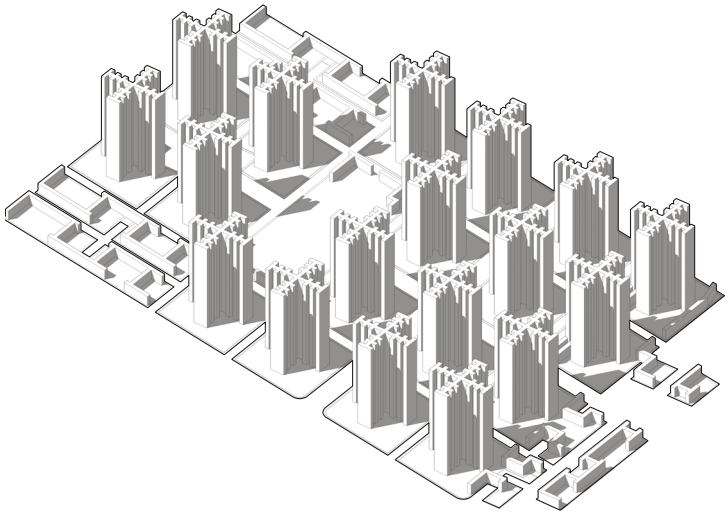
3.1.1.1. Minimum housing

This philosophy was related to the development of mass housing for the working class (Saldarriaga & Carrascal, 2006, p. 13). The Second International Congress on Modern Architecture (*Congreso Internacional de Arquitectura Moderna,* CIAM[10]), held in Frankfurt in 1929, had "Housing for the Minimum Standard of Living" as one of its topics. Walter Gropius contributed with a text entitled "The Sociological Foundations of Minimum Housing for the Working Population of the City," in which he proposed that the optimal minimum size should be found to satisfy the needs of life at the lowest price possible. Gropius believed that the fundamental aspect of this model was found in knowing the minimum amount of air, light and space necessary for the development of vital functions, variables that could be modified according to the specific conditions of a city, region or climate (Gropius, 1973, pp. 120-121).

The text summarized the idea of finding some minimum, scientifically supported living standards. Substantial differences were found between simplification (as an aesthetic problem) and the minimization of living standards (as a social problem).

Minimum housing was one of the most studied aspects in the conception of modern life, worker housing and planned cities. This philosophy proposed that housing in the XX Century should be austere, efficient and functional (Saldarriaga & Carrascal, 2006, pp. 14-15). The model was called *Existenzminimum* and guided the development of some projects in Western Europe from 1920, beginning with the principles of functionalism and constructive rationalization (Graphic 13) (Saldarriaga & Carrascal, 2006, p. 15).

10 For its acronym in Spanish



Graphic 14
Industrially produced mass housing. *Ville Radieuse*. Architect: Le Corbusier.

3.1.1.2. Mass housing

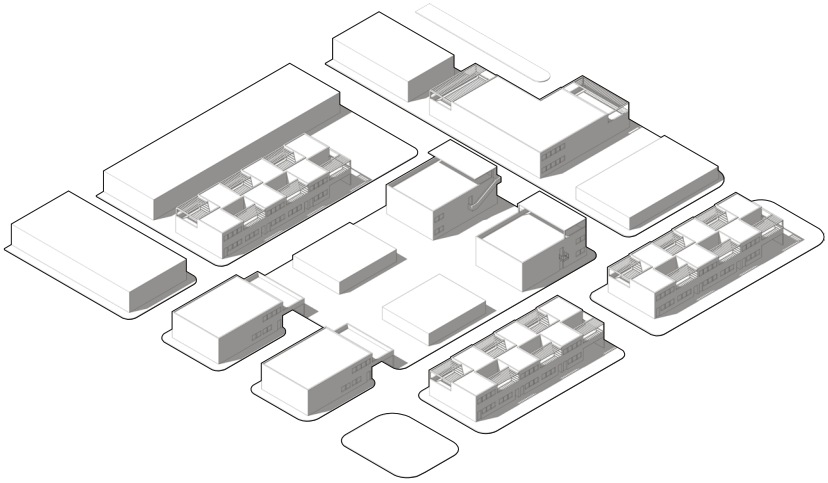
This method had two models with few typological variations: one- or two-story single-family homes and multifamily buildings with apartments.

Reconstruction of cities after the war and the mass production of housing boosted research and the development of other construction systems, in which prefabrication was one of the most used (Saldarriaga & Carrascal, 2006, p. 16).

In 1923, Le Corbusier reflected on the industry as an inspiration for housing in "Towards a New Architecture". He referred to the influence of economic laws in man's way of thinking and acting. He highlighted the home as a fundamental component of society; he proposed a review of the houses' construction elements, saying that mass production should be based on analysis and experience, and that the industry should take care of construction (Le Corbusier, 1976, p. 96). In 1951, the Constructa Exhibition was held in the city of Hannover, where German architecture schools showed the proposals of *Wiederaufbau* (reconstruction) to raise new homes in a short term after World War II. In another context, the First Secretary of the Soviet Union's Communist Party, Nikita Khrushchev, addressed the National Conference of Constructors, Architects and Workers in 1954 to request industrialization as a mechanism for the construction of new homes (Sambricio, 2012, p. 11). Mass production of the elements that comprised them was made to reduce costs and time, increase industrial efficiency and deliver a greater number of living solutions in less time (Graphic 14).

3.1.1.3. The neighborhood unit

This model summarizes the elements that make up a modern city: high-rise construction, mass housing and the garden city. The neighborhood unit, set up as a housing unit with common services and free areas, gradually replaced the concept of the neighborhood as an urban development unit, formed by grouping individual lots with some common areas (Saldarriaga & Carrascal, 2006, p. 19). In *Notes on Housing* Groups (1929), Clarence Perry stated that the occupants of a neighborhood unit should have access to an elementary school, spaces to play and retail shopping centers (Posada, as cited in Saldarriaga & Carrascal, 2006, p. 19). In the 1930 CIAM, Le Corbusier proposed the creation of new domestic spaces with an outdoor use, such as terraces or covered gardens, an increase in public spaces for community gatherings and an improvement in pedestrian mobility (Le Corbusier, 1973, as cited in Saldarriaga & Carrascal, 2006, p. 20). In the Athens Charter, written in the 1933 CIAM and published in 1941, it was suggested that the basic nucleus of urban planning consisted of housing, which should be grouped into housing units to provide them with the common services they required (CIAM, as cited in Saldarriaga & Carrascal, 2006, p. 20). Among the most widespread examples in Western Europe, in the second and third decades of the XX Century, were the *Weißenhofsiedlung* in Stuttgart, the rational models of Alexander Klein and the garden cities of Le Corbusier. In all of them, the fundamental existed: residential units, super city blocks, the garden city and community life (Graphic 15) (Saldarriaga & Carrascal, 2006, pp. 21-22).



Graphic 15
A neighborhood unit with garden city housing models. Garden City. Architect: Le Corbusier.

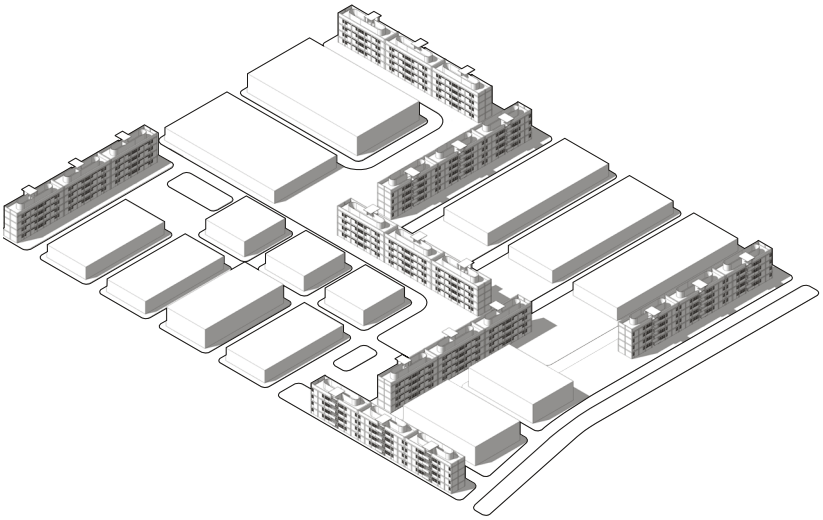
3.1.2. In Latin America

Latin American social housing is classified in three periods: workers' housing, government housing and the experimental phase of social housing.

Workers' housing, understood as the response of cities to the migration of rural people, generated new areas of development, worker neighborhoods and urban areas. State housing was proposed by Government programs as a response to the growing housing deficit. The experimental phase of social housing, where new housing proposals rethought aspects, such as quality of urban life, the implementation of new construction systems and the development schemes of planned growth. In this period, a new way to interpret the needs of families and cities in constant growth were proposed.

3.1.2.1. Workers' housing

State policies increased in Latin America since the early XX Century, a period in which some legal and institutional bases were established for the development of new projects. The economic crisis of 1929 and migration from the countryside to the city led to the rethinking of some Latin American economic policies. Industrialization was installed in urban centers in the middle of the century, which coincided with the arrival of new family groups from the countryside to the cities, which began to grow and incorporate some aspects of modernization, such as communications, transport and mass culture (Saldarriaga & Carrascal, 2006, pp. 23-24). Family groups that arrived in cities and were not able to find jobs joined the informal sector of the economy. The meeting of worker group traditions and mass housing's rationality showed cultural imbalances, and generated transformations in the function and language of residential spaces (Graphic 16) (Saldarriaga & Carrascal, 2006, p. 24).



Graphic 16
Living models for working-class housing in Latin America. Matute Housing Units, La Victoria, Lima. Architect: Santiago Agurto Calvo

3.1.2.2. State housing

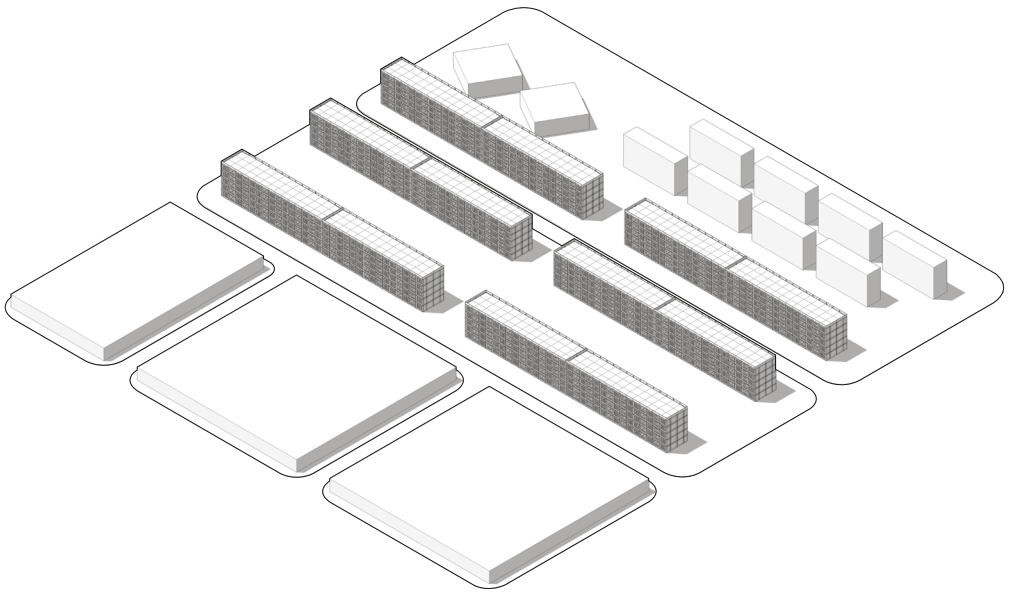
Before 1920, some Latin American countries began to establish legal and institutional bases to develop social-housing programs. Its construction in the early decades of the XX Century was driven by a governmental action that promoted modernization. Between 1940 and 1960, some governments began an industrialization process that replaced imports and favored the emergence of a middle socioeconomic class. This modernization had public investments and was reflected in the improvement of living conditions of economic classes with lower purchasing power. The first State mass housing projects in Latin America were built in the 1950s. Later, this evolved into the development of neighborhood units, conceived as neighborhoods with services and equipment, which would later determine future urban growth (Sambricio, 2012, p. 12). State housing was thought of as a mean to develop public policies, to find an agreement between official sectors and society, and to improve the working class' quality of life. Some governments assumed its construction as a strategy to strengthen themselves politically, and to win public support. Other technocratic governments sustained a more streamlined vision of the problem and approached it relying on international models (Saldarriaga & Carrascal, 2006, p. 23).

Most countries delayed in achieving a significant degree of industrialization and the users of these projects were, for a long time, recently urbanized families (Saldarriaga & Carrascal, 2006, p. 24). While being replicated in different contexts, the advantages of State housing were reaffirmed and their weaknesses were evident. Failure to consider cultural differences or the specific aspects of each context made some communities resist the uniformity and modification of their living spaces (Graphic 17). Since the early years of the XXI Century, State action has been gradually reduced, due to macroeconomic policies and the privatization actions originally undertaken by the State (Saldarriaga & Carrascal, 2006, p. 23).

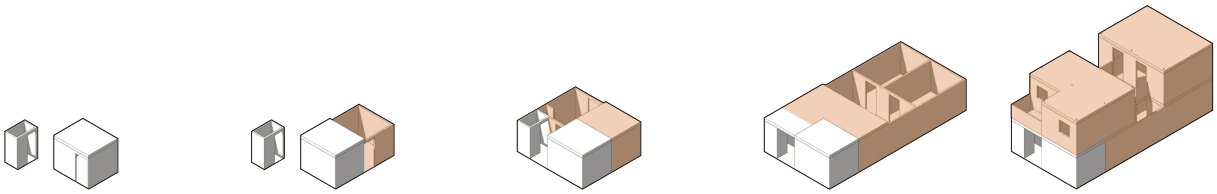
3.1.2.3. Experimental housing

Since 1960, the first experiences of self-construction and progressive development were documented. This process was carried out in popular neighborhoods with the participation of its inhabitants in the construction, which was regulated to avoid the specific initiatives from being above those of the community. With individual plots, each family could undertake the construction of its home with its own resources. In self-construction, the owner took responsibility to carry out part of the process or all the activities that comprised it: acquisition of the lot of land, project planning and construction. Sometimes, labor came solely from the owner with the help of his family. In self-management, labor could be contracted by the owner, who in some cases also contributed with his work (Rueda, 1979, as cited in Saldarriaga & Carrascal, 2006, p. 26). English architect John Turner, who worked in poor neighborhoods in Lima, Perú, proposed incorporating self-construction in State programs as an alternative to reduce costs, improve the process' quality and obtain better results. In his book *Freedom to Build* (1972), he proposed, among other aspects, the following:

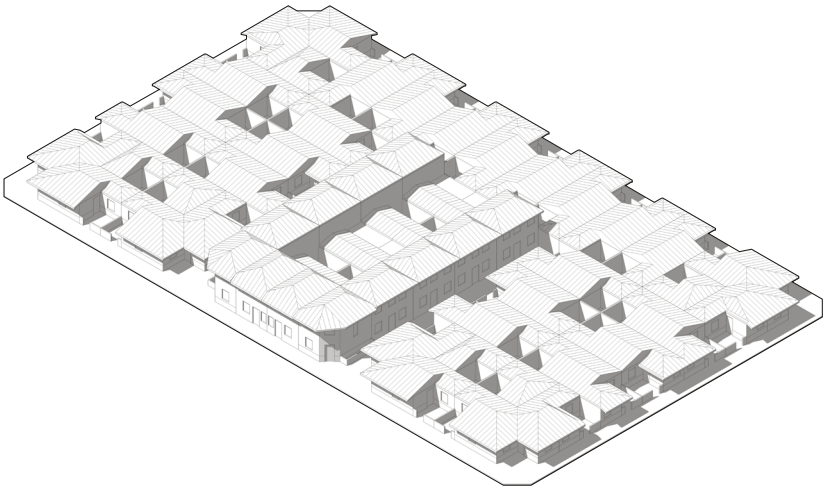
> *When users can make their own contribution to the design, construction or administration, the process and the environment stimulate individual and group welfare. When people have no control or responsibility in the decisions that guide the definition of housing-project policies, the resulting settlements can become a barrier to personal satisfaction and a burden for the economy [...]. The production and distribution of resources must be organized in easily accessible networks, without authoritarian hierarchical structures [...]. The most significant resources are represented by the real and potential savings of the population. The economy is a matter of the efficient use of the resources available at any given time. (Rueda, 1979, as cited in Saldarriaga & Carrascal, 2006, pp. 26-27)*



Graphic 17
Living models of State housing in Latin America. José Martí District, Santiago de Cuba. Architects: Dean, Baeza, López, Cárdenas, Rodríguez and Azze.



Graphic 18
Collective housing in Latin America (experimental model). Lima. Architect: John Turner.



Graphic 19
Housing models built in Colombia in the Hygienist Period. Colombia Neighborhood, Bogotá. Architects: BCH.

Self-construction was the most affordable housing alternative in Latin America and proposed other types of conditions to models institutionalized by the CIAM. Turner's proposals were received with enthusiasm and were transferred to "self-directed" State plans, which were started in the 1960s by some entities and self-help groups (Graphic 18) (Saldarriaga & Carrascal, 2006, p. 27).

3.1.3. In Colombia and Antioquia

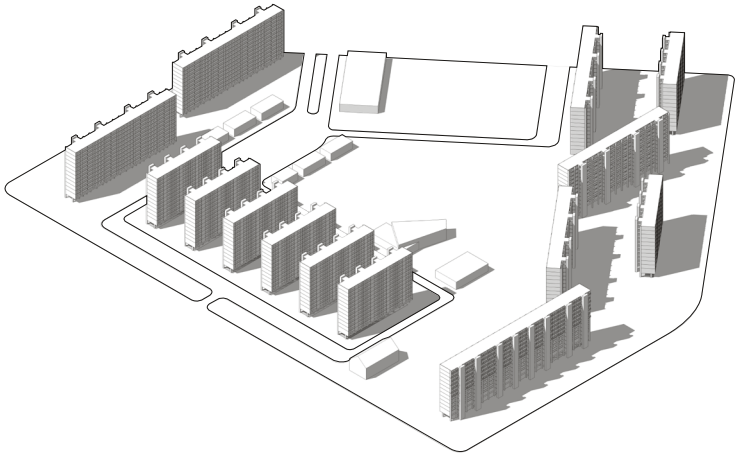
Attention by local governments to the population's housing needs intensified in the early XX Century, with their interest in resolving the lack of water and sewage in some homes. Subsequently, State action was aimed at establishing methods of public administration, by developing institutional forms of social assistance and industrialization. Labor affiliation of workers to a company through formal contracts and labor legislation permitted them to ensure an income with which they could pay rent or purchase a home (Saldarriaga & Carrascal, 2006, p. 12). Article 44 of Law 9 of 1989 introduced the concept of Priority Social-Interest Housing (*Vivienda de Interés Social Prioritaria,* VIP) and Social-Interest Housing (*Vivienda de Interés Social,* VIS), with a maximum selling price defined by the minimum monthly wage. Article 91 of Law 388 of 1997 defined them as those "that ensure the right to housing of households with lower incomes", indicating that in each National Development Plan (*Plan Nacional de Desarrollo,* PND[11]), the National Government would establish the type and maximum price of the solutions destined for these households, taking housing deficit, possibilities to access credit, the conditions of the offers and State funds into consideration. Housing policies in Colombia are classified in five periods: Hygienist, Institutional, Transitional, Corporate and Commercial.

3.1.3.1. Hygienist (1918-1942)

The Hygienist Period was driven to preserve health and living conditions in cities and the countryside. With Law 46 of 1980, the construction of housing for workers and employees was promoted (Saldarriaga & Carrascal, 2006, p. 29). Since 1920, the Colombian State began to shape public institutions to promote urban housing. The Constitutional reform of 1936 determined its social function, established strategies for individual financing and promoted the construction of worker homes and family farms for rural inhabitants. Municipalities were authorized to provide a subsidy of 20% to 25% of its cost, a down payment of 10% and variable subsidies for the payment of interest rates. In 1939, the State founded the Institute for Territorial Credit (*Instituto de Crédito Territorial,* ICT[12]) and the Agrarian Bank (*Banco Agrario*), initially intended for the financing and construction of rural housing. In this period, progress was made in the regulation of credit; the establishment of supply banks was promoted and the first worker neighborhood models were built (*Minvivienda,* 2014, p. 26). In 1942, the Department of Urban Housing opened within the ICT (Graphic 19) (Saldarriaga & Carrascal, 2006, p. 29).

11 For its acronym in Spanish

12 For its acronym in Spanish



Graphic 20
Housing models built in Colombia in the Institutional Period. Antonio Nariño Urban Center, Bogotá. Architects: Gutiérrez, Esguerra Sáenz, Urdaneta and Suárez.

3.1.3.2. Institutional (1942-1965)

During this period, State intervention was consolidated through the existing official institutions. The functions and fiscal resources of the Central Mortgage Bank (*Banco Central Hipotecario,* BCH[13]) and the ICT were expanded.

Between 1952 and 1957, the family subsidy was created for an amount that was granted depending on the number of children of the beneficiary. At that time, a growing concern was observed in the quality of existing houses, and regulations were created to establish conditions on the location of projects and their relationship to the service infrastructure in cities. Among other requirements, there had to be a minimum area for each user, a specific number of rooms, a minimum area of windows for lighting and ventilation, the kitchen and bathroom had to be separated from other spaces, quality construction supplies had to be used and there had to be a maximum price cap. To reduce costs, the production and importation of supplies were proposed according to their prices, and prefabrication was considered as an alternative for the construction.

The concept of progressive development was contemplated for the first time, a practice that was subsequently replicated in different projects. In 1954, the ICT temporarily disappeared to be merged with the Public Utilities Corporation (*Corporación de Servicios Públicos*) and the family subsidy was established. The ICT reappeared in 1957, after the fall of a military Government in Colombia (Saldarriaga & Carrascal, 2006, p. 29). In the same year, the Agrarian, Industrial and Mining Credit Bank (*Caja de Crédito Agrario, Industrial y Minero*) was created to implement rural housing programs, associated with the concept of affordable housing.

The subsidy policies were decentralized to include cooperative institutes and associations for workers or employees, considered potential credit beneficiaries. In this period, the private sector intervened as an operator and provider of housing credit. In addition to supporting the purchase of new housing, financing to purchase a lot and construction, repair of used housing and mortgage payments were included.

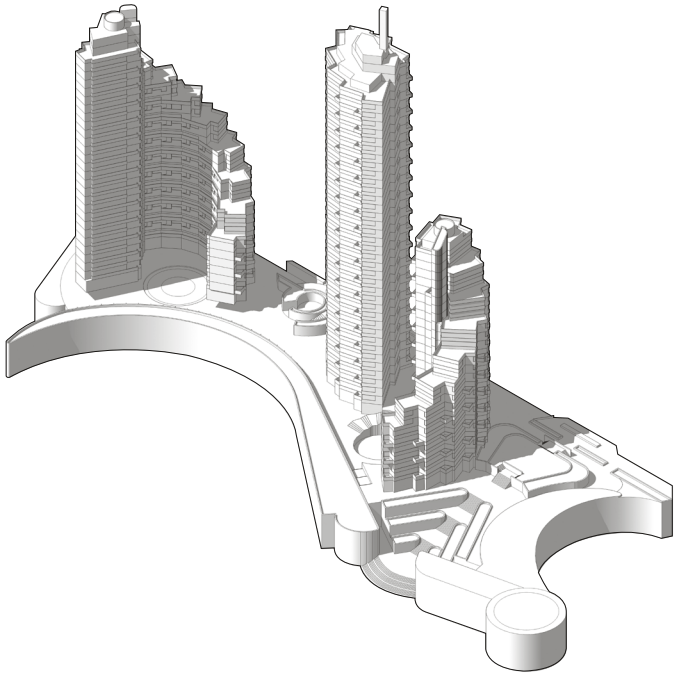
Between 1958 and 1962, measures were taken to complement the institutional approach. The location of projects in the outskirts was a factor that increased costs, due to the necessary extension of public-utility networks. The lack of financing to constructors was attributed to the low profitability of the business, which led to the creation of tax incentives for private investment. Plans were established for the construction of new housing with resources from ICT, construction companies and beneficiaries through initial down payments. In this period, high-rise buildings were constructed to reduce the incidence of urban land in the cost of projects (Graphic 20). The sum of economic requirements led to the conclusion that the country's fiscal resources were insufficient and the support of international entities should be proposed. The conception of this policy corresponded to the universal model of the "Welfare Theory," which argued that the State should intervene in the generation of social services. The stimulation of private resources, as a mechanism to finance construction, would book investment, generate employment for available labor, achieve better living standards and create favorable conditions for industrial growth (*Minvivienda,* 2014, pp. 27-33).

3.1.3.3. Transitional (1965-1972)

In this period, there was a State action that moved towards a new model in which banks, associations and savings associations assumed financial control of housing projects (Saldarriaga & Carrascal, 2006, p. 29). From 1966, subsidies were introduced into the segment immediately above the population classified as being in a state of poverty. The institutional approach and State action were reinforced with the creation of the National Savings Fund (*Fondo Nacional del Ahorro,* FNA[14]) in 1968. This entity was assigned the task of administering the severance pay of officials from the Colombian public sector, developing housing programs and offering mortgage credit lines. In 1969, the Superior Council of Housing and Urban Development (*Consejo Superior de Vivienda y Desarrollo Urbano*) was created as the governing entity for housing and urban policy in Colombia. The multi-

13 For its acronym in Spanish

14 For its acronym in Spanish



Graphic 21
Housing models built in Colombia in the Transitional Period. *El Parque* Residences, Bogotá. Architect: Rogelio Salmona.

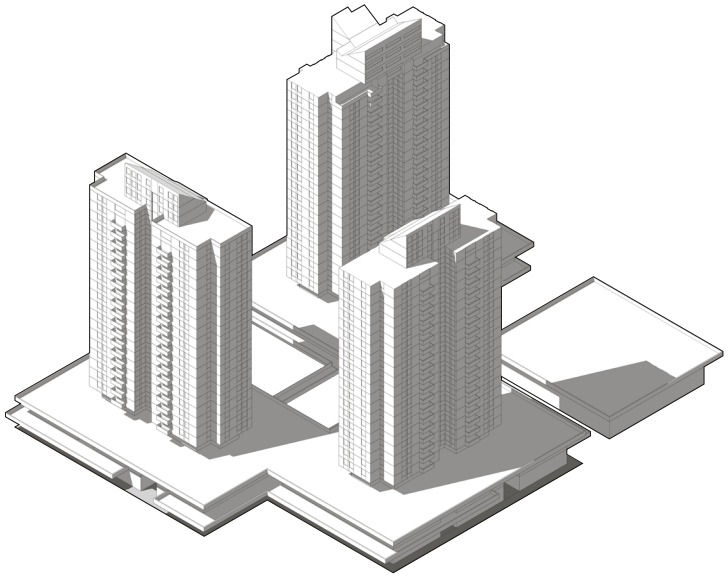
family typology was favored in public projects, and the need to densify cities with new housing projects, which could operate as instruments of development, was proposed (Graphic 21) (*Minvivienda,* 2014, pp. 34-35).

3.1.3.4. Corporate (1972-1991)

In this period, there were two different approaches: the participation of State institutions, and Savings and Housing Corporations (*Corporaciones de Ahorro y Vivienda,* CAV[15]), which would work with the Constant Purchasing Power Unit (*Unidades de Poder Adquisitivo Constante,* UPAC[16]) (Saldarriaga & Carrascal, 2006, p. 29). These corporations were conceived as private entities that were authorized by the State to finance residential projects. Between 1978 and 1982, the National Government encouraged the development of new housing groups and increased the share of construction in the country's Gross Domestic Product (GDP). Between 1982 and 1986, the Government refocused its attention in the quantitative deficit, reinforcing the financial and operational capacity of ICT. The policy focused on "Housing with No Down Payment" and established the goal of building 400,000 units in four years, half of which were of social interest. Considering the participation of the private sector, the UPAC system was regulated, which aimed to maintain the purchasing power of money and offer a solution to families that needed to take out a long-term loan. The savings accounts in UPAC would adjust their value according to inflation, to ensure that money maintained its purchasing power. The Savings and Housing Corporations were required to place a percentage of their portfolios in social-housing segments, and the financial conditions of mortgage credits were regulated. BCH was assigned projects to promote the re-densification in popular urban sectors and improve informal settlements. The housing program with no down payment marked the last milestone of ICT in regards to the construction of new units (Graphic 22). The budget assigned to it at the time allowed it to generate approximately one third of the total units built by this entity since 1939.

For the first time, the National Administrative Department of Planning (*Departamento Administrativo Nacional de Planeación,* DANE) separated the quantitative deficit from the qualitative deficit. This led the ICT to concentrate itself in programs aimed at improving homes built in the cities. The Savings and Housing Corporation period ended when the UPAC system achieved the stage of greatest vitality, which would operate until the 1999 economic crisis, triggered by the difficulties in collecting payments. In the 1990s, the ICT (which in 1990 added nearly 700,000 units in more than 600 municipalities in the country) and BCH were liquidated. The responsibility for implementing the policy and land-use planning was transferred to the municipalities. At that time, the quantitative and qualitative deficit affected nearly one third of Colombia's homes. Thus, the conception of housing policies based on the Welfare State ended. The insufficient housing solutions of this model, added to state projects that did not correspond to the needs and payment capabilities of households in deficit, caused the development of an autonomous social production of homes, with problems of illegality and informality in the process of self-construction (*Minvivienda,* 2014, pp. 35-39).

15 For its acronym in Spanish
16 For its acronym in Spanish



Graphic 22
Collective housing built in Colombia by the ICT during the Corporate Period. Marco Fidel Suárez Towers, Medellín. Architect: Eduardo Arango.

3.1.3.5. Conception of market and subsidies on demand (from 1991)

Law 3 of 1991 proposed dismantling the forms of State intervention and increasing purchasing power through subsidies (in cash or kind) (Saldarriaga & Carrascal, 2006, p. 30). The private sector's participation was promoted in social-interest projects to attract the financial sector (*Minvivienda,* 2014, pp. 40-44). Through Law 388 of 1997, a policy was formulated, based on the definition of areas destined for social housing and the employment of new instruments to regulate lot prices, as well as the participation of capital gains and expropriation through administrative means. Subsidies for three types of programs were established: improvement of the environment and housing, legalization of ownership deeds and acquisition. The Government gave a strategic role to the financial sector through mechanisms such as housing leasing (a financial system that did not require prior savings or a down payment; the user paid a periodic amount to acquire his housing) (*Plan Nacional de Desarrollo,* as cited in Saldarriaga & Carrascal, 2006, p. 31) and housing microcredit (financing that was awarded for the acquisition, construction or improvement of real estate with an amount that did not exceed 25 SMMLV, to be paid in a period of five years and an interest rate equivalent to that provided for the funding of VIS) (Ley 795, 2003, Art. 95, as cited in Saldarriaga & Carrascal, 2006, p. 31)[17]. According to this model, the State should not supplant or compete with the private sector in the production of goods and services. In this period, public institutions reported an unfavorable balance in their production, financing and quality. The situation was evident in the financial crisis of the ICT and in the deficit's magnitude. The exclusion of large sectors of the population from the housing market was also argued, due to their low levels of income and the informality of their occupations. The National Social-Interest Housing System (*Sistema Nacional de Vivienda de Interés Social*) emerged, as well as the Family Housing Subsidy (*Subsidio Familiar de Vivienda*) and the National Institute of Social-Interest Housing and Urban Reform (*Subsidio Familiar de Vivienda y el Instituto Nacional de Vivienda de Interés Social y Reforma Urbana,* INURBE[18]), replacing the ICT. In this period, the new 1991 Constitution of Colombia went into effect, and its Article 51 enshrined the right of Colombians to decent housing.

During the following administrative periods, the National development plans retained this conception of market and its legislation. INURBE's function was focused on the management of the Family Housing Subsidy. During the administrative period that began in 1994, an integral urban vision was conceived to replace construction and improvement of housing policies.

The Urban Social Housing Policy (*Política de Vivienda Social Urbana*) was established for households with lower income and the Social Solidarity Network (*Red de Solidaridad Social*) was created to manage the urban and rural programs aimed at the population with lower economic resources (Graphic 23) (*Ministerio de Desarrollo Económico,* 1995, as cited in Minvivienda, 2014, p. 42).

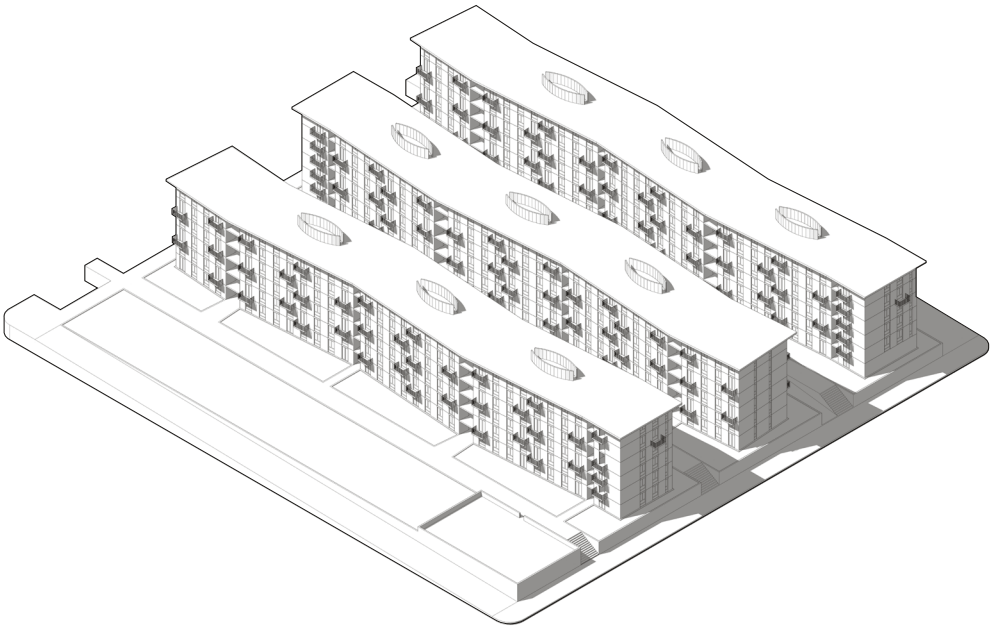
Law 546 of 1999 (the Housing Financing Law) had an impact in ending the UPAC system after having financed nearly 1.5 million homes in the country since 1972. In 1998, the Savings Accounts to Promote Construction (*Ahorro para el Fomento a la Construcción,* AFC[19]) were created. In 2003, the National Housing Fund (*Fondo Nacional de Vivienda,* FONVIVIENDA[20]) was created under the Vice Ministry of Housing and Territorial Development. In the period between 2006 and 2010, the Friendly Cities (*Ciudades Amables*) housing policy was implemented, which was part of the strategy to promote employment and equity with the following actions: articulation and implementation of sectorial policies

17 Article 95 of Law 795 of 2003. Real-Estate Microcredit (*Microcrédito Inmobiliario*).

18 For its acronym in Spanish

19 For its acronym in Spanish

20 For its abbreviation in Spanish



Graphic 23
Urban social housing built in Colombia during the conception period of market and demand subsidies. *La Playa* Residences, Medellín. Architects: Ana E. Vélez and Juan B. Echeverri.

(integral improvement of neighborhoods, macro-projects for social housing, urban renewal, urban re-densification and strengthening of the housing offer), creation of supply banks and motivation to new strategies, such as agreements with the financial sector.

Disbursement problems, access to mortgage credit and savings constraints led the housing policy to be focused on effective demand, which excluded sectors of the population with lower incomes. In 2010, the National Development Plan included the construction of one million homes, of which 649,454 would be VIS.

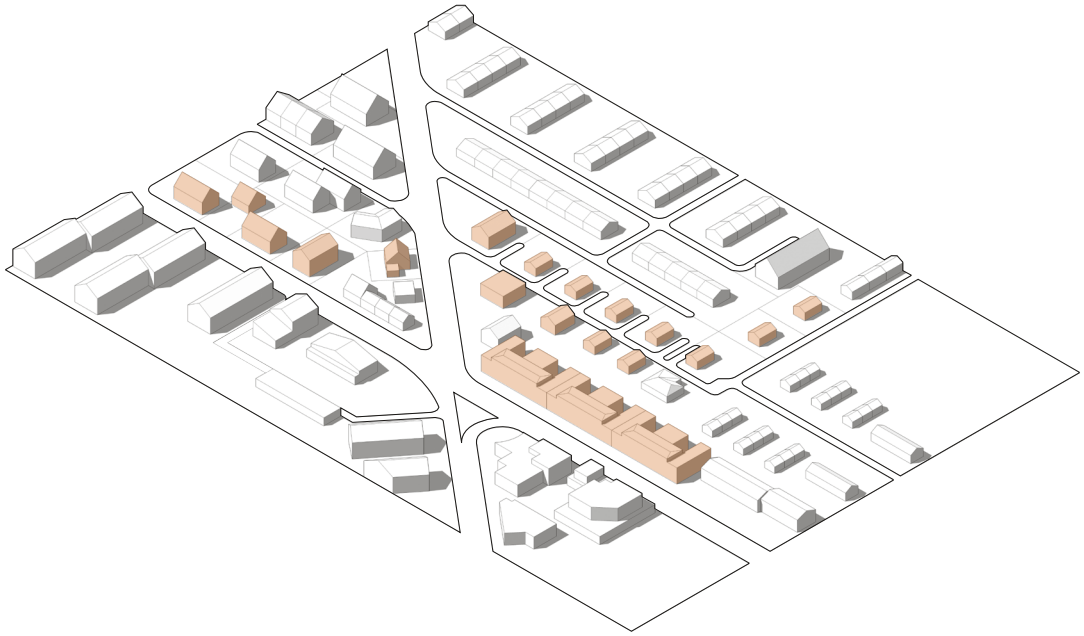
The plan maintained VIP and VIS categories in the price scales defined, and qualified a third type called Urban Renewal VIS, with a price of up to 175 SMMLV for housing units built in areas of urban renewal.

Since 2010, institutional management has boosted supply-and-demand interventions with the participation of the private sector. Direct State action was recovered in mortgage loans and in promoting VIP and VIS. This process was led directly by the Ministry of Housing, City and Territory and operated based on the offer, financial instruments, production forms and price control of inputs (*Minvivienda,* 2014, p. 43).

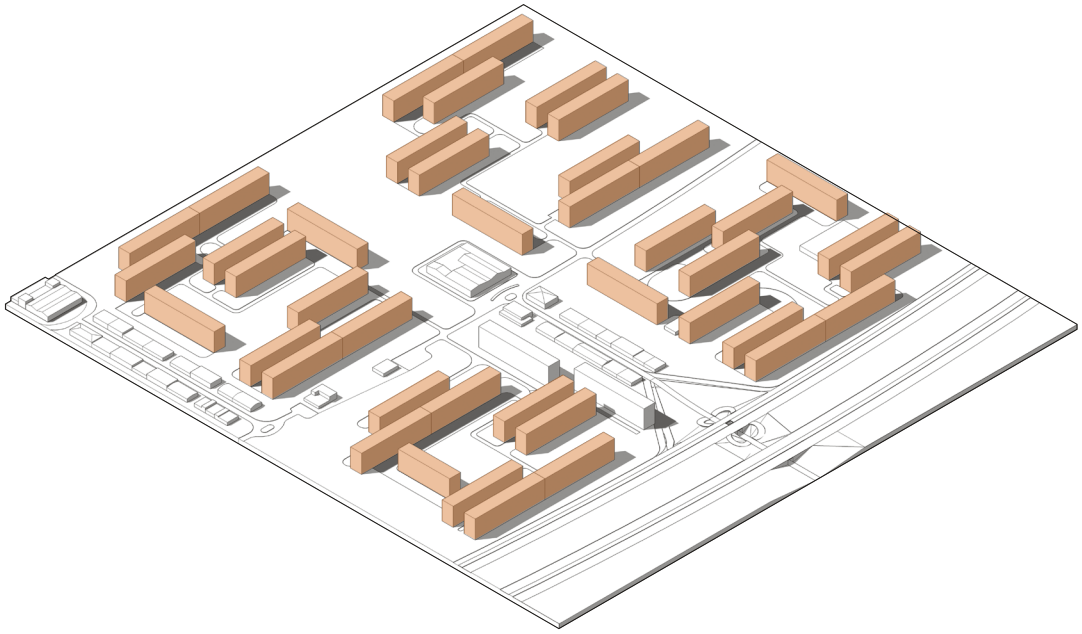
3.2. Urban, architectural and technical design of social housing in the XXI Century

Urban space, buildings and housing units have had spatial variations; they have returned to typological aspects and have explored other types of technical solutions in Western Europe, Latin America, Colombia and Antioquia. According to researchers Aurora Fernández Per, Javier Mozas and Javier Arpa, in *Density Is Home* (2011), urban contexts in which collective housing has been built is classified as disperse, modern, expansive, central and recycled (Fernández, Mozas & Arpa, 2011, p. 33). Collective housing has also been built in re-densified contexts (Graphics 24 to 29).

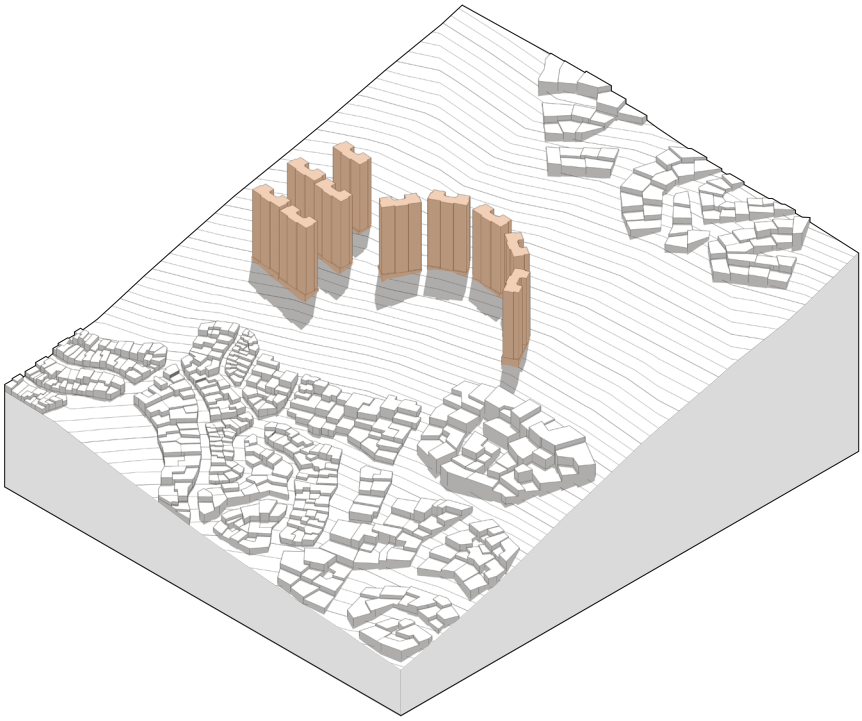
Each of these contexts presents different conditions regarding the location of the buildings and occupation of the territories: dispersed contexts are generally located in the urban peripheries, generally with low densities; modern contexts generate different types of zoning in cities, generally associated with use. Expansive contexts are the result of the growth – planned or not – of the cities; central contexts have re-densified the inhabited and constructed city, while recycled contexts correspond to the use of industrial infrastructures or other uses, which have left the cities to expand into other territories and have left spaces to be intervened by urban developments.



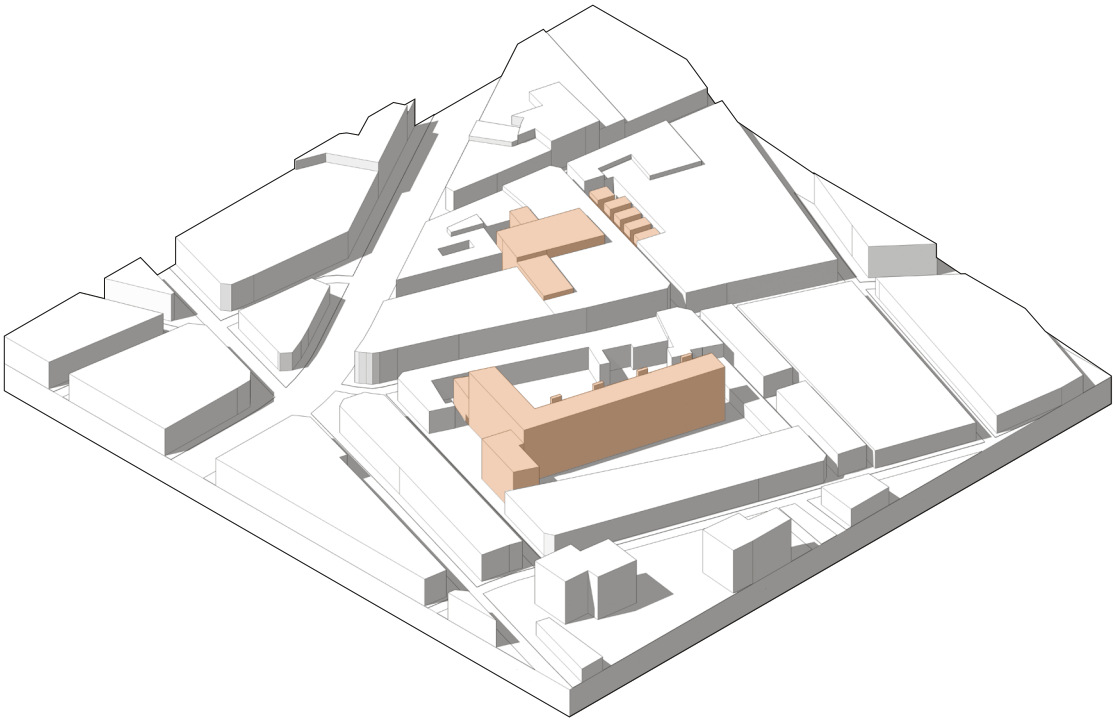
Graphic 24
Disperse city context. Rosenberg Conversion, Winterthur. Architects: EM2N.



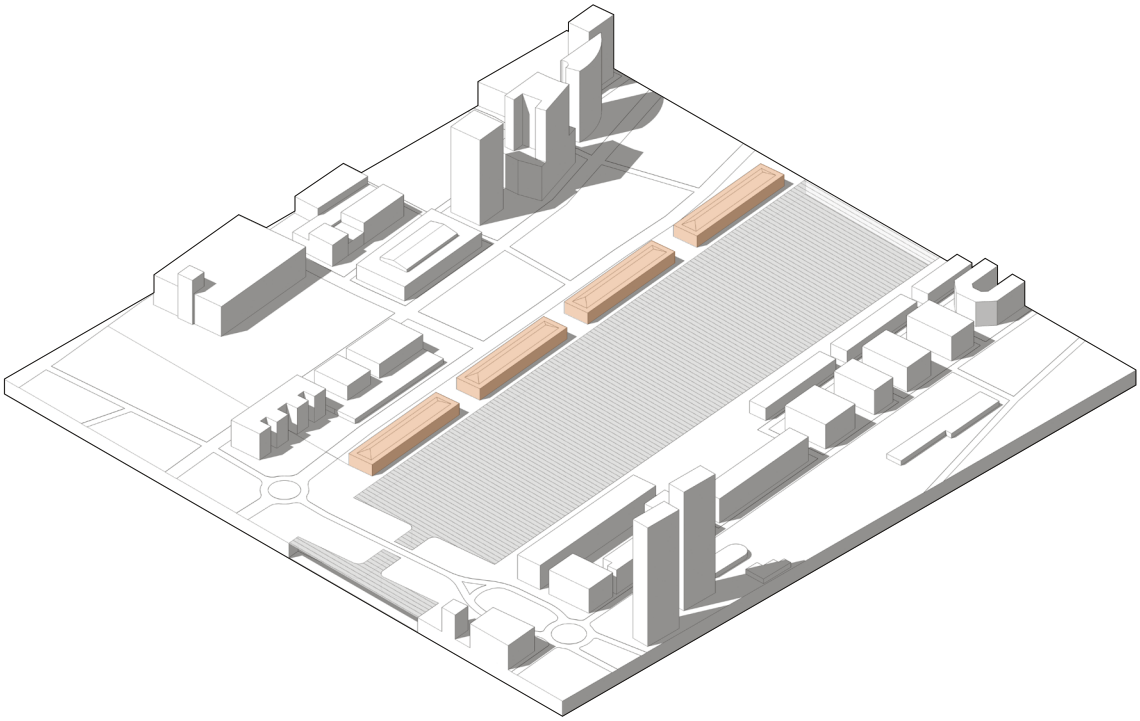
Graphic 25
Modern city context. Brasilia, Brazil. Architect: Lucio Costa.



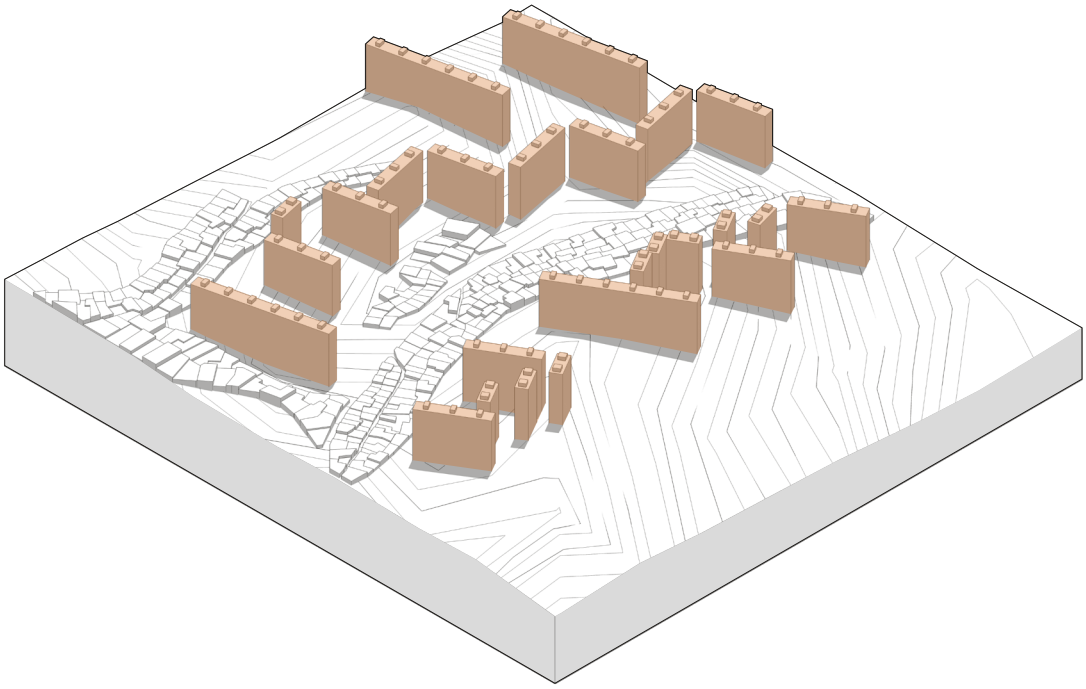
Graphic 26
Expansive urban context. *Pajarito La Aurora* Housing Units, Medellín. Architects: *Instituto Social para la Vivienda y el Hábitat de Medellín,* ISVIMED.



Graphic 27
Central urban context. Emile Chaíne Area Regeneration, Paris. Architects: Moussafir, Katz and Tachon.



Graphic 28
Recycled city context. *Puerto Madero,* Buenos Aires.



Graphic 29
Re-densified city context. Neighborhood Zone, Caracas.

3.2.1. Western Europe

With the exception of immigration processes in the second decade of the XXI Century, where some European cities have had to prepare themselves to receive many families that have arrived for different reasons, collective housing in Western Europe has not presented the housing deficits found in Latin America, Colombia and Antioquia. Its evolution has been given through different aspects related to urban planning, inhabiting modalities and construction techniques.

3.2.1.1. Urban planning

The context of the disperse city is the one occupying the generally disjointed urban peripheries and requiring additional infrastructures to avoid housing isolation. Its real-estate success lies in the fact that the costs of land located in the periphery – with agricultural use in most cases – are less expensive, less dense and less favorable for construction. Some projects built since 2000 have contributed to higher residential densities in their environment, and in some cases they have introduced aspects complementary to residential use (Fernández, Mozas & Arpa, 2011, p. 35).

The modern city is the result of the economic expansion after World War II, an aspect that had an impact on low-cost housing construction for workers and immigrants. These residential complexes were the result of policies that proposed the rupture of the existing urban conformation fabric in the city through residential blocks that changed neighborhoods into segregated parts. Spaces between the buildings caused security problems. The repetition of constructive solutions and the standardization of living space distanced the relationship between families and the place (Fernández, et al., 2011, p. 141).

Expansive urban contexts relied on the growth of the Gross Domestic Product (GDP), which – according to figures from the World Bank – increased 206% between 1995 and 2008 (World Bank, n. d.). That moment's economic outlook led to the formulation of urban plans with land occupations that behaved like new sleeper cities, and that were not integrated into the existing city from the beginning. The location of an isolated context allowed these projects to experiment with new forms, urban clusters, architectural typologies and the use of other materials (Fernández, et al., 2011, p. 81).

Central urban contexts appeared as a response to modernity and were aimed to show that the overlapping of uses and pedestrian paths in the historic city were almost indispensable for more sustainable development. In the face of the market thrust, many cities experienced an increase in land costs. In Western Europe, compact neighborhoods that needed the construction of urban and housing projects to improve accessibility, public space and their facilities can still be found. In several of its cities, examples are found with recycling operations, re-densification, replacement or growth of traditional urban forms These collective housing projects have introduced some public facilities, social groups of different ages, interests or resources (Fernández, et al., 2011, p. 206).

The recycled city was a result of the relocation of industries to other places, the renewal of public infrastructure and the construction of new urban spaces. These actions generated areas of opportunities. The recycling of these terrains, adjacent to urban areas, prompted many cities to grow from within. Industrial landscapes, shaped by existing buildings, remained in the hands of new uses that cities adapted to their infrastructures. Social housing in the recycled city was located in areas integrated into its environment and was built through official programs or private investments. In these depressed areas, public housing was used as a solution for future uses and developments, which have been necessary for the regeneration of projects to positively intervene in the urban surroundings (Fernández, et al., 2011, p. 321).

3.2.1.2. Housing

In the first fifteen years of the XXI Century, in Western Europe, this topic has been studied from the typology of the building and the program of interior spaces with their average built-up areas.

3.2.1.2.1. Typologies

Typologies are classified based on the territory's occupation, urban clusters and architectural variants. Compact buildings are generally located in urban areas, occupying a space of the city block, between dividing walls or in a corner. To increase the number of units, they are repeated in height, without further typological variations. Extended buildings occupy a larger area of the terrain, generally on peripheral lots. They configure their system of collective circulations with interior corridors toward the courtyards or toward the exterior façades. The building's architectural typology varies according to existing regulations, with occupancy rates of terrain, permitted densities, maximum heights or market use.

3.2.1.2.2. Program

Contemporary social housing in Western Europe develops a program with slight variations, where domestic spaces are generally divided into three uses: services (consisting of a kitchen, one or two bathrooms and a laundry area, sometimes located in common areas of the building); the social area (made up of a living room, a dining room and occasionally by a balcony or a studio); and a private area (which has one to three bedrooms). The areas constructed vary according to the program and may measure between 25 m^2 and 80 m^2. The formation of high-rise buildings and the occupation of urban space vary according to the context in which they are located, and with the permitted density of occupation by local regulations.

3.2.1.3. Construction techniques

Most structural systems in European social housing, in the XXI Century, can be classified into two types: skeletal (columns and beams) and load-bearing walls. The skeletal system has concrete structures cast *in situ*, precast concrete, metallic structural profiles and – in some cases – wood. Load-bearing walls are generally built with structural masonry, concrete cast *in situ* or precast concrete. Technical evolution has shown developments in non-structural elements, such as façade walls and interior divisions. These have been traditionally built in non-structural masonry and, eventually, coatings in stone, concrete or clay have been used. The technical change has been focused on using industrialized panels in different materials (wood, metal and high-performance precast

concrete), which has accelerated the construction processes of some buildings and generated different languages.

3.2.2. Latin America

In 2012, the Inter-American Development Bank (IADB) reported that Latin America had a growing housing shortage, which could be reduced with more investment from its governments and the private sector to increase the supply of adequate, low-cost housing. In May of that same year, one in three families (a total of 59 million people) had no housing, lived in inadequate housing built with precarious materials or lacked basic utilities. Two thirds of the families each year, between 2000 and 2012, were forced to settle in informal housing and slums (Inter-American Development Bank, 2014). According to the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), during most of the XX Century, housing policies were characterized by the State's presence in construction and financing. ECLAC posted that, beginning in 2010, every ten years, Latin American population in cities would increase by 2.5%. Given the constraints of land use and due to an unplanned urbanization process, the search for solutions to the problem of housing shortage has become more complex (The United Nations Economic Commission for Latin America and the Caribbean, ECLAC, 2010).

3.2.2.1. Urban planning

According to Alejandro Aravena y Andrés Iacobelli, public policies and the market have developed two strategies to deal with the scarcity of resources that generally relate to the design and construction of social housing in Latin America. One is to reduce the area. The other is to locate it in remote surroundings, where land costs less, in peripheries lacking utilities and which are marginalized from opportunities that are concentrated in cities (Aravena & Iacobelli, 2012, p. 14). Much of Latin American social housing in the XXI Century has been built in disperse contexts and, in some other cases, in expansive contexts. Some housing projects have proposed re-densifications in previously occupied urban areas. Three types of context accompany these urban developments: the disperse city, the expansive city and the re-densified city.

In the disperse city, social housing has generally occupied disjointed peripheries. The cost of these lands has permitted viable projects that subsequently require urban infrastructure, such as roads, parks, businesses, educational and health buildings, transport and spaces for sports.

Expensive urban environments have been formulated within urban plans that have never been integrated to the existing city. These residential complexes were conceived independently and then integrated into the city, due to the growth of its periphery.

Some cases of the re-densified city, with collective housing projects, have revitalized traditionally marginalized sectors and those lacking opportunities. Several examples of operations to replace or re-densify traditional urban forms have been integrated into the surroundings and have been articulated with public spaces, existing homes, ancillary services (health, business, education, culture, etc.) and road infrastructure. Social housing, designed and built to re-densify urban land, has improved environmental conditions and its habitability.

3.2.2.2. Housing

In the first fifteen years of the 21st Century, the study of collective housing in Latin America has included the types of buildings and interior spaces the programs of.

3.2.2.2.1. Typologies

In this context, contemporary social housing has had different nuances. One of them is the construction of projects that have improved the quality of life, from insertion into urban contexts and from the understanding of the housing dynamics, which has allowed the programmed growth of their areas. Some experiences – such as those developed in Chile and Mexico by the *Elemental* study, and housing programs such as *Minha Casa – Nossa Cidade* (My House, Our City) in Brazil – have permitted the growth of housing to meet the needs of each family, delivering the individuality sought by its inhabitants in the housing complex.

In a second case, social housing has been developed through massive buildings that are isolated from the urban structure. The typological repetition of programs, areas, spaces and languages has not considered the diversity of the communities' social and cultural traditions. This has generated an absence related to a sense of belonging and the lack of ownership by families.

A third case, made up by the informal growth of cities through self-construction, has been the formula used by communities with fewer economic resources to resolve their lack of habitat. Differences in the conformation of family groups, the increase in its members over time and the appearance of (primarily economic) complementary activities, has progressively transformed the use and language of popular housing in Latin America.

According to each context, collective-housing buildings respond to existing regulations: density, land occupation index, construction index and maximum heights. Housing patterns are units that – when repeated – generate housing complexes with similar languages, heights, land occupation and architectural programs. These are located within the urban context or in isolation; on terrain intended for future real-estate developments.

3.2.2.2.2. Program

Latin American social housing is generally composed of a service area (with a kitchen, one or two bathrooms and a laundry area, sometimes accompanied by a patio); a social area (with a living room and a dining room, which are usually integrated, sometimes with a balcony or a studio); and a private area (having two or three bedrooms on average). The constructed areas vary between 40 m2 and 80 m2. Over time, family needs have driven growth on the ground and top floor, or interior space transformations to condition the initial areas to their needs.

3.2.2.3. Construction techniques

Latin America has had a technical tradition in the construction of social housing since the early years of the XX Century. Structural systems used are classified in two types: skeletal (comprised of columns and beams) and load-bearing walls. The skeletal system has concrete structures cast *in situ*. In countries like Chile and Brazil, wood elements have been used to build these types of structures. Sometimes, metallic structural profiles have been used in countries such as Argentina, Venezuela, Chile, Ecuador and Brazil. Load-bearing walls have traditionally been constructed in concrete blocks or ceramic bricks, materials widely used throughout the region, known by the communities and worked by themselves in self-construction processes. Load-bearing walls or structural walls have also been built with concrete cast *in situ*. Non-structural elements (some dividing or façade walls) have been built in concrete blocks or ceramic bricks. In some cases, surface finishes, such as wall coverings, plasters and paints, have been applied. These materials, which permit its transformation over time, have allowed the pursuit of different languages and progressive growths, according to the needs of each family group.

3.2.3. Colombia and Antioquia

3.2.3.1. Urban planning

Land occupation strategies in Colombia and Antioquia have occurred in disperse contexts, expansive contexts and contexts where urban or rural space has been re-densified.

A fraction of the projects has been built in urban or rural peripheries, in disperse contexts. These interventions have allowed the occupation of terrains with other complementary housing activities. A lack of flat terrains and with an availability of primarily sloping land, areas of expansion determined by land-use instruments have been occupied. In rural and urban surroundings, official and private entities have built detached homes, through which the land has been deeded to the owners; actions within the standards of legality.

Complexes located in expansive urban and rural areas have gradually been integrated into the existing city. In these cases, environmental improvement programs have been led by official or private entities to integrate the homes into urban space (VIVA, 2015, p. 168). Despite the limitations of physical space, the existing legal conditions and the scarcity of financial resources, official entities have implemented basic urban-planning projects to complement the surroundings.

Some housing complexes have given new life to re-densified urban areas and have revitalized complex sectors, from the social component to their physical infrastructure. The construction of these houses has invigorated neighborhood economies; they have generated appropriations of different terrains and the gap in the quantitative deficit has been decreased. These projects have articulated centers in terms of accessibility, pedestrian continuity and the relationship with their surroundings (VIVA, 2015, p. 162).

3.2.3.2. Housing

This study has considered building typologies and their interior spaces program, with the average traditionally built areas.

3.2.3.2.1. Typologies

In national and local contexts, the typology of these buildings is classified by land-use strategies and architectural characteristics. Some of these projects have collected the traditions of family groups to offer various possibilities regarding interior spaces, and allow their transformation over time. Building heights are regulated by existing regulations. Above five stories, the installation of an elevator is mandatory.

A first case, consisting of buildings constructed in the early years of the XXI Century, has understood habitat as a succession of events and transformations that make the domestic space a dynamic place that can change over time. These proposals (that have not been replicated massively in our local context) have allowed housing to respond to the needs of each family.

In a second case, housing complexes have replicated their programs, areas and language in very few variations and in different surroundings. Land occupation has generated different social problems by building them in places where sufficient complementary urban infrastructures to housing do not exist. The family groups that occupy these buildings do not recognize the surroundings as their own space and sometimes these projects have not facilitated access to complementary services. The insertion of these complexes with minimum typological variations has generated problems of violence and deficiencies in the community's quality of life.

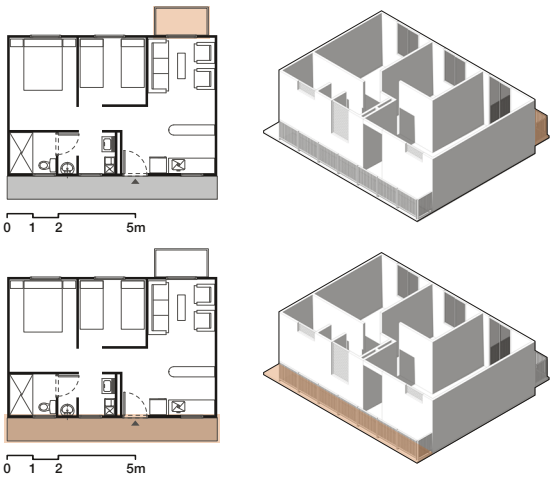
A third case, defined by non-programmed growth through informal construction on the periphery of cities, has been the response of communities with fewer economic resources to housing deficit. When the State or private companies do not provide the solutions that these families need, illegal occupation of land and self-construction processes have been the response to the lack of habitat, generating structural risks by settling in geologically unstable areas and promoting conditions of insalubrity, overcrowding and insecurity.

3.2.3.2.2. Program

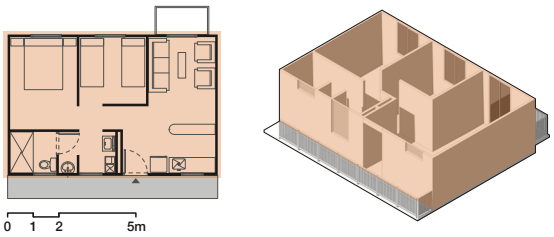
In a local context, social housing is made up of these three groups of spaces: a service area (with a kitchen, one or two bathrooms and a laundry area); a social area (with a living room and a dining room, almost always integrated, sometimes with a balcony or a studio); and a private area (generally having two or three bedrooms). The average constructed areas are 45 m² for Priority-Interest Housing (VIP) and from 45 to 65 m² for Social-Interest Housing (VIS).

In *Vivienda Urbana* (*Urban Housing*) (2014), the Housing Company of Antioquia (VIVA) proposed systems of nucleated or collective-housing clusters with different configurations that contemplated these fundamental strategies: elementary geometry, elementary nucleated utilities, served spaces, intermediate spaces, technology, bioclimatics and perception.

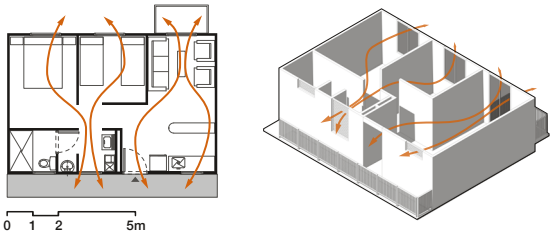
- The elementary geometry of the unit is the conformation of a space that can be grouped in different ways, according to the architectural typology selected (Graphic 30).
- Nucleated services (comprised of a bathroom, a kitchen and a laundry area) are concentrated in a space to decrease the distances of technical installations (Graphic 31).
- Served spaces are the areas to sleep, circulate, eat or gather. They can have either two or three bedrooms, and circulation is proposed in the most efficient way possible, to avoid excessive distances (Graphic 32).
- Intermediate spaces are balconies or exterior corridors that favor the relationship of the interior space with the environment (Graphic 33).
- Technology and bioclimatics establish the principles of wellness in an interior space. The structure is proposed with columns and beams or structural masonry, for buildings up to five stories (Graphic 34).
- Perception is focused on principles of spatial quality, which must convey a dignified image with its own identity (Graphic 35).

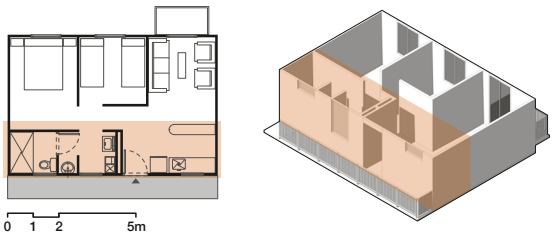


Graphic 33
Intermediate spaces.

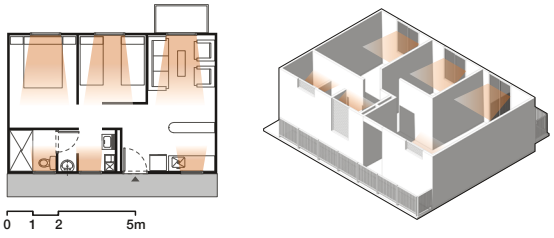


Graphic 30
Elementary geometry.

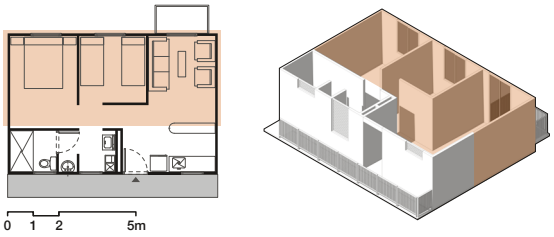




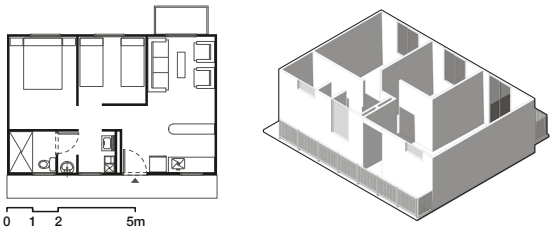
Graphic 31
Nucleated services.



Graphic 34
Technology and bioclimatics



Graphic 32
Served spaces.



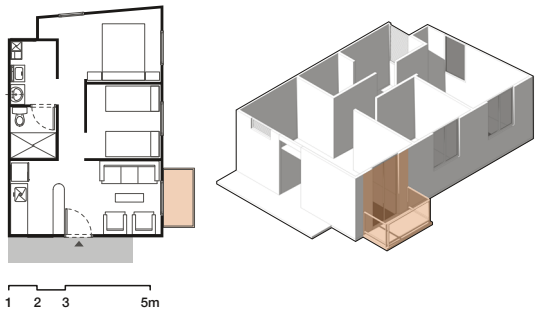
Graphic 35
Perception.

VIVA's proposal includes topographic, climatic and cultural adaptability. These prototypes correspond to the spaces that make them up and are classified as: balcony, indoor walkway, gallery and patio.

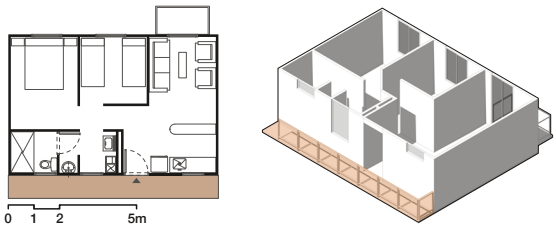
- The prototype balcony proposes a lateral access; services are grouped on the internal dividing wall and three served spaces to the façade, to capture natural lighting and ventilation from its four sides (Graphic 36).
- The prototype indoor walkway has access to the back, next to the services that are grouped toward the same façade. The rooms and social area face the main façade for natural ventilation and lighting (Graphic 37).
- The homes have a gallery with a naturally ventilated, illuminated space for clothes, located on the access façade, which generates a hall next to the social area. Services are grouped in a nucleus that is illuminated and ventilated by the patio, for clothes. Towards the main façade, the social area and bedrooms are located. A variant of this spatial system is the sum of an additional bedroom and the grouping of services on one side (Graphic 38).
- The prototype patio has an outdoor corridor and an access hall, resulting from grouping the units. Services are concentrated on one of the interior dividing walls and a backyard captures the greatest amount of lighting and generates cross ventilation. The social area is in the center and each of the two bedrooms face each façade. This prototype permits rear growth (Graphic 39) (VIVA, 2014, pp. 28-44).

3.2.3.3. Construction techniques

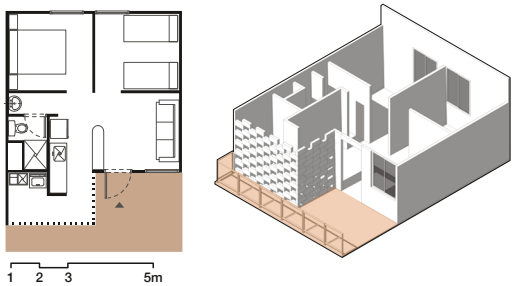
In the local context, essentially three types of structural systems have been built: skeletal (consisting of beams and columns), load-bearing walls and a third possibility that combines the structures of beams, columns and load-bearing walls (known as the dual system). The beams and columns are generally used for buildings more than five stories tall, highlighting the nearly exclusive use of *in-situ* cast concrete. Load-bearing walls are generally used in buildings up to five stories tall and have been built with structural masonry (in concrete blocks or brick), and occasionally with *in-situ* cast concrete. Non-structural elements on façades and interior walls are in masonry (concrete blocks or brick). In some cases, wood has been used in the construction of façades and the division of the interior spaces. The construction tradition for social housing in the country has not been recognized for its technological innovation. Its contributions in this field have not been evident and – due to the high costs of other materials such as steel or wooden structures – they are almost never used in these projects.



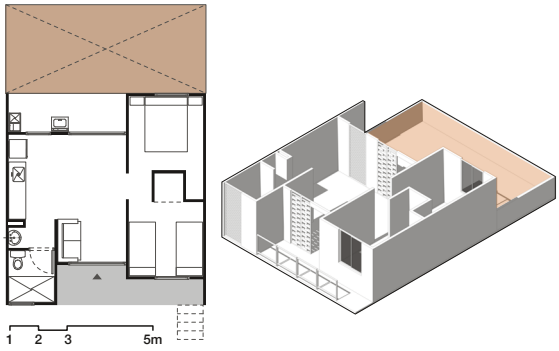
Graphic 36
Prototype balcony.



Graphic 37
Prototype indoor walkway.



Graphic 38
Prototype gallery.



Graphic 39
Prototype patio.

Summary

The urban, architectural and technical design of social housing

In international, national or local contexts, social housing has had similar developments in urban, typological, programmatic and technical terms. The evolution of the concept has occurred mainly in aspects of grouping, housing and some construction techniques. Conceptual principles developed in Western Europe were subsequently replicated in Latin America, Colombia and Antioquia. Initially, social housing in Western Europe proposed concepts, such as minimal housing, series housing, and neighborhood units. In Latin America, given the conditions of the social and political context, these conditions led to the conceptualization of worker housing, housing promoted by the State and experimental housing. In the local context, these principles led to the conception of social housing classified into five periods: Hygienist, Institutional, Transitional, Corporate and to the Conception of demand according to the market and the subsidies.

The search for minimal, repetitive and grouped housing in Western European neighborhoods since the early years of the XX Century is still in force. Proposals for new social-interest housing in the local context must consider efficient spaces more than minimal, replicable rather than repetitive and that conform neighborhood- and collective-life units. Housing projects in Antioquia should be a commitment to the community, for the reconstruction of family ties, for neighborhood life. Therefore, collective, efficient, replicable and versatile housing proposals that consider housing values in other contexts are a guiding principle for the urban and architectural design of these spaces.

In the working-class, State-owned and experimental housing in Latin America, there is evidence for whom, from where and how new collective-housing schemes are proposed. Social housing today is a habitat for working-class communities (called worker communities in the Latin American context); they must be planned by the State and private intentions (allowing the participation of private enterprise) and should have an experimental character when incorporating the needs and tastes raised by the communities themselves into their experiences, seeking alternatives in construction systems that improve living conditions.

The conception of social housing is the rational, experimental exercise to reduce its costs and construction time, and to think of principles that improve the quality of life of communities. Social housing is the place where the living conditions of communities can be improved in an integral manner through urban planning aimed at strengthening communities, with collective spaces for the gathering of families and with comfortable private spaces adaptable to the conditions of their inhabitants. From urban planning, social housing should form a collective space for the gathering of communities and families, in which community life accompanies individual life.

Social housing must be conceived in three moments:

The first is the stage of industrialization, made in factories by specialists in material-producing plants. There, the productive process of the support structure is made with all the standards of quality and replicability of its components.

The second is personalization. Through the search for individuality, the structure is carried to the perimeter of the space (walls between dwellings and slabs) so that the interior spaces are free areas, initially occupied by a service module that contains the bathroom, kitchen and laundry units, located in a way that permits different uses of the interior space. It is done by architectural professionals and with designs in which the community has participated. The interior space must be conceived with the least presence of structural elements to adapt it to the needs or desires of its inhabitants. The façades are also conceived by means of non-structural elements, which can be adapted to the environmental, cultural or social conditions of the environment in which they are located.

The third moment is the transformation or incrementality, which permits processes to modify the dwelling during occupation by the families, who can adapt them to their needs or desires.

The construction techniques that start from an industrial process in the conception and installation of the support structure are complemented with traditional methods that allow self-construction processes with materials traditionally used in the non-structural elements, which can modify the use of the interior space and adapt the housing to the needs or preferences of its inhabitants.



Precast-Concrete Technology

The Colombian Earthquake-Resistant Construction Regulations, NSR-10, defines precast concrete as "the element in structural concrete constructed in a place different from its final location" (*Comisión Sismorresistente & Minambiente,* 2010, p. C-29). Conventional concrete, the basis for the production of precast concrete, is defined as "a material composed of a binding material (generally Portland cement or any other hydraulic cement), fine aggregate, coarse aggregate and water, with or without additives" (*Comisión Sismorresistente & Minambiente,* 2010, p. C-28). According to NSR-10, the compressive strength for structural elements in concrete should not be less than 17 MPa, 28 days after casting (*Comisión Sismorresistente & Minambiente,* 2010, p. C-1).

In precast concrete elements, higher strengths can be obtained in the same period of time due the workability that must be achieved in the first eight hours after the casting process. In addition to the components of conventional concrete, structural precast concrete may contain additives and reinforcements, such as cables, metal rods, structural fibers, textile meshes and nanomaterials, among other elements, which improve its mechanical behavior.

4.1. Generalities

With precast concrete, buildings can be formed from the support structure and the non-structural elements through a language without coatings, where the least amount of joints is desirable to increase construction yields, reduce work activities and ensure the continuity of the elements that make them up (Mañà, González, Cuchí, Zamora & Roca, 2001, p. 78). From the architectural design, it is necessary to consider that in the production process of the elements, the building must be divided into the parts that comprise it and join them in the assembly process. These parts must be produced with the sizes and weights adapted to transportation and on-site installation requirements. In *Alternatives to the Conventional Construction of Homes* (2002), Josep María González-Barroso states that prefabrication must meet two requirements: continuity and flexibility.

4.1.1. Continuity

This requirement proposes the industrial production of the building in a set of parts with similar characteristics, which are then put together in the on-site assembly process. Continuity allows understanding the building as an integral element and the sum of its parts. It establishes three conditions indicated in Table 5: structural continuity, spatial continuity and constructive continuity (Mañà et al., 2001, pp. 23-26).

4.1.1.1. Structural continuity

Precast concrete must ensure the continuous transport of stresses in structural and non-structural elements, guaranteeing its stability and the seismic-resistance with deformations acceptable by all the subsystems of the building. In prefabrication, the building is conceived in components or parts, with dimensions that allow transportation to the project site. In the assembly process, a unity criterion is important, as they were designed to ensure the structural stability of the building.

To achieve this condition, joining procedures, such as simple support with friction between the pieces, knot concreting with continuous inner reinforcements, joints through interior or exterior metallic elements, and post-tensioning systems, have been used (Mañà et al., 2001, p. 24).

4.1.1.2. Spatial continuity

This refers to the visual perception that users have traditionally had about the continuity of the elements that make up a building, and its relationship with living spaces. This perception only admits discontinuities or visible joints in certain places, such as those found between walls and slabs or between beams and columns. The coatings used try to hide these discontinuities behind a uniform appearance. Precast elements tend to evidence the joints, and their presence is not considered visually admissible in the elements that make up a space. Therefore, from the architectural design process and the industrial production of these pieces, the divisions desired for the building must be considered in order to locate them in admissible places. To ensure spatial continuity, these joints must be coordinated with all of the structure's elements, the façades, and the components of interior spaces (Mañà et al., 2001, p. 25).

4.1.1.3. Constructive continuity

Prefabrication allows the introduction of other industrial methods, different from their specific conditions, to control the quality, cost and execution time in the work. This allows the system to have continuity in the construction process and does not depend on other alternate processes, providing the ability to autonomously resolve its activities and determine the main work route. This independence implies that precast systems solve the maximum of possible technical activities to increase the efficiency of constructive processes. With the exception of foundations, which have traditionally been built with *in-situ* cast concrete, prefabrication in concrete comprises the greatest number of processes on site, establishes precedence, the order of construction, and determines the time in the activity schedule (Mañà et al., 2001, p. 24).

4.1.2. Flexibility

The demand for flexibility in prefabrication is aimed at finding an ideal proportion between the standardization of its parts and some formal and modular variations, derived from the criteria of uniformity and repetition, in order to generate responses on different scales: urban, building, housing and other construction subsystems, as indicated in Table 6.

4.1.2.1. On an urban scale

Urban environments require accessibility conditions and spaces adapted to the processes of transport, collection, elevation, and fixation of precast elements. In this case, there is a requirement of space and accessibility that is sometimes overwhelming. In these cases, where precast elements can be used in the site's conditions, the configuration of the building should respond to the urban characteristics desired for the project, and also to the possibilities of transport, assembly and maneuvering of necessary equipment (Mañà et al., 2001, p. 27).

Continuity requirements	
Structural	Stability of the building and an articulated, harmonious behavior among all of its components
Spatial	Integral visual perception of the elements and spaces that make up the building
Constructive	Coordination of the precast construction process with other technical systems

Table 5
Continuity requirements in precast concrete: structural, spatial, constructive.

Flexibility requirements	
On an urban scale	Characteristics of the context, accessibility and adaptability of the system
On the scale of a building	Articulation of structural and non-structural elements to define uses and languages
On a housing scale	Adaptation to different living conditions, uses and languages
On the scale of other constructive systems	Convergence of different materials, technical systems and constructive processes

Table 6
Demands for flexibility in designs and construction with precast concrete: on urban, building and housing scales, and the scale of other construction subsystems.

4.1.2.2. On the scale of a building

Precast concrete essentially resolves the structural component of the building. The standardized elements that make up the structure and some of its enclosures are articulated to permit different uses, languages and architectural typologies. Buildings with precast concrete structures combine parking lots in the basements, shops on the first levels and different residential typologies in the upper stories. This adaptation implies a spatial, structural and typological flexibility that is resolved from the architectural design, the constructive system and the logistics to install precast elements (Mañà et al., 2001, pp. 27-28).

4.1.2.3. On a housing scale

The house is a set of spaces with different uses, characteristics and proportions. The arrangement of precast elements in the building should be understood as a sum of the pieces that conform different residential typologies, and that permit their standardized reproduction or their adaptation to different housing conditions, from modular and repetitive elements. This adaptation implies an order of dimensional and housing flexibility that combines different typologies from a rational, repetitive and modular constructive system.

4.1.2.4. On the scale of other constructive subsystems

A building is formed by the convergence of different spaces, materials, technical installations and constructive systems. Precast concrete has permitted the incursion of other systems that have complemented it and improved its efficiency (Mañà et al., 2001, pp. 28-29). The progressive technical improvement of construction processes has been added to other systems of enclosing, coating and installing, which have diversified their responses, improved their efficiency and adapted to different technical, environmental and cultural settings.

4.1.3. Prefabrication systems in concrete

Different studies classify prefabrication in concrete in three systems: closed, open and partially industrialized. According to Table 7, they are defined by the source, the characteristics of the elements that make them up and the degree of relation with other materials or constructive processes (Staib, Dörrhöfer & Rosenthal, 2008a, p. 42).

4.1.3.1. Closed

In closed prefabrication systems, all the elements must be produced with the same industrial and technical characteristics, and ideally by the same manufacturer (Staib et al., 2008a, p. 42). Its aim is to industrialize the entire building as a unitary concept, with the least amount of variation among the elements to preserve the standardization criteria and improve efficiency in the production and installation processes. The manufacturer must ensure that the system's components are compatible with each other, in order to achieve the coordinated installation of all the structural and non-structural elements that make up the building (Mañà et al., 2001, pp. 79-80).

4.1.3.2. Open

Open prefabrication systems allow combining precast concrete elements with elements prefabricated in other materials, which increases flexibility in the design process and in the selection of the structural and non-structural components. In this system, all the elements must be precast; they can be conformed by different materials and may be produced by different manufacturers (Staib et al., 2008a, p. 42). Open prefabrication systems define the common criteria (types, dimensional coordination and order of installation) to design and construct buildings with precast elements that come from different industrial processes, with diversity in their materials, formats and geometric characteristics (Mañà et al., 2001, pp. 80-81).

Prefabricated Construction Systems		
Closed	Open	Partially Industrialized
A single prefabricated material	Different prefabricated materials	Precast and non-precast materials
Elements from a single producer	Elements from different producers	Elements from different producers
Combination among defined elements	Combination of variable elements	Combination of variable elements

Table 7
Classification of prefabrication systems in concrete: closed, open and partially industrialized. Taken from Detail: *Elemente + Systeme*, p. 43.

4.1.3.3. Partially industrialized

In partially industrialized prefabrication systems, the building may combine different construction processes. In this case, precast concrete elements are combined with traditional systems, such as masonry in brick, concrete blocks, divisions in wood, metallic elements or with other types of precast elements, which are adapted to the technical conditions of the building and increase the possibilities of being combined with other materials. This is a less dogmatic version of prefabrication, where a conception that leads to the optimization of the advantages of each technique becomes evident (Mañà et al., 2001, pp. 81).

4.2. Components of precast reinforced concrete

Different types of concrete can be used in prefabrication processes. Its classification is proposed according to the materials that make up a mixture: binder material (generally Portland cement or any other type of hydraulic cement), aggregates, reinforcements, additives and water.

4.2.1. Conglomerate material

The most used conglomerating material is Portland cement, which is made up of a mixture of clinker and gypsum. Clinker is the result of the calcination of limestone and clay at temperatures of up to 1450ºC. Gypsum allows the mixture to mold and harden after coming into contact with water (Figure 3) (*Comisión Sismorresistente & Minambiente,* 2010, p. C-29). The cement is produced when gypsum is added to the clinker, through which the mixture acquires the property to bind by adding water and then hardening.



Figure 3
The most used conglomerating material is Portland cement, formed by a mixture of clinker (calcified clay and limestone) and gypsum.

4.2.2. Aggregates

According to the Colombian Earthquake-Resistant Construction Regulations, NSR-10, aggregates are granular materials, such as crushed stone, gravel, sand and blast-furnace slag, which are mixed with a cementing medium to form hydraulic concrete or mortar (*Comisión Sismorresistente & Minambiente,* 2010, p. C-25).

Normal-weight aggregates for concrete must comply with Colombian Technical Standard (*Norma Técnica Colombiana,* NTC) 174 (ASTM C33); lightweight aggregates must comply with NTC 4045 (ASTM C330).

Some definitions classify aggregates as fine and coarse, according to their sizes. Fine aggregate is generally composed of natural or manufactured sand or a combination of both. The best-suited sand fineness modulus to produce concrete must be between 2.0 and 3.1. A value less than 2.0 indicates a fine sand; 2.5 indicates a medium-fine sand, and a value greater than 3.0 indicates coarse sand. The maximum nominal size of coarse must not be more than one fifth (1/5) of the lesser separation between the sides of the formwork; one third (1/3) the height of the slab or three fourths (3/4) of the free minimum space between the individual reinforcement bars or wires, tendons or ducts (Figure 4) (*Comisión Sismorresistente & Minambiente,* 2010, p. C-43).

The smaller the aggregate size, a denser concrete mix can be designed, which affects the final strength of the structural or non-structural prefabricated elements.

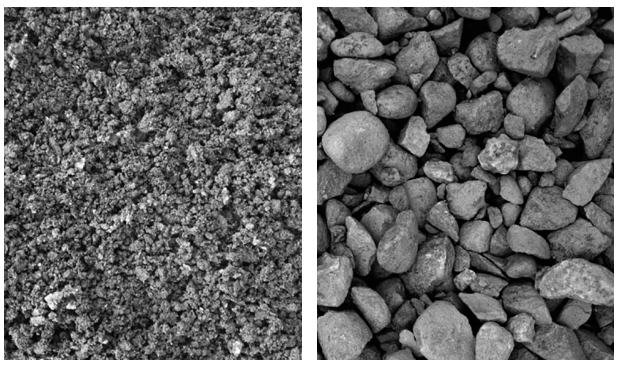


Figure 4
Fine and coarse aggregates, classified according to the fineness modulus and maximum nominal sizes.

4.2.3. Reinforcements

Reinforcements for precast concrete may be classified in three groups, according to their geometry:

- Linear reinforcements, such as reinforcement bars, cables for the construction of pre-stressed elements and procedures for the construction of post-tensioned structures.
- Continuous surface reinforcements, such as metal mesh or textile reinforcements.
- Discontinuous reinforcements, such as fibers.

4.2.3.1. Linear

Linear reinforcements for precast concrete are made up of passive elements and active elements, with the following characteristics:

4.2.3.1.1. Passive reinforcements

The NSR-10 explains that passive metal reinforcements, such as metal rods, must be corrugated (Figure 5). Smooth reinforcements may only be used in stirrups, spirals (or tendons) and reinforcements for distribution and temperature.

The corrugated reinforcement bars must be low-alloy steel that complies with the NTC 2289 (ASTM A706M) standard. The NSR-10 Regulations allow the use of stainless-steel bars manufactured under the ASTM A955M standard, only when they comply with the requirements of the NTC 2289 (ASTM A706M) standard.

The conditions to use reinforced steel for precast concrete elements are indicated in the NSR-10 Regulations, Chapter C.3. Materials, Section C.3.5 Reinforcement Steel (*Comisión Sismorresistente & Minambiente,* 2010, p. C-44). These reinforcements may also be used for the connections between precast elements. The joints that are made using these reinforcements are exposed, ensuring the structural continuity necessary for the system's stability.

4.2.3.1.2. Active reinforcements

The active linear reinforcements are metal cables that support tension forces and are primarily used in pre-stressed and post-tensioned precast concrete structures. The loads they are subjected to are divided equally among the cable's threads, allowing each one to be subjected to the same admissible tension. According to the number of filaments that make them up, the cables may be single strand or multi strand (Figure 6) (Salvadori & Heller, 1978, p. 374).

4.2.3.2. Continuous

In this type of reinforcements, there are metal structural mesh and textile reinforcements. Structural mesh is formed by corrugated metal rods that meet all the NSR-10 specifications for the reinforcement of *in-situ* cast concrete structures or precast concrete structures. Textile reinforcements are a continuous mesh that will be located in areas of great tension, with which thinner structures are obtained and come with a high-load capacity due to the presence of corrosion-resistant carbon fibers, which reduce the amount of concrete usually needed to cover the corrugated steel bars (Figure 7) (Schätzke & Schneider, 2006, pp. 32-37).

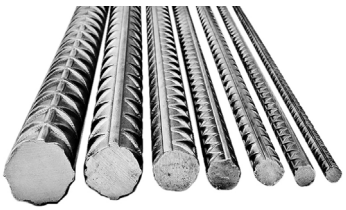


Figure 5
Corrugated metal rods, passive precast concrete reinforcements. Accessed December 12, 2015; available at: http://img.aws.ehowcdn.com/intl-1200x630/ds-photo/getty/article/110/41/92828224.jpg

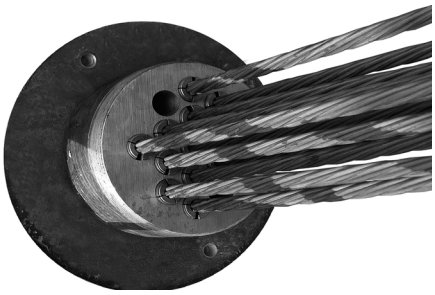


Figure 6
Single and multi-strand cables. Active linear reinforcements in pre-stressed and post-tensioned precast concrete structures

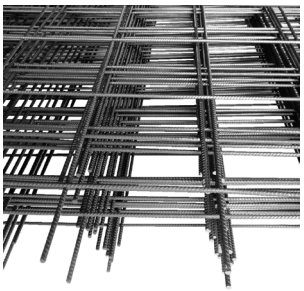




Figure 7
Continuous reinforcements used in precast concrete: metal structural mesh and textile reinforcements

4.2.3.3. Discontinuous

The production of precast concrete elements has used other components to increase the resistance of the material and to reduce weights and volumes. Given their proportions and weights, these discontinuous reinforcements are known as fibers and may complement the conventional reinforcements of the corrugated metal rods in structural concrete. In some cases, the reinforcements are completely replaced in the construction of non-structural elements. The standards that regulate the use of fibers in concrete mixtures for the prefabrication of structural and non-structural elements in Colombia is found in Table 8:

- ASTM C 1339: Test method to determine the average residual stress on fiber-reinforced concrete.
- ASTM C 1609: Test method to determine the performance of fiber-reinforced concrete (using a beam loaded on thirds).
- ASTM C 1550: Test method to determine the flex toughness of fiber-reinforced concrete (using a central load on a round panel).

Regulations	
ASTM C 1339	Test method to determine the average residual stress on fiber-reinforced concrete.
ASTM C 1609	Test method to determine the performance of fiber-reinforced concrete (using a beam loaded on thirds).
ASTM C 1550	Test method to determine the toughness to flection of fiber-reinforced concrete.
EN 14889-1	Fibers for concrete, Part 1: Steel fibers. Definition, specifications and conformity.
EN 14889-2	Fibers for concrete, Part 2: Polymer or synthetic fibers. Definition, specifications and conformity.
NTC 5214	Steel fibers for concrete reinforcing, equivalent to the ASTM A 820 standard.
NTC 5541	Fiber-reinforced concretes, equivalent to the ASTM C 1116 standard.
NTC 5721	Test method to determine the absorption capacity of energy (tenacity) of fiber-reinforced concrete.
IIS-SF4	Test method to determine the tenacity of concrete reinforced with fiber.

Table 8
Standards for the use of fibers in precast concrete in Colombia.

- EN 14889-1: Fibers for concrete. Part 1, Steel Fibers. Definition, specifications and conformity.
- EN 14889-2: Fibers for concrete. Part 2, Polymer or Synthetic fibers. Definition, specifications and conformity.
- NTC 5214: Steel fibers for concrete reinforcing, equivalent to the ASTM A 820 standard.
- NTC 5541: Fiber-reinforced concretes, equivalent to the ASTM C 1116 standard.
- NTC 5721: Test method to determine the energy absorption capability (tenacity) of fiber-reinforced concrete (European Federation of National Associations Representing Producers and Applicators of Specialist Building Products for Concrete, EFNARC).
- IIS-SF4: Test method to determine the tenacity of concrete reinforced with fiber.

The addition of fibers to the concrete is used to improve the mechanical properties of the mix. Reinforcements may be non-continuous steel, plastic, glass, carbon or natural fibers in different shapes and sizes. Fibers with a reduced rigidity, like plastic or natural fibers, provide advantages to improve the tensile strength of concrete and are used to reduce the formation of expansions due to contraction. NSR-10 permits the use of fibers for the construction of non-structural elements. The fibers available to reinforce concrete are classified in Table 9 as: metal fibers (steel, stainless steel, iron, ductile iron, nickel, titanium and aluminum), organic-origin fibers (nylon, polyester and polypropylene) and inorganic-origin fibers, such as glass, boron or carbon (Figure 8) (*Comisión Sismorresistente & Minambiente,* 2010, pp. C-56-C-58).

4.2.4. Additives

Additives are incorporated into the precast concrete before or during its production to modify its properties (*Comisión Sismorresistente & Minambiente,* 2010, p. C-25). The dosage varies according to the product and the desired effect between 0.5% and 5% of the cement's weight in the mixture (*Instrucción Española del Hormigón Estructural,* EHE, n. d.). According to its dosage, the incorporation of additives reduces the content of cement in the final dosage by up to 20% and increases the resistance of the concrete to compression and tension. The use of additives in the concrete mixture is regulated in Chapter C.3, Materials, Section C.3.6, Additives, of NSR-10 (*Comisión Sismorresistente & Minambiente,* 2010, pp. C-51-C-52). Colombian Technical Standard NTC 1299,



Figure 8
Fibers used as discontinuous reinforcements for precast elements.

"Chemical Admixtures for Concrete" (equal to the ASTM C494M standard), explains seven types of additives. Those that are necessary to produce fluid concrete are found in the NTC 4023 (ASTM C1017M) standard. To reduce the mixture's weight, air-incorporating additives are found in the NTC 3502 (ASTM C260) standard. In precast concrete, Type E, which is a water reducer and a setting accelerator, stands out. The additives that incorporate air (which reduces the weight of the concrete and maintains its resistances) are included in the ASTM C260 standard, "Specifications for Air Entraining Admixtures for Concrete".

The combination of all the elements that conform precast concrete requires high initial resistance to be demolded, before completing 12 hours of having been poured and to manipulate them in the plant. For the construction of structural elements, precast concrete uses dosages, which are similar to those that appear in Table 10.

4.2.5. Established developments

The innovations made for precast concrete have modified its technical conditions and have diversified the characteristics of its surfaces. These developments have reduced the volume and weight of elements, which have influenced the temperature absorption conditions in lightweight concrete. Also, recycled aggregates from construction waste, textile reinforcements and natural or synthetic fibers have been used in structural elements. With the development of Ultra High-Performance Concrete (UHPC), and with the use of pre-stressing and post-tensioning techniques, materials resistances have been improved, and the volumes conventionally used have been reduced. With these procedures, the versatility of precast parts has increased and the efficiency in their structural behavior has been improved.

Discontinuous reinforcements for precast concrete		
Metal fibers	Organic-originated fibers	Inorganic-originated fibers
Steel	Nylon	Glass
Iron	Polyester	Boron
Ductile iron	Polypropylene	Carbon
Nickel		
Titanium		
Aluminum		

Table 9
Discontinuous reinforcements for precast concrete: metallic, organic and inorganic fibers.

Components	kg/m³	Weight (%)	Cost (%)
Cement 52,5	400	16.6	74.49
Fine Arid (Sand 0–5)	850	35.42	6.84
Coarse Arid (Sand 5–10)	1000	41.67	8.24
Additives (polycarboxylate)	4	0.17	9.47
Water	146	6.08	0.96
Total	2400	100	100

Table 10
Housing Construction Cost Index (Índice de Costos de la Construcción de Vivienda, ICCV[21]), Colombia, July 2014.
Regás, Xavier. Average dosage of the precast concrete mixture. Barcelona, March 2012.
Arango, Jesús Humberto. Average dosage of the precast concrete mixture. Medellín, August 2013.
Prices provided by Proyectar Architectural Budget Firm, located in Medellín, Colombia. Engineers Juan Carlos Gómez and Nathalie Rúa, July 2014.

4.2.5.1. Lightweight precast concrete

4.2.5.1.1. With expanded aggregates

This type of concrete must meet the specifications of NTC 4045 (ASTM C330). The expanded aggregates replaced natural stone aggregates. They have a cellular structure that provides low density, resistance to compression adapted to regulations and thermal insulation capability (Figure 9). Low density is achieved by incorporating an organic product into the clay that will form gases at high temperatures and generate porosity or clays rich in hematite (Elías, 2009, p. 348).

4.2.5.1.2. With wood particles

This component is used in a mixture composed of cement, water and additives. Concrete with wood particles is specified in Standard DIN EN 206-1 (Figure 10). According to the dosage used with these ingredients, densities of between 400 and 1700 kg/m3 may be obtained. This material, developed through research conducted at the Technische Universität München (TUM) in Germany, presents thermal insulation properties and resistance to abrasion. It also presents contractions and dilations due to expansion and the tendency to crack, which are directly related to the mineralization process of wood's components (Krippner, 2005, p. 67).



Figure 9
Lightweight aggregates with a cellular structure that provides low density and permits thermal insulation. Expanded clay and slate.

4.2.5.1.3. Cellular concrete

This is a mixture of cement, finely ground silica sand, lime, gypsum, aluminum powder and water (Figure 11). Once the mixture has set, a curing process in an autoclave (which is an instrument that retains the moisture of concrete pieces with steam) is then carried out (Elías, 2009, p. 382). Cellular concrete is characterized by a compressive strength (between 3 and 10 N/mm²), a reduced density (from 400 to 800 kg/mg³) and a high porosity, a characteristic that makes it lighter. Its alveolar construction, composed of micro air cells, gives it thermal and acoustic insulation properties. This type of insulation is known as "shared insulation", since the air cavities are placed in the material's mass. It serves as a barrier against outdoor heat in warm climates or as a control for indoor temperature in cold climates (Hess Group, n. d.).

21 For its acronym in Spanish.

4.2.5.2. Precast concrete with recycled aggregates

Recycled aggregates in precast concrete elements are used to reduce costs and to improve environmental conditions. The demands for waste reuse are an important factor to promote sustainable construction without the long-term depletion of renewable or non-renewable resources (Krippner, 2005, p. 38). Among this type of concrete are the following developments:

4.2.5.2.1. Concrete with fly ash

Fly ash is a residue that usually comes from power plants that consume anthracite, coal or lignite. It is obtained from pulverized coal from the fires of the power plant furnaces, which is dragged in the process' gases and recuperated in the filters[22]. Xavier Elías (2009) proposes that it is possible to make structural concrete with fly ash that reaches up to 30% of the cement's weight in the mixture. Its structure is essentially vitreous, due to the high temperatures with which it is obtained. It is a fine powder with a grain size of up to 45 microns, which provides it with a specific surface of 3000 cm2/g. When fly ash is activated with a lime-and-water grout, it produces a pozzolanic reaction that produces a stable product. This property is used when added to the concrete mix. The addition of fly ash to concrete is its main destination and its presence generates these reactions in the mix:

- The mass' densification, which improves the aggregate-cement contact and reduces the possibilities of component segregation.
- The spherical shape of fly ash, which is smaller than that of cement, improves and compensates the angular and irregular geometry of cement particles, distributing the granulometry of the mix better and reducing the amount of water required.
- The increase of concrete's mechanical resistance.
- Fly ash can retard the curing time, an undesired situation for precast concrete elements. In this case, accelerating additives may be used in the curing, or the alkalinity of the mixture may be increased when it is fresh (Figure 12) (Elías, 2009, p. 396).

4.2.5.2.2. Precast concrete with recycled materials from construction processes

Stone materials obtained from demolition processes can be used as aggregates in the concrete (Figure 13). It also uses a part of the premixed concrete that is returned to the material's production plants. These stone materials are classified according to their sizes; their composition can replace conventional aggregates according to the resistance designed for specified structural and non-structural elements. The technical requirements for recycled aggregates are those related to its use in concrete structural elements, as described in the DIN EN 206-1 and the DIN 1045 regulations.

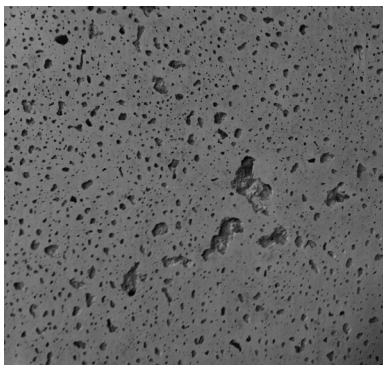


Figure 10
Surface of a concrete element built with wood particles as aggregates. Technische Universität München (TUM).



Figure 11
Cellular concrete. Air cavities cause the mix to be lighter and less dense. Because of its conformation, it has acoustic and temperature insulation properties.



Figure 12
Fly ash. Industrial waste that can be used in the construction of precast concrete structural and non-structural elements.



Figure 13
Stone, ceramic and concrete materials obtained from demolition processes could be used as recycled aggregates to produce precast-concrete elements.

22 Spanish normalization on fly ash UNE 83-415-87, as cited in Elías, 2009, pp. 395-396

4.2.5.2.3. Concretes with blast furnace slag cement

Once cooled, blast furnace slag is homogenized and stored (Figure 14). It can be sent to the cement factory, where it is dried and then mixed with the clinker and with gypsum to produce cement. The amount of slag in the cement can reach up to 70% and will depend on its reactivity, according to the proposal by Xavier Elías (2009). This characteristic also depends on its granulometric distribution. The Blaine fineness of the slag must be more than 400 m²/kg. The reduced amount of water necessary for hydration minimizes contractions and reduces porosity (Elías, 2009, p. 392). The most outstanding property of slag cements is its resistance to sulfate attacks, which makes its use ideal in environments near tropical coasts (Elías, 2009, p. 392).

4.2.5.3. Precast concrete reinforced with textiles and fibers

4.2.5.3.1. Precast concrete reinforced with textile meshes

The behavior of this concrete is influenced by the properties of textile reinforcements and its adherence to the mixture. The materials most commonly used as reinforcement are alkaline-resistant fibers, carbon fibers, aramid, fiberglass and synthetics such as polypropylene and polyvinyl alcohol (PVA) (Schätzke & Schneider, 2005, pp. 32-33). The textile-reinforced fibers should be comprised of filaments with diameters of between 10 and 30 microns (µm). The reinforcements that have been used are multi-axial networks, mesh separators and continuous textile tubes:

- Multi-axial networks are composed of several layers of fibers grouped in rovings or in yarn, which are arranged in different directions. These networks are joined by crosslinking the threads (Figure 15) (Schätzke & Schneider, 2005, pp. 32-33).
- Mesh separators are a tridimensional grid with two layers of mesh united by strands, perpendicular to the fabric's plane (Figure 16). These fabrics are used when a definitive separation is needed between the reinforcement layers.
- Continuous textile tubes are tridimensional fabrics with a closed and tubular transversal section (Figure 17). Each one of the strands is placed parallel to the tube's axis and at angles ranging from 20º to 80º. These tubes are generally used to reinforce hollow elements such as columns, hollow beams or box girders (Schätzke & Schneider, 2005, pp. 32-33).

With this type of concrete, reinforced by textile meshes, sections from 10mm to 20mm have been achieved in precast elements of up to four (4) meters long (Schätzke & Schneider, 2005, p. 32). The technique of sandwich panels or grooved elements is an option for the construction of structural elements with bioclimatic behavior. The production of these elements consists of two concrete sides and a core of insulating material, such as expanded polyurethane or expanded polystyrene (Figure 18). The grooved elements have a smooth surface on the outside and elements perpendicular to the surface on the inside, in order to structurally reinforce the façade panel. Since 2005, Dresden International University and RWTH Aachen University, both in Germany, have constructed prototypes with an expanded polystyrene core, which can also function to remove the insulation material and to allow the structure's lightening by leaving voids in the outer layers of the concrete. (Figure 19) (Schätzke & Schneider, 2005, p. 32).

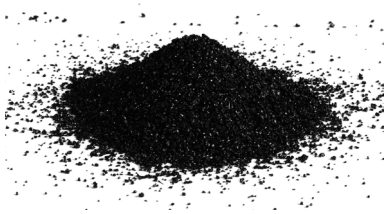


Figure 14
Blast-furnace slag, used to produce precast concrete elements when it is mixed with clinker and gypsum.

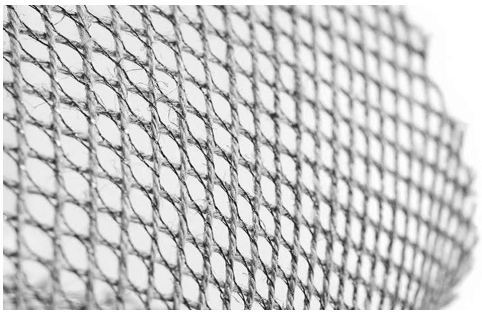


Figure 15
Multiaxial networks. Composed of layers of fibers grouped in rovings or in yarn and arranged in different directions.

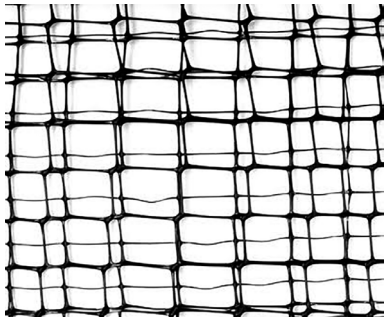


Figure 16
Mesh separator. Tridimensional element with two layers of mesh united by strands perpendicular to the plane of the fabric.

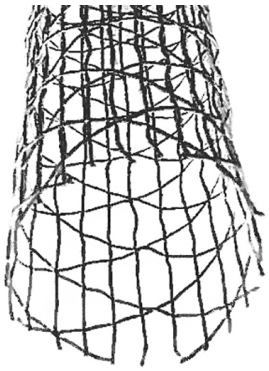


Figure 17
Textile tubes to reinforce hollow elements. Photo: *Detail*. Munich: *Institut für internationale Architektur-Dokumentation GmbH & Co.* KG, 2005.

4.2.5.3.2. Steel-fiber reinforced precast concrete

In reinforced concrete with discontinuous elements, an amount of fibers that is less than 2% of the volume of the mix is used to reduce the formation of expansions due to contraction. The most common are round steel fibers, which are produced by cutting wires with diameters of up to 1mm and lengths between 10mm and 75mm (Figure 20). Average volumes (between 1% and 2%) improve resistance to tension, flection and torsion. The toughness against breakage and impact resistance can be improved up to three time compared to conventional concrete. A fiber reinforcement greater than 5% of the mixture's volume can influence the concrete's workability (Elías, 2009, pp. 386-392). Steel fibers, like all the fibers that can be used to reinforce precast concrete elements, must be distributed proportionally and in different directions in the mix.

4.2.5.3.3. Glass-fiber reinforced precast concrete (GRC)

This is a compound material produced by incorporating glass fibers into concrete. The thickness of precast panels may reach a thicknesses of between 8mm and 20mm, with surfaces that may be up to four meters long and two meters wide. Generally, these panels have an interior structure to increase their rigidity. Alkali-resistant fiberglass is one of the most used reinforcements, since zirconium dioxide provides durability properties greater than those obtained with conventional glass fibers (Figure 21). The use of carbon fiber is an alternative to glass fibers and offers a high module of elasticity, elevated load capacity and prolonged durability. The glass or carbon fibers have a tensile strength of between 800 and 1800 MPa (which equals between 8157.43 kg/cm2 and 18354.2 kg/cm^2), and a resistance greater than that of conventionally reinforced steel, which is 412 MPa (Elías, 2009, pp. 386-392).

4.2.5.3.4. Polyethylene-fiber reinforced precast concrete

This is a synthetic and structural macro fiber that combines polyethylene terephthalate (PET) and conventional polypropylene (Figure 22). PET is a clear, linear thermoplastic polymer, which can be processed by extrusion to recycle used materials. This type of fiber is manufactured to replace welded wire mesh and has various applications. The toughness of PET, joined to the properties of the original polypropylene, and with additives, makes these fibers suitable to reinforce concrete.

4.2.5.4. Ultra High-Performance Precast Concrete (UHPC)

This type of precast concrete is a combination of Portland cement, silica fume, quartz sand, fine silica sand, water-reducing admixtures and fibers made from steel, glass and organic fibers (Figure 23). Due to its high content of conglomerating material (which exceeds that of conventional precast elements), the additives that are incorporated and the resistance of the fibers, it has the capacity to resist compression stresses that exceed 150 MPa, flection resistances up to 50 MPa and tension resistances up to 10 MPa (American Concrete, 2008). In standard DIN EN 206-1, it is classified in the category of hardness C100/115. UHPC has a water-cement material ratio (w/cm) of less than 0.2, which increases its density and increases its resistance to compression (Portland Cement Association, n. d.). To increase tensile strength, a high percentage of fibers should be oriented parallel to the direction of this reinforcement. According to the American Concrete Institute, fiber-reinforced UHPC presents some variants according to the size of its fibers, as shown in Table 11.

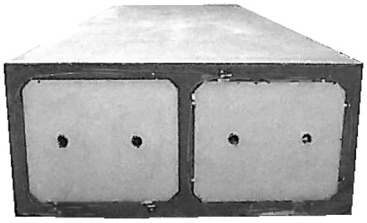


Figure 18
Sandwich panels: two concrete sides and a core of insulating material.



Figure 19
Elements in a hollow box with an expanded polystyrene core or with voids between the outer layers of concrete.



Figure 20
Metal fibers to reinforce the concrete.



Figure 21
Glass fibers in the precast concrete panels. *Prefabricados Moià*, Barcelona, January 2013.

Variants of fiber-reinforced UHPC	Content of fibers (%)	Longitude (mm)
With high proportions of short fibers	5 to 10	Up to 6
With intermediate proportions of long fibers	2 to 3	13 to 20
With very high proportions of fibers in various lengths	Up to 11	1 to 20

Table 11
Fiber-reinforced UHPC variants.

- UHPC with high proportions of short fibers: in this mixture, the content of fibers reached up to between 5% and 10% of the volume, and does not exceed 6 mm in length. The fibers improve resistance to tension but do not increase its ductility. Therefore, the material is used in structures with high percentages of rods with traditional reinforcements.
- UHPC with intermediate proportions of long fibers: the content of fibers in the mix varies between 2% and 3% of the volume. Its length is between 13 and 20 mm. The fibers improve resistance to tension, concrete's ductility and aim to replace all or part of the reinforcement rods that are normally used in pre-stressed or reinforced concrete elements.
- UHPC with very high proportions of fibers in various lengths: the content of fibers in the mix can be up to 11% of its volume. Short fibers may vary between 1 and 20 mm in length. These fibers increase resistance to tension, the concrete's ductility and may replace all the traditional reinforcement rods in an element (American Concrete Institute, 2008).

4.2.5.5. Pre-tensioned and post-tensioned precast concrete

Through the use of active linear reinforcements, such as cables, the structural behavior and the volumes required to produce precast elements with conventional passive reinforcements has been modified. These variants are pre-stressed concrete, which responds to the manner of producing precast elements and post-tensioned concrete, which defines the mechanism of installation of these elements.

One of the most characteristic aspects of prefabrication in concrete is that its elements can be produced by techniques that allow reaching a greater resistance through the behavior and arrangement of its reinforcements, reducing concrete volumes and generating elements with lower thicknesses with respect to *in-situ* cast concrete. The union mechanism obtained with the post-tensioning allows the reinforcements to be continuous and internal to the prefabricated elements, which increases the rigidity of the structure and the relationship between the concrete and its reinforcements.

4.2.5.5.1. Pre-tensioned precast concrete

This type of precast concrete opened a new field in the design of structural pieces by increasing the resistance of the material through the use of active reinforcements such as bars, wires or steel cables, tensioned before the casting process in the plant. The volume of concrete and the thickness of the elements were reduced in comparison to conventional precast elements, due to the arrangement and behavior of these reinforcements (Figure 24). This technique has been used to overcome the natural weakness of concrete against tensile forces and was patented by Eugène Freyssinet



Figure 22
Recycled polyethylene fibers for the construction of precast concrete elements.



Figure 23
Ribbed plate in UHPC and the installed element as a facade panel. Barcelona, January 2013.

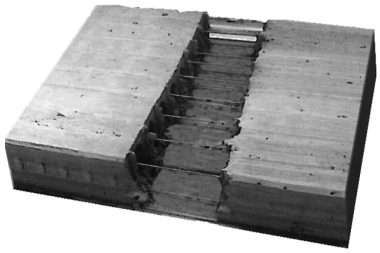


Figure 24
Pre-stressed process of an alveolar slab.

in 1920 (Nilson, 1987, p. 14). Through this process, elements such as slabs and beams have been produced with different formal and structural characteristics: alveolar slabs, solid slabs, double-t slabs, beams with I, C, T or L sections, hollow beams and box girders (Figures 25 and 26). The presence of lightenings or longitudinal perforations in alveolar slabs has reduced the amount of concrete between 45% and 70% in contrast to the solid precast slabs or *in-situ* cast concrete slabs. The amount of reinforcing steel has been reduced by up to 50% in pre-stressed precast elements such as beams and slabs. Elements in pre-stressed concrete occasionally

require a certain amount of passive armatures (without applied tension), such as conventional reinforced steel.

4.2.5.5.2. Post-tensioned precast-concrete

This process permitted a new conception of material when constructing continuous pieces formed by smaller precast elements. This condition brought new developments in the design of pieces, in the architectural and structural designs and in the assembly process. The post-tensioning concrete is subjected to compression and tension forces through active reinforcements (steel cables mounted within sheaths inside the precast elements), which are stressed once they have been installed on site. Lighter projects have been constructed; mounting equipment with lower specifications than those necessary to mount large format elements has been used and greater distances between supports have been achieved, compared to those that have been obtained with conventional precast elements. The segments that form part of a structural element achieve their maximum structural capability in their installation. This process is done in most cases with pre-tensed, precast elements, which reduces the consumption of conventional reinforcing steel and concrete. Longitudinal perforations are left in this case for the placement of reinforcement cables in the assembly process, which create stresses once all the precast pieces have been installed until the resistances required are achieved (Araújo, 1997, p. 8). This system has resolved one of the most frequent problems in prefabrication: the continuity of the joints between their elements, which ensures the continuity of the structure and its reinforcements (Figures 27, 28 and 29).

4.2.6. Resistance evaluation

The Colombian Earthquake-Resistant Construction Regulations, NSR-10, has established the criteria to evaluate the resistance of concrete in the design of structural and non-structural elements, as indicated in Table 12.

- Section C.16.10 of NSR-10 (Precast Concrete) explains the procedures to evaluate the resistance of structural elements. Section C.16.10.1 indicates that the evaluations must be made complying with these requirements:
- Section C.16.10.1.1: The test loads should be applied only when the calculations indicate that compression or buckling is not critical for the isolated precast element.
- Section C.16.10.1.2: The test load should be the load that, when applied to the isolated precast element, induces the same total forces in the tensile reinforcement as those that would be induced by loading the compound element with the test loads indicated in Section C.20.3.2 of the NSR-10 Regulations (*Comisión Sismorresistente & Minambiente,* 2010, p. C-306).

Chapter C.20.5 specifies the requirements to accept or reject the precast elements. In the sections that comprises it, the minimum requirements necessary to approve are explained:

- Section C.20.5.1: indicates that the evaluated portion of the structure should not show evidence of failure. The flaking and crushing of compressed concrete should be considered a failure. The evidence of failure includes cracking, flaking or deflection. The flaking of some precast concrete elements, due to imperfections in the stripping,

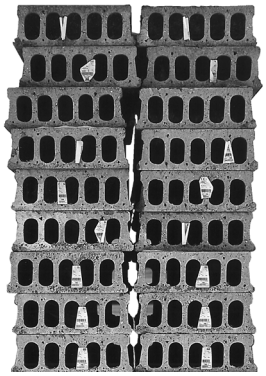


Figure 25
Pre-stressed, precast concrete alveolar slabs. Accessed December 13, 2015; available at: https://plexa.com.mx/sites/default/files/ct/gdi/ALVEOLAR2.jpg.

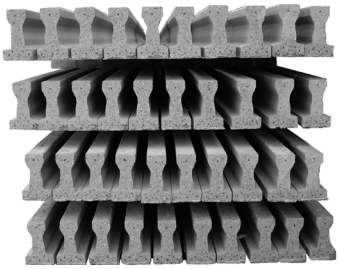


Figure 26
Pre-stressed, precast concrete beams. Accessed December 13, 2015; available at: http://www.forsecusa.es/s/cc_images/cache_10816935.jpg.



Figure 27
Pre-stressed, precast-concrete elements installed through post-tensioning processes. Photos, *Tectónica.* 1998.

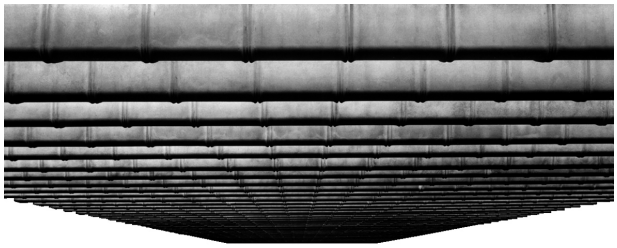


Figure 28
Pre-stressed, precast-concrete elements installed through post-tensioning processes. https://alrededordelaarquitectura.files.wordpress.com/2013/07/nave.jpg, accessed December 13, 2015.

Section	Object of Study
Section C.16.10.1.1.	Compression is not critical for the isolated precast element.
Section C.16.10.1.2.	Isolated precast element, induces the same total forces in the tensile reinforcement.
Section C.20.5.1.	Indicates that the portion of the structure that is evaluated should not show evidence of failure.
Section C.20.5.2.	Limits of maximum deflections measured.
Section C.20.5.3.	The precast structural elements tested must not have fissures that indicate imminent shear failure.
Section 20.5.4.	Structural fissures inclined with respect to the longitudinal axis.

Table 12
Criteria for the evaluation of resistance of precast concrete.

do not necessarily indicate overall structural deterioration. The fissure's widths indicate the deterioration condition or the structure's failure, and must be observed to determine if its condition is satisfactory and meets the minimum safety requirements. (*Comisión Sismorresistente & Minambiente,* 2010, p. C-355)

- Section C.20.5.2 specifies the limits of maximum deflections measured, in accordance with the proportion of precast structural elements and the concrete's mixture composition to produce them. They may be used if, in the load tests, the structure does not show evidence of failure (*Comisión Sismorresistente & Minambiente,* 2010, p. C-355).
- Section C.20.5.3 indicates that the precast structural elements tested must not have fissures that indicate imminent shear failure. If the fissure's length extends to an approximate a horizontal length that is equal to the height of the element, if it widens or if the stirrups begin to lose their anchoring, it is assumed that the element is close to a shear failure (*Comisión Sismorresistente & Minambiente,* 2010, p. C-355).
- Section 20.5.4 proposes that the areas that do not have transversal reinforcement should be evaluated, as well as where structural fissures incline according to where the longitudinal axis appears with a horizontal projection greater than the height of the element in the midpoint of the fissure. Attention must be given to the structural implications of the included fissures observed, which can lead to a fragile collapse of the elements with no transversal reinforcement (*Comisión Sismorresistente & Minambiente,* 2010, p. C-356).

In areas of splicing or overlap assemblies, the appearance of a series of inclined short fissures or horizontal fissures (Figure 30) throughout the line of reinforcement must be investigated, according to what is specified in Section 20.5.5 of the NSR-10 Regulations. Fissuring along the reinforcement's axis in anchoring areas may be related to high stresses associated with the transfer of forces between the reinforcement and the concrete. These fissures may be an indication of a potentially fragile failure of the element and it is important to assess its causes and consequences (*Comisión Sismorresistente & Minambiente,* 2010, p. C-356).

4.2.7. Technical design

This activity refers to the architectural and structural design, production, transportation and installation of precast concrete structural and non-structural elements in Antioquia, which are governed by the same structural regulations that must be used in Colombia. Chapter C.16 of the NSR-10 indicates that



Figure 29
Pre-stressed, precast-concrete elements installed through post-tensioning processes. http://blogs.elpais.com/.a/6a00d8341bfb1653ef017c32434 3e6970b-pi, accessed December 13, 2015.



Figure 30
Horizontal fissuring of a precast concrete element along the axis is occupied by structural reinforcements.

the design of precast elements and their connections must consider the load conditions and restrictions ranging from initial fabrication to the completion of the structure, including demolding, storage, transport and assembly (*Comisión Sismorresistente & Minambiente,* 2010, p. C-299). When the precast elements are incorporated into a structural system, the stresses and deformations of these elements and their connections should be included in the technical design. The tolerances of precast elements with the connection elements must also be specified. The NSR-10 clarifies the fact that structural behavior of precast elements may differ substantially from the behavior of similar elements constructed with in-situ cast concrete. In the construction of precast structures, the design of connections requires special attention for structural

continuity; due to retraction, plastic flow, temperature variation, elastic deformations, differential settlements, wind and earthquakes (Figure 31) (*Comisión Sismorresistente & Minambiente,* 2010, p. C-299).

For the structural design of the elements, NSR-10 requires that the following information be included in the contract documents, reports and technical drawings:

- Structural-reinforcement details, internal reinforcements, connecting elements and the lifting devices necessary to withstand the temporary forces resulting from handling, storage, transport and assembly.
- Concrete's resistance to defined structural efforts in every stage of the construction process.

Section C.16.4 clarifies that in pre-tensioned concrete, elements with a width no greater than 3.7 meters such as alveolar slabs, solid slabs or ribbed slabs, cross braces are usually not necessary to support forces due to retraction and temperature variation in the shortest direction. These principles may also be applied to the floor slabs and the non pre-tensioned roof. The 3.7-meter width is less than the width in which the retraction forces and temperature variation may reach a magnitude that requires cross braces (*Comisión Sismorresistente & Minambiente,* 2010, pp. C-300-C-301).

For precast elements, most of the retraction occurs before these elements have been installed in the structure. The lateral restriction forces caused by retraction and temperature variation are significantly reduced. NSR-10 indicates that this consideration does not apply to elements that require reinforcement to resist transversal bending forces, like the simple-t or double-t elements (*Comisión Sismorresistente & Minambiente,* 2010, pp. C-300-C-301). For precast walls in non pre-tensioned concrete, the reinforcements must be designed in accordance to the provisions of Chapters 10 (Flection and Axial Loads) and 14 (Walls) of NSR-10. For the technical design, the fact that each area of vertical and horizontal reinforcement must not be less than 0.001 square millimeters, must be considered. The spacing of the reinforcement must not exceed five (5) times the thickness of the wall or 750mm for interior walls, or 450mm for exterior walls. The gross area of the concrete section in square millimeters is expressed with the "Ag" convention. The code clarifies that, for a section with empty or lightened spaces, "Ag" considers only the concrete area and does not include the empty area. Assessments of the resistance of precast structures are considered in NSR-10 Section C16.10 (*Comisión Sismorresistente & Minambiente,* 2010, p. C-306). The regulation allows flex evaluation as if the structures were isolated precast elements that receive *in-situ* cast concrete to complement their installation.

To evaluate the resistance of precast structures, the provisions of NSR-10's Section C.20.5 (Acceptance Criteria) form the bases for the approval or rejection of structural elements. In the production activity, technical design intervenes in the dosage of each component of the mixture, in the characteristics of the molds to generate surfaces, in the strategies to reduce the weight and costs and to increase the resistance of precast elements. In transport and installation activities, the technical design defines the assembly strategies, the type of joints between the precast elements and the programming of the order of installation (*Comisión Sismorresistente & Minambiente,* 2010, pp. C-354). The architectural design in prefabrication is also a construction design. The assembly of elements must work harmoniously and efficiently to build domestic spaces with control of quality, time and costs.



Figure 31
Structural continuity in precast concrete elements through the design of their connections. Photo: *Elematic.*

4.3. Formworks

For the production of precast-concrete elements, it is necessary to use molds or formworks. Pre-tensioned elements, such as alveolar slabs, are manufactured in surfaces that can reach more than 250m in length. On these surfaces, the reinforcements are previously stressed and then the concrete is cast. To increase efficiency in the industrial production of precast elements, according to the required speed of production, it is suggested that the elements be demolded between 4 to 12 hours after casting. According to the formwork's, they may be classified as rigid or flexible.

4.3.1. Rigid

Rigid formworks are those that maintain their geometry during the casting, setting and demolding of precast concrete elements. In this study, formworks in different materials – metallic, wood boards, wood slats, formworks in polyester laminated with fiberglass and in glass fiber-reinforced concrete (GRC) – are considered.

4.3.1.1. Metallic

This type of formworks are the most used in the production of precast elements, due to their resistance, the number of reuses and the speed in which precast elements may be demolded. Metal formworks may be produced with different degrees of complexity. In most cases, it may be necessary to have a metal structure that ensures the resistance and stability of the surfaces in contact with the concrete. These surfaces, in contact with the formwork structure (metal sheets or other materials), must be replaced when the precast elements begin to have unwanted appearances or when the maximum number of uses has been met (Regás & Bolaños, 2007, p. 140). Metal formwork generates smooth surfaces in precast elements. These should be produced through complete casting with uniform and continuous compaction, to avoid the excessive appearance of porosity and bubbles on the surface (Figure 32). The finishes of the formwork's original metallic surfaces may also be modified to obtain different textures in precast elements.

4.3.1.2. Wood boards

Wood boards are mainly available with dimensions of 122cm x 244cm or 153 cm x 244cm, which conditions the dimensions or the joints of precast elements. Compared to other materials, wood board molds allow more uses than formwork in natural wood, but have fewer uses than metallic formwork. For large scale precast elements, the wood boards in contact with the precast surface must be reinforced with a structure that ensures their stability against the thrusts of concrete. Some of these boards have moisture treatments that allow a certain number of reuses without losing the surfaces' characteristics. Molds for precast elements of a moderate complexity can be built using these boards, which can also generate different types of textures on the surface (Figure 33).

4.3.1.3. Wood slats

Conventional wood-slat molds have traditionally been used in the construction of structural and non-structural elements with *in-situ* cast concrete. They may also be used for building precast elements, which according to their dimensions may also require an additional support structure to ensure their stability. The surfaces built on these molds can have various finishes, according to sizes, textures and the types of wood selected (Figure 34). Generally, the use of traditional wood slats transmits textures that show the joints between the elements and the texture they make up.

4.3.1.4. Polyester laminated with fiberglass

In this type of formwork, each one of its walls has a thickness of between 4mm and 6mm, and must have a structure that supports the thrusts of concrete to prevent deformation and facilitate its settling (Regás & Bolaños, 2007, p. 84). The number of uses is similar to the formworks in wood boards and less than metallic formworks. This type of mold generates high quality concrete surfaces, due to the regularity of its finishes. Due to its flexibility, these molds permit the production of precast concrete elements with different geometries, followed by an agile, safe demolding process that does not deteriorate the surfaces of the pieces' processes (Figure 35) (Cárdenas & Peláez, 2010, p. 25).

4.3.1.5. Glass fiber-reinforced concrete (GRC)

These formworks are produced from a model or initial piece that is built on a natural scale, and include all the characteristics specified in its architectural design (Regás & Bolaños, 2007, p. 84). The characteristics of the surfaces can be as diverse as desired (Figure 36). Formworks in GRC can be used a number of times, similar to that of formworks in wood boards. It is necessary to use a demolding agent between the surface of the mold and the precast element, which allows the piece to be removed without suffering damage.

4.3.2. Flexible

These formworks are generally produced in polyurethanes, elastomers, silicone or textile elements. During the casting, setting and demolding processes of these molds, their geometry may be modified according to the final specifies form, which facilitates the generation of unconventional forms and the stripping process. A flexible mold for prefabrication of large-format elements, specified with flat surfaces and regular forms, needs a rigid counter mold



Figure 32
Surface obtained using a metal formwork. Photo: Cementos Argos, Medellín 2010.

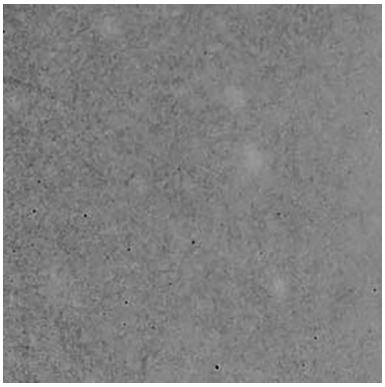


Figure 33
Concrete surfaces obtained through the use of wood boards. Photo: Cementos Argos, Medellín 2010.



Figure 34
Concrete surface obtained through the use of a wooden-board formwork. Photo: Cementos Argos, Medellín, 2010.

that sustains it and prevents undesired deformations caused by the thrusts of concrete. With the use of an appropriate demolder, these formworks permit removing the precast elements without it adhering to their surfaces. Printed textures or different surfaces may be obtained according to the architectural specifications of each project and to the manufacturing processes of formworks with flexible behaviors, which may have the appearances desired for the precast elements on their surfaces (Figure 37).

4.4. Production

Precast concrete elements may be manufactured in industrial plants or on the project's site itself through the use of transportable field factories. These places must ensure appropriate conditions for continuous production and the elements' storage before being transported to the project.

4.4.1. Industrial plants

Prefabrication industries have the suitable spaces and equipment to produce precast elements (Figure 38). These industrial plants are usually located in the outskirts of cities due to the large areas they must use, the volume of materials handled and the cost of urban land. The prefabrication process is sequential and has specific areas to produce structural and non-structural precast concrete elements: batching and mixing yards, casting yards, curing yards, demolding yards, cleaning and oiling yards and storing yards (12). Although precast elements may be produced in the open, it is recommended that the production spaces be covered to improve the conditions of comfort for the workforce and to protect the equipment used in the process.

4.4.2. Field factories

Restricted accessibility to lots, due to the size of the precast elements, the transport costs and the distance from the industrial plants to the project site, have generated the alternative of implementing mobile plants located at the construction site. These plants must be adapted to the terrain's topography and to existing spatial and climatic conditions, with all the technical specifications necessary to produce precast concrete elements (Figure 39). The use of field factories has brought the production of precast elements to the work site. It is necessary to consider that the work, storage and displacement spaces for the installation of these precast elements must be coordinated with the availability of space on site and with the constructive processes of the building, to improve the processes' efficiency.

4.5. Transport

This is the displacement of precast concrete elements from the production plant to the project site. In this activity, it is necessary to ensure that the structural design, according to the handling of loadings (those that occur in the displacement, raising and storage of the elements) and service loadings (those that take place once the pieces are installed), comply with the requirements established in Title C of the NSR-10 Regulations. The transport of precast elements in a local context may be done in three ways: by land, river or railway.

Transport conditions the prefabrication, since it determines – in many cases, due to the proportions of its elements – the viability of a project. In addition to transport, equipment for lifting and installing the parts must be considered. As an alternative to this condition, field factories have been built on the project site, which require sufficient areas for the production, handling and storage of the prefabricated elements.

4.5.1. Ground transportation

Road infrastructure in the Department of Antioquia is conformed by the Highways for Prosperity (Autopistas para la Prosperidad) and primary, secondary and tertiary roads, classified as such according to their widths and physical characteristics. According to the Civil Aeronautics of Colombia, 99.9% of the cargo in Antioquia is moved by land (VIVA, 2015, p. 32). In December of 2015, the primary road network consisted of 1,672km; the secondary road network had 4,690km, while the tertiary road network was 11,507km in length. As of December of 2015, the total extension of land routes in Antioquia amounted to 17,869km (VIVA, 2015, p. 32).

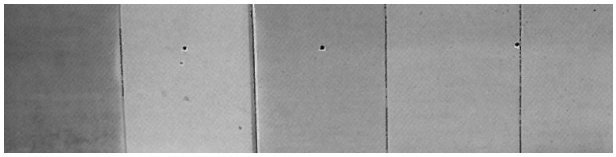


Figure 35
Concrete surface obtained through the use of a formwork built with polyester and laminated with fiberglass. Photo: *Cementos Argos,* Medellín, 2010.



Figure 36
Concrete surface obtained through the use of a formwork in GRC. Photo: F. Regás and J. Bolaños, *Piedra Moldeada: GRC y hormigón arquitectónico*, 2010.



Figure 37
Concrete surface obtained through the use of a formwork in polyurethane elastomers. Photo: F. Regás and J. Bolaños, *Piedra Moldeada: GRC y hormigón arquitectónico*, 2010.

4.5.1.1. Permissible weights and lengths

Colombian Technical Standard 4788 (*Norma Técnica Colombiana,* NTC 4788) regulates the type of cargo vehicles and aspects such as maximum gross weights and dimensions, so that they can operate normally on the country's road networks. Automotive land transportation of cargo is regulated through Decree 173 of 2001, in accordance with the Ministry of Transport of the Republic of Colombia. The gross vehicular weight (GVW) (*peso bruto vehicular,* PBV) is the sum of the vehicle's weight plus its cargo. The PBV limits defined in NTC 4788 have the following ranges in Table 13:

It is possible to transport precast concrete elements of up to 4.40m in height, with a width of 2.60m and lengths of up to 12.20m for vehicles with three and four axes. (*Mintransporte,* n. d. a).

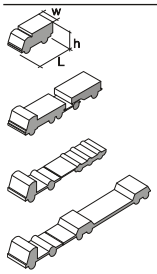
	Type of transport	Length (meters)	Width (meters)	Height (meters)	Capacity (Tons)
	Trucks	10,80	2,60	4,40	16 to 32
	Semi-tractor-trailer trucks	12,20	2,60	4,40	27 to 52
	Trailer trucks	18,50	2,60	4,40	16 to 48
	Balanced trailer trucks	18,50	2,60	4,40	15 to 48

Table 13
Ranges for gross vehicular weight (GVW) defined in NTC 4788.

4.5.1.2. Characteristics and classification of roads

The Colombian Ministry of Transport has classified national roads in the following types:

- Primary roads, 30m wide: These roads communicate the country's capital cities of with other national commercial centers or abroad. They are classified according to the role they play in the national economy.
- Secondary roads, 24m wide: These roads communicate municipalities with the country's capital cities or with other neighboring municipalities. They also communicate regions or can communicate a municipality with a primary road.
- Tertiary roads, 20m wide: These roads communicate small and medium hamlets (*caseríos*), villages (*veredas*) or areas (*parajes*) with urban centers. They normally converge to a secondary or primary network (*Gobernación de Antioquia,* 2006). According to Antioquia's road map, the network of paved primary roads covers 85% of the communications between Medellín and the other municipalities. Through paved and unpaved secondary roads, there is access to the remaining 15% of the municipalities (*Gobernación de Antioquia,* n. d. b).
- Urban roads: The maximum dimensions that may be transported are also conditioned by the width and condition of the roads of some neighborhoods (*barrios*) within a municipality. The dimensions of precast elements are conditioned by the accessibility to the project.

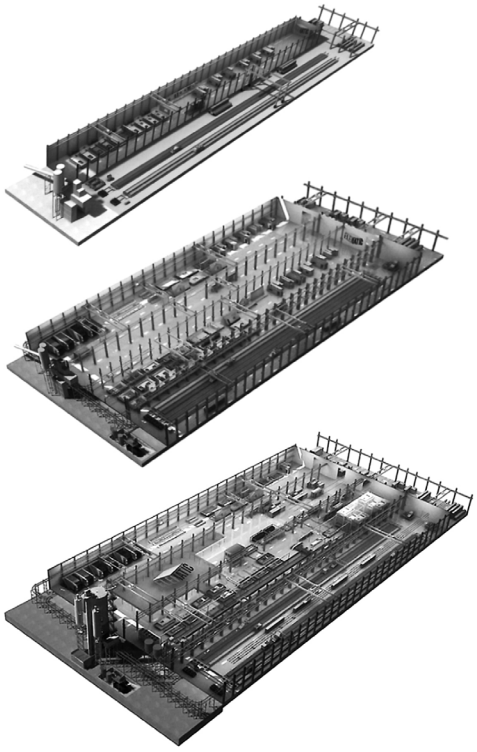


Figure 38
Operating systems and spatial organization in a precast element production plant. Model taken from the production organization of the Elematic firm in Helsinki, Finland, June 2012. Elematic. Complete precast plant. SEMI, PRO, EDGE Catalogues. Aldus, Finland, 2013. Helsinki, Finland, June 2013.

4.5.2. River transportation

The transport of heavy and large-scale elements by rivers is generally made on barges, which are flat-bottomed non-motorized naval units driven by another vessel. They may be temporarily placed in sandy beaches without the need of docks or piers for loading or unloading.

4.5.2.1. Permissible weights and lengths

The average dimensions that have been used for river transportation in barges are 40m long (the length of the boat from the stern to the bow) and 10m wide (the maximum width of the boat). These barges can carry up to 3,200 tons of weight. Other barges, with dimensions of 35m long by 15m wide, have a transport capacity of up to 4,000 tons (Ostornol & Cardozo, n. d.). The load capacity of fluvial means of transportation, the widths of rivers and the depth of their channels condition the proportions and weights of precast concrete elements, as indicated in Table 14.



Figure 39
Model of the field factory commercially offered by *Weiler*, Germany.

4.5.2.2. Characteristics and classifications of rivers

According to the National Planning Department of Colombia (*Departamento Nacional de Planeación,* DNP[23]) and the Ministry of Transport, Colombian rivers have a length of 24,725km. Approximately 18,225km (74% of their extension) allow lesser navigation throughout the year. The DNP indicated that a total of 7,063km , equivalent to 39% of its extension, supports greater and permanent navigation, mainly on the Magdalena River, followed by the Cauca River. An extension of 4,210km, equal to 23% of its extension, permits a temporary navigation of larger vessels in the east, center and north of the country on the Orinoco, Magdalena, León and Atrato Rivers. Leticia, on the Amazon River and in the south of the country, is an important fluvial port that has connections with Peru, Brazil and the Atlantic Ocean. The remaining 6,500km of rivers in the country, nearly 36%, are not navigable (DNP, 2005, pp. 179-180). In Antioquia, the most important rivers are the Atrato, which separates Antioquia from the Department of Chocó; the Cauca, which crosses the center of Antioquia and separates the Western Mountain Range (*cordillera*) from the Central Mountain Range (*cordillera*); and the Magdalena, which separates Antioquia from the Department of Santander in the extreme east of the region (*Gobernación de Antioquia,* n. d. a).

4.5.3. Rail transportation

In the first fifteen years of the 21st Century, the railway lines in Colombia had a total extension of 3,304km. Its coverage centered on locations in the center of the country and some municipalities to the North and West (*Mintransporte,* n. d. b). Plans to expand rail networks in Antioquia have been developed since 2016 to communicate Medellín with different municipalities, which will increase the transportation of construction elements through new rail lines.

4.5.3.1. Permissible weights and lengths

Precast concrete elements may be transported in gondolas, flatbeds or platforms, which are open wagons where material that does not need to be protected from the rain or sun can be transported.

These wagons are designed to facilitate loading and unloading with cranes (*Mintransporte,* n. d.). The gondolas are 12.72m long, 2.91m wide and 2.8m high. They can transport an internal volume of 83 m³ with a load of 70 tons.

The flatbeds and platforms are 13.40m long and 2.87m wide. They can transport elements with a height of up to 3.00m and a volume load of up to 115.30 m³. The flatbeds' maximum capacity is 73 tons, while that of the platforms is 72 tons (*Mintransporte,* n. d.). In Table 15, cargo dimensions and volumes are indicated for rail transportation.

4.5.3.2. Characteristics and classifications of railroads

The railway system in Colombia is composed by the Atlantic and the Pacific railroad networks and is classified by its free widths, which determine the cargo capacity of the trains and the transport volume. The Atlantic Rail Network extends from Bogotá to Santa Marta (from the center of the country to the north, on the Caribbean Sea) and passes through the Departments of Antioquia, Cesar, Magdalena, Santander, Boyacá, Cundinamarca and Caldas. The line that connects the Cerrejón coalmine to Puerto Bolívar, on the Atlantic Ocean, has a standard width of 1,435 mm. The other lines have a standard width of 914 mm (DNP, 2008, p. 2). The Pacific Rail Network, with a width of 914 mm, extends from the center to the west of the country and unites the Departments of Caldas, Quindío, Risaralda and Valle del Cauca with the Pacific Ocean (DNP, 2008, p. 2).

4.6. Structural systems

The structures used in the construction with precast concrete are classified in three groups, according to the shape of the elements and the way of transporting the loads toward the foundations and to the terrain: skeletal, walls and spatial cells. In construction with precast concrete, two of these groups may be combined, which can form a mixed structure.

4.6.1. Skeletal

Skeletal structures are formed by columns, beams and slabs (Figure 40). The union between these elements forms frames or diaphragms with span lengths and solutions of typified support (Araújo, 1997, p. 5). There are several experiences in which the joints between columns, beams and slabs are resolved with an independent stabilization (Araújo, 1997, p. 5). The precast concrete pieces that form part of the skeletal systems could control its quality, generate other types of joints and develop new functions. Skeletal systems can have pieces with greater lengths than those conventionally built with *in-situ* cast concrete through the use of pre-tensioned precast concrete. The formal design of each elements that forms the precast skeletal systems can incorporate functional aspects and can modify the conventional prefabrication aesthetics of collective housing (Araújo, 1997, p. 8).

4.6.1.1. Elements

The elements that comprise the skeletal precast structures are classified by their location in the project and their geometry. The forms and proportions for the structural and non-structural elements of prefabrication can be as large as wanted and may vary in each project according to the architectural and structural designs. The following examples correspond to a classification made by the German Professional Association for Precast Concrete (*Fachvereinigung Deutscher Betonfertigteilbau e.V.,* FDB[24]).

4.6.1.1.1. Foundations

The relationship between the building's weight, topographic profiles and soil resistance has been resolved with the construction of isolated foundations that may be precast or cast in situ, which receive the loads transmitted by the columns, beams or slabs (Graphic 40). These foundations are hardened through the construction of tie beams (Böttger, 1974, p. 125). The precast foundations should have rigid assemblies to ensure the stability of the system and distribute the loads to the terrain.

23 For its acronym in Spanish.

24 For its acronym in German

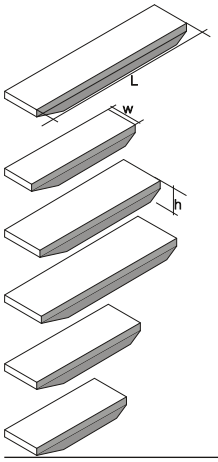
	Type of transport	Length (meters)	Width (meters)	Height (meters)	Capacity (Tons)
	Mississippi Hopper Barges	40.00	10.00	3 to 9	197.91
	Multi-purpose Barges (Bulk)	25.00	7.00	3 to 9	86.59
	10,000-bl-tank Barges	30.00	15.00	3 to 9	222.65
	Flat Barges	35.00	15.00	3 to 9	259.76
	Semi-convoys	30.00	12.00	3 to 9	178.12
	Barges	22.00	10.00	3 to 9	108.85

Table 14
Average dimensions and weights for fluvial transportation in Antioquia.

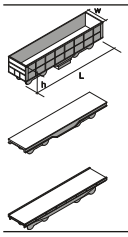
	Type of transport	Length (meters)	Width (meters)	Height (meters)	Capacity (Tons)
	Gondolas	12.72	2.91	2.81	70.00
	Flatbeds	13.40	2.87	3.00	73.00
	Platforms	13.40	2.87	3.00	72.00

Table 15
Cargo dimensions and volumes permitted for rail transport with gondolas, flatbeds and platforms.

4.6.1.1.2. Columns

Although the design of precast columns may be as versatile as the architectural designs for which they are specified, the FDB has classified the basic geometry of the columns into two groups: square and round. All the dimensions of these elements are proposed to meet the requirements of Class F90-A fire resistance according to the DIN 4102 standard (*Fachvereinigung Deutscher Betonfertigteilbau,* FDB, n. d.).

Square columns: The base (b) and the height (h) of these elements are variable, according to the characteristics of the building and the desired resistance for the concrete mix (Graphic 41). The FDB suggests building one-centimeter bevels in each corner of the element.

Round columns: These dimensions can have different proportions in their diameter (d), according to the loads they must support, the load-bearing capability of the terrain and their height (h), according to the characteristics of the building (Graphic 41).

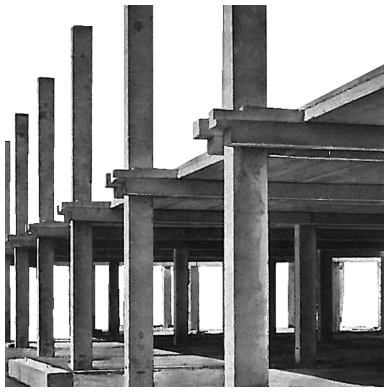


Figure 40
Construction of a building with a precast skeletal structure. The assemblies among beams, columns and slabs must ensure the continuity of the structure. Photo: *Montagebau Konstruktiver Entwurf.*

4.6.1.1.3. Beams and joists

According to their geometry, beams and joists may be classified as straight-corner beams, console beams, trapezoidal beams, beams with an "I", "C" or "T" shape, hollow beams and box girders. Like columns, the dimensions and shapes of these elements can be different in each project, according to the architectural and structural designs proposed. In all elements, the lengths are variable, according to the characteristics of the building and the resistance of the concrete mixture. The FDB recommends the construction of one-centimeter bevels for each corner of the element (FDB, n. d.).

Straight-corner beams: These beams have a geometry formed by straight angles. The dimensions of the base (b) and the height (h) are variable, according to the characteristics of the building and the load-bearing capability of the terrain (Graphic 42) (FDB, n. d.).

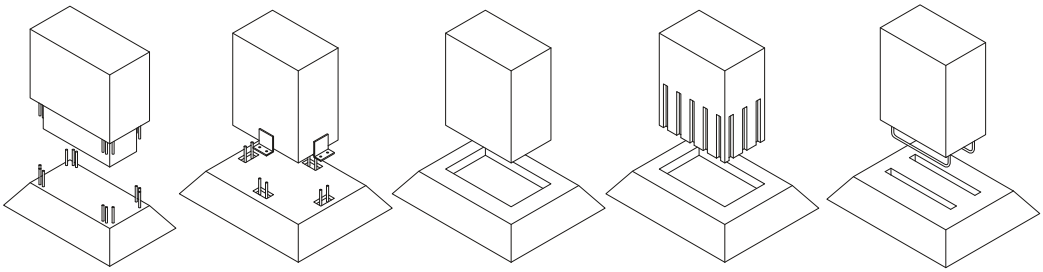
Console beams: The FDB proposes four different geometries for these elements. In a "T", in an "L", in a cross and in a "T" turned to 90º. The geometry is defined by the location of the brackets in the structural element. For each one of the elements, the base (b) dimensions, heights (h) and the proportion of the brackets (*Linienkonsole*) may have variable sections (Graphic 42) (FDB, n. d.).

Trapezoidal: Trapezoidal beams present a difference between the lower base and the upper base. The difference between the lower base (b) and the upper base (bo) of the elements ranges between 12% for minor elements and 15% for larger elements (Graphic 43) (FDB, n. d.).

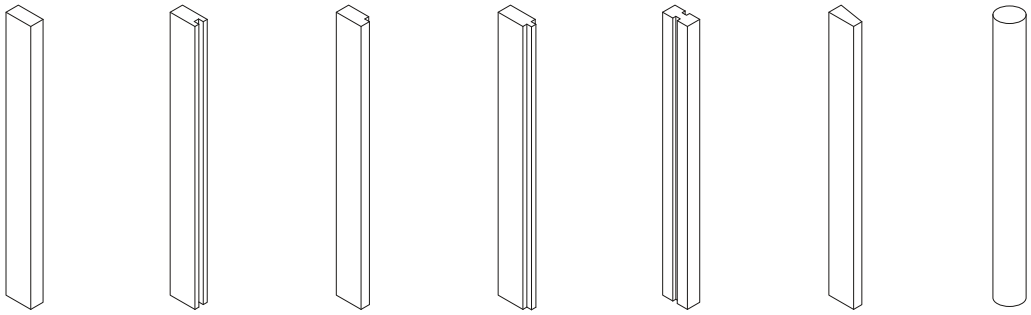
"I" Beams: These are made up of vertical elements that have two horizontal flanges on the upper and lower parts. The parts that comprise it are: a base (b), (bu) or (bo) and a height (h) with variable dimensions (Graphic 43) (FDB, n. d.).

"C" Beams: These are made up of a vertical element and two horizontal flanges that support the axis and occupy only one of its sides. The parts that comprise it are: a base (b), and a height (h) with variable dimensions (Graphic 43) (FDB, n. d.).

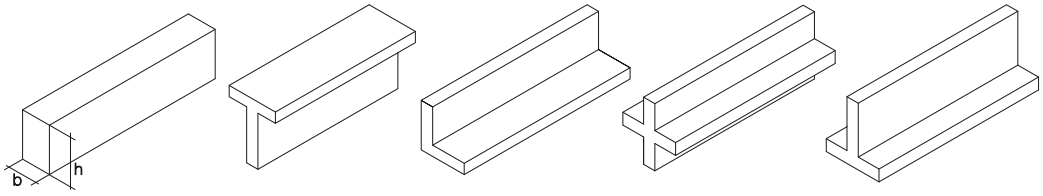
"T" Beams: In this element, the flange is located only on one of the two sides of a vertical beam. Its components are: a base (b) and (bo), and a height (h) with variable dimensions (Graphic 44) (FDB, n. d.).



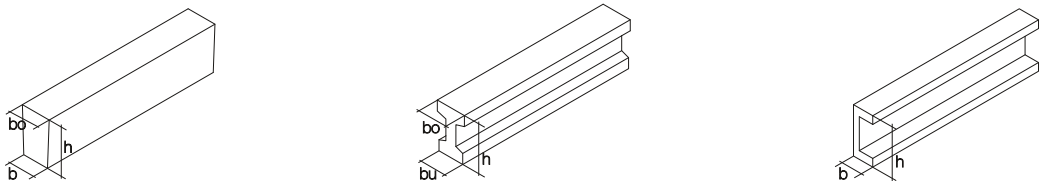
Graphic 40
Joints in the precast concrete foundations for skeletal structures. Graphics taken by Böttger, Dietrich. Montagebau. Berlin: *VEB Verlag für Bauwesen, 1974, p. 125.*



Graphic 41
Rectangular and circular section precast concrete columns. FDB Germany, 2013.



Graphic 42
Rectangular section precast concrete beam and consoles. FDB Germany, 2013.



Graphic 43
Precast concrete trapezoidal, "I" and "C" beams. FDB, Germany, 2013

Hollow Beams: These beams concentrate the concrete on the perimeter, leaving the interior empty. They are generally produced through pre-stressed processes. These elements may be installed through post-tensioning processes. The situation of core tension in the hollow beams must be the result of forces on the center of gravity. This solution lightens the weight of the beams and, when pre-stressed, reduces the concrete sections that are conventionally required (Graphic 44).

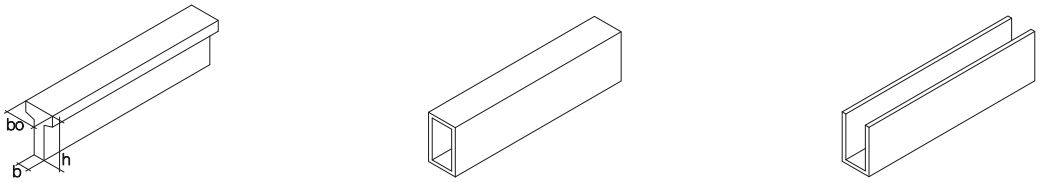
Box Girder: This type of beam has an open section and is formed on three sides, forming a "U". They may be used as floor joists to which vast concrete and structural reinforcements are subsequently added to support the floor or roof slabs, where they also serve as rainwater collecting channels (Graphic 44).

4.6.1.1.4. Consoles.

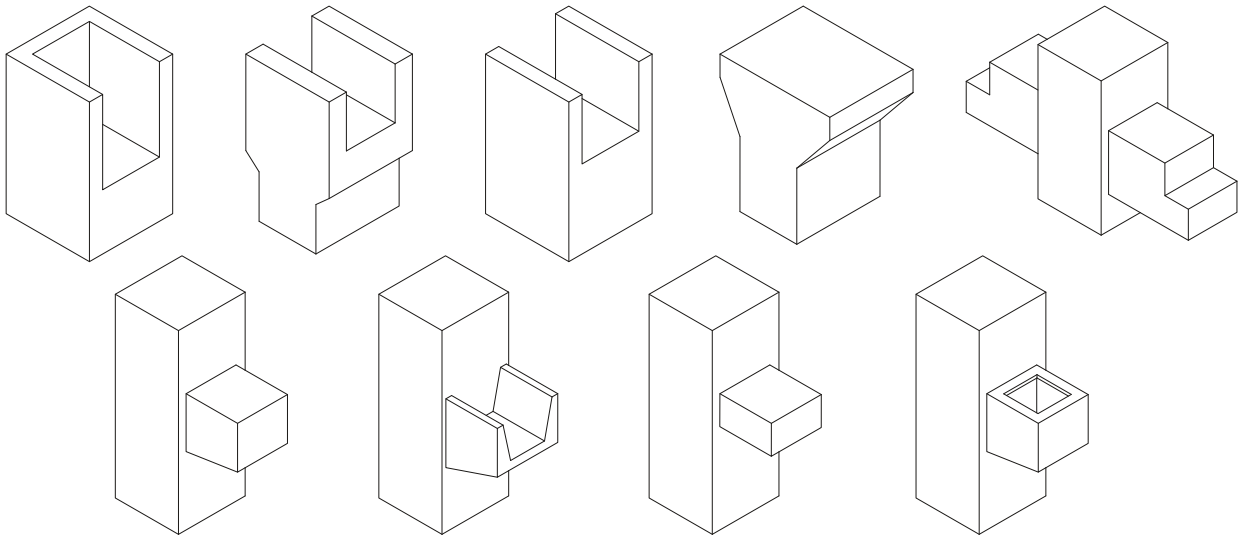
The union of beams and columns has generally been resolved through a change of section in the columns, with an element that forms an integral part of them. These brackets must be designed structurally to attend the shear stresses produced by the weight of the beams (Graphic 45) (Mañà et al., 2001, p. 24).

4.6.1.1.5. Slabs.

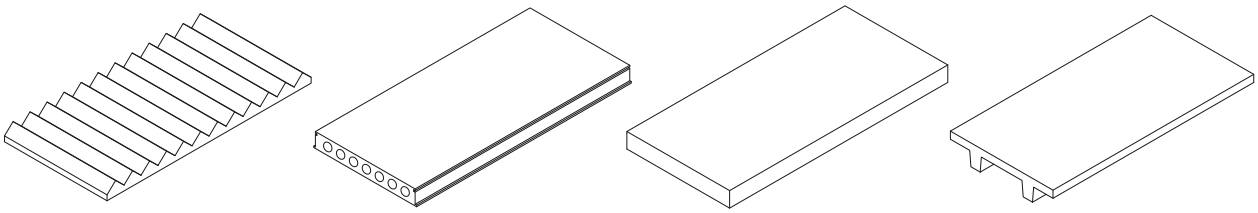
Plates may be used, supported on the ground, floors or rooves. According to their geometry, the FDB classifies them as: elementary (*Elementplatten*), alveolar (*Hohlplatten and Spannbeton Hohlplatten*), solid (*Vollplatten, Massivplatten*) and in Double "T" (*TT Platten*) (FDB, n. d.).



Graphic 44
Precast concrete "T", hollow and box girders beams.



Graphic 45
Types of consoles in precast concrete. FDB, Germany, 2013



Graphic 46
Types of precast concrete slabs. FDB, Germany, 2013

Elementary: According to the FDB, simple elementary plates have a minimum height of 5cm and a width that ranges from 120cm to 300cm. These elements may be produced in pre-tensioned concrete in lengths that may exceed 250m and which are then cut according to the measurement required. After their installation, these plates must have cast concrete with a height of between 5cm to 10cm to level the surface, install finishing materials or permit the passage of technical installations between the surface of the slab and the finished floor, with a height defined by the technical specifications of the structural calculation (Graphic 46) (FDB, n. d.).

Alveolar: These plates are generally lightened with circular or polygonal perforations, which are separated on an average of 2.5cm from the elements' surface. The distance between the weight shavings also has an average of 2.5cm. According to the FDB, its height (h) has a range of between 16cm and 32cm, and a width (b) of between 120cm and 300cm (Graphic 46) (FDB, n. d.). These alveolar slabs are generally pre-stressed and have a smaller height than conventional alveolar plates, because their resistance increases in the production process (FDB, n. d.).

Solid: In accordance with the FDB, solid plates have a range in height of between 10cm and 32cm. Its width has dimensions of between 120cm and 300cm and may be produced in pre-tensioned concrete (Graphic 46) (FDB, n. d.).

In Double "T": These slabs have the geometry of solid horizontal pieces, placed with vertical elements integrated into their geometry to increase inertia and reduce thickness in contrast to other types of plates. The width of the upper plate (b) has a dimensional range of between 150cm and 300cm. The heights (h), (ho), (hu) of these elements range from between 6cm and 25cm. The two vertical elements that end to confirm the system should be separated 100cm between their two internal surfaces and have heights that range from 60cm to 80cm, with widths (bo), (bu), of between 19cm and 27cm (Graphic 46) (FDB, n. d.).

4.6.1.2. Joints

A key feature of precast concrete is its initial discontinuity, a situation given by the number of elements that make up a specific project. Konrad Wachsmann suggested that the principle of construction with precast elements is the connection. In addition to evidencing the nature of the system and complying with technical functions, the joints or expansions can complement the projects' language through rhythms of lines, light and shadows on surfaces. The connections and joints show the material and the method, the construction principle, the standardization and the order of construction (Wachsmann, 1959, p. 44). The design of joints is made to ensure the structural continuity of the building and the stability of non-structural elements. Besides the connections, it is necessary to consider the reinforcement designs to raise the parts in the installation process (Wachsmann, 1959, p. 40).

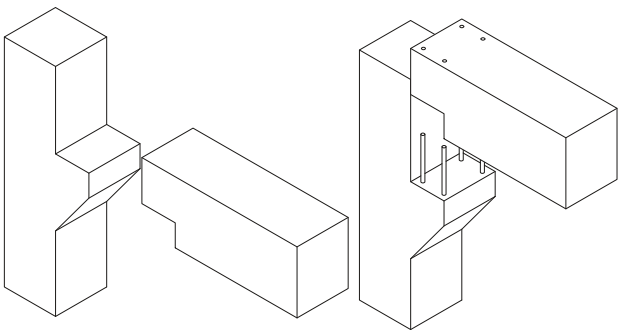
In accordance with NSR-10 and the texts Joints for the Precast Concrete Elements (*Knotenverbindungen für Betonfertigteile*) (Tillmann, 2011, pp. 9-53) and *Alternatives to the Conventional Construction of Homes (Alternativas a la Construcción Convencional de Viviendas)* (Mañà et al., 2001, p. 17), the joints to achieve structural continuity among the precast elements can be classified into five types: simple support, cast concrete, internal metallic elements, external metallic elements, and post-tensioned systems.

Simple support: This type of joint has been resolved through friction forces among the elements transmitted by its own weight. The simple support joint is given by the support of beams on the brackets, which forms a multi-articulated structure that entrusts its stability to assembly by geometry and by the rubbing or friction among the pieces (Graphic 47).

Cast concrete: In the skeletal structures, joints may be resolved by casting concrete in the cavities where the metallic reinforcements of columns, beams and slabs are exposed. This type of joint increases resistance to bending moments. It is frequently used in our local context due to its rigidity (Graphic 48).

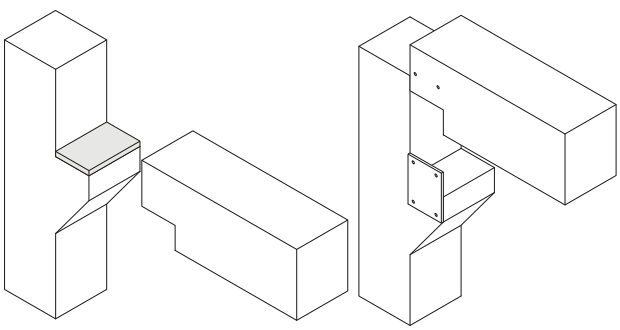
Internal metallic elements: In this type of connection, the metallic pieces embedded in the concrete make the joint between the precast elements. These connectors are generally metallic rods, screws or bolts that can generate cleaner and rigid joints. It is also possible to specify welded joints among the metal plates embedded in the columns, beams or slabs, which generate adequate resistances to bending moments without concreting (Graphic 49).

External metallic elements: These joints are made through exterior metallic connections, which are installed during the mounting process. The connectors may be metal plates or pins such as rods, bolts or screws. The perforations for these metallic connectors are generally constructed in the industrial plant where the precast elements are produced (Graphic 50).



Graphic 47
Joints with friction support between components.

Graphic 48
Connections through the continuity between the reinforcements and a final casting of concrete to increase its rigidity.



Graphic 49
Joints between metallic elements embedded in the concrete, which are joined through metallic pins or through welding.

Graphic 50
Metallic elements installed during the mounting process that stiffens the joint between precast elements.

Post-tensioned joints: This joint system uses metal cables or tendons inside the structural elements (Graphic 51). They are generally used to join beams to columns, beams with slabs or sections of beams. The nature of the joint allows having beams or slabs formed by a specific number of elements, which facilitates the transport and assembly process since mechanical equipment with lower specifications is required for their installation. In the post-tensioning process, these elements are joined and may achieve greater distances between the supports than conventional precast elements, as they have a continuous interior reinforcement. For the fixation of the structural elements, anchors are used on their ends, where mechanical equipment holds the tensioned cables or tendons until the resistance necessary is achieved.

This tensioning equipment is specified according to the characteristics of the prefabricated elements, their weights, distances between supports and geometries. These union mechanisms guarantee the continuity of the behavior of the reinforcements and permit joining a set of prefabricated elements with smaller dimensions, which allows considering other equipment in the transport and installation process.

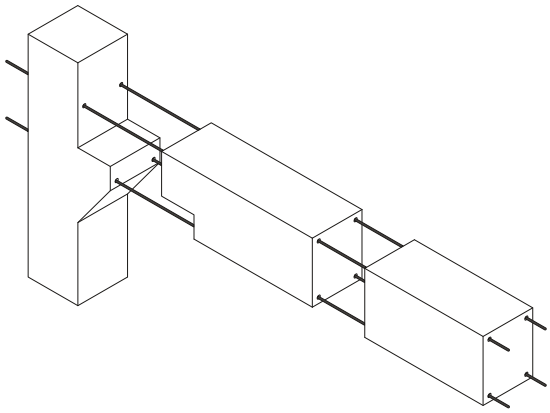
4.6.2. Walls

Due to its physical conditions (massiveness, weight and resistance to compression forces), precast concrete adequately responds to the idea of building with structural walls. The systems' stability can be obtained through the change in the direction of walls, which helps to solve the problem of joints. The construction system with structural walls has been characterized as having some limitations in the designs of interior space and on the distance that must exist between their supports. Generally, solutions have been proposed, in which the interior walls and the façades are structural, which reduces the flexibility of interior spaces and the buildings' language.

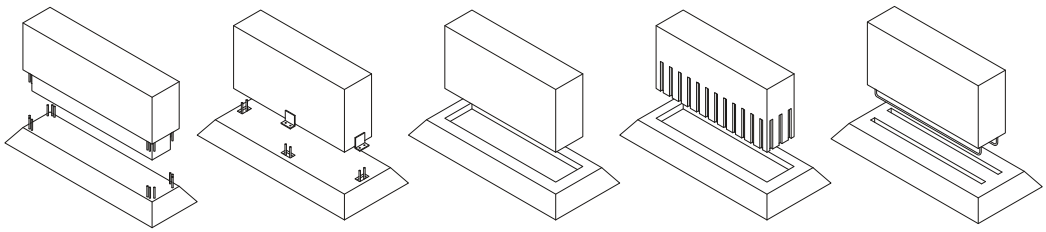
4.6.2.1. Elements

4.6.2.1.1. Foundations

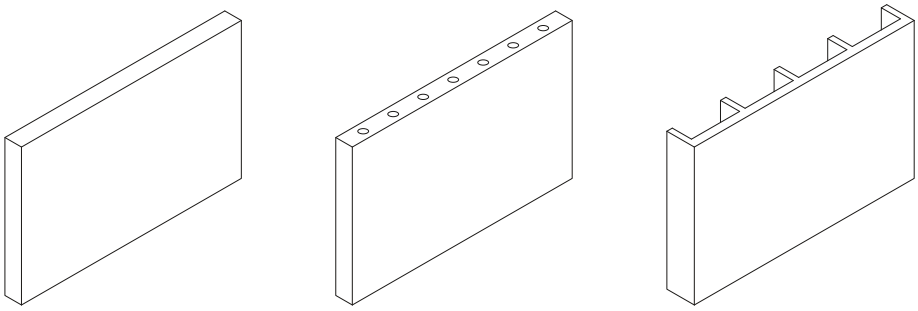
For structural walls, foundations are generally a set of beams that make up a diaphragm. The slabs are also specified. Each system is constructed according to the area that the structural walls occupy or with the weight that the buildings transmit onto the terrain. Foundations for the system of structural walls are generally built in cast concrete. In some cases, according to the characteristics of the terrain or the structural specifications, they are constructed in precast concrete (Graphic 52).



Graphic 51
Post-tensioned joints that are stiffen after the installation of precast elements.



Graphic 52
Types of joints in precast concrete foundations: joints by geometries between the precast elements or overlapped between their metallic reinforcements plus a subsequent concrete casting. Graphics taken by Böttger, Dietrich. Montagebau. Berlin: VEB *Verlag für Bauwesen*, 1974, p. 125.



Graphic 53
Walls in precast concrete. FDB, Germany, 2013.

4.6.2.1.2. Walls

Structural walls receive the loads from the roof, slabs and beams. They may have variations due to the installation of thermal and acoustic insulations and may be produced with different geometries and dimensions, in accordance with the architectural and structural requirements of each project. They may be solid (*Vollwand, Massivwand*), alveolar (*Hohlwände*) or laminate, which must have elements that harden them (Graphic 53) (Böttger, 1974, p. 124).

4.6.2.1.3. Beams and joists

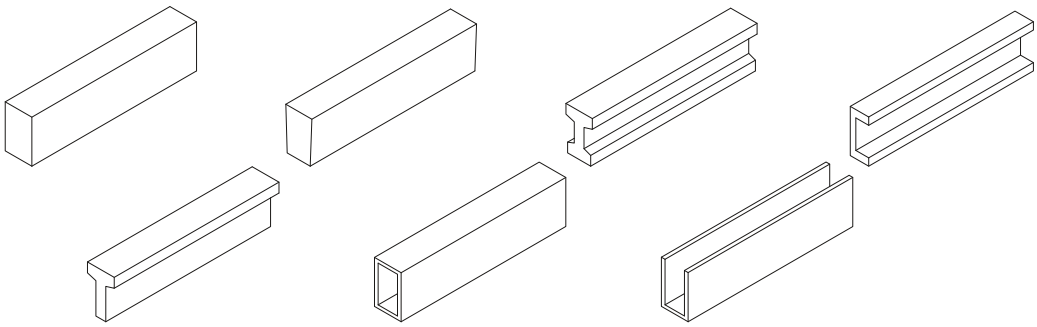
The beams and joists in structural wall systems are classified according to their geometry: straight-corner beams, console beams, trapezoidal beams, beams with an "I", "C" or "T" shape, hollow beams and box girders. They are installed on the walls' surface through different setting mechanisms or on consoles that can be used as supports for beams and slabs (Graphic 54).

4.6.2.1.4. Consoles

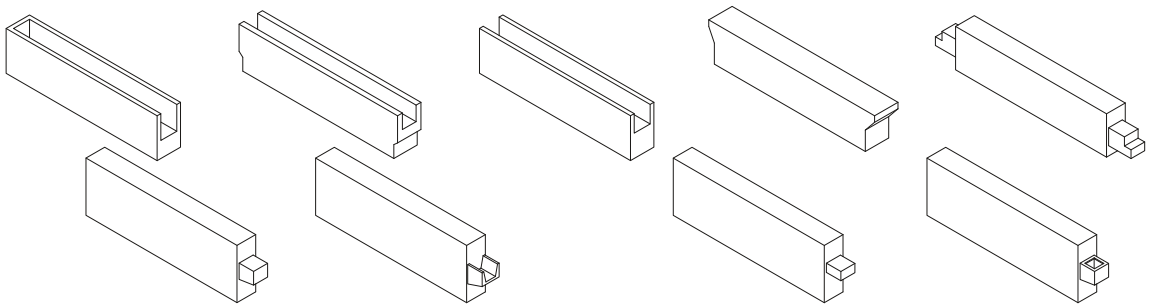
This element is used to join beams or slabs with structural walls. Generally, the brackets form an integral part of the walls and must resist shear stress. As in the skeletal structures, the union of these elements can be resolved with friction between the pieces; with the strengthening of joints with cast concrete; through mechanical joints such as screws, bolts and welding between metallic plates; or through post-tensioned joints (Graphic 55) (Mañà et al., 2001, p. 24).

4.6.2.1.5. Slabs

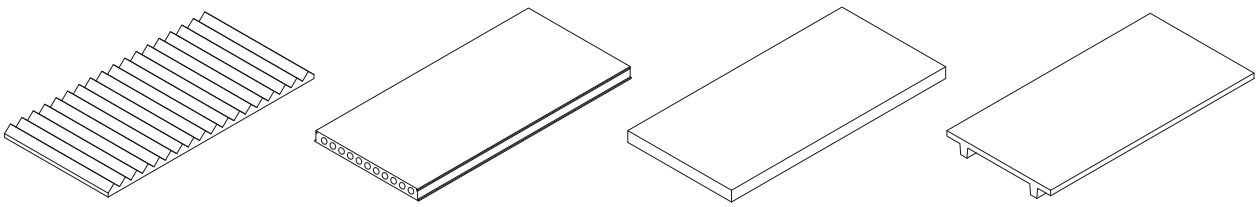
In load-bearing wall systems, slabs are joined to the walls through brackets or beams. They may also be used as slabs supported on the ground, floor or rooves (Graphic 56). As in the skeletal systems, slabs are classified according to their geometry as: elementary (*Elementplatten*), alveolar (*Hohlplatten* and *Spannbeton Hohlplatten*), solid (*Vollplatten, Massivplatten*) and in Double "T" (TT Platten) (FDB, n. d.).



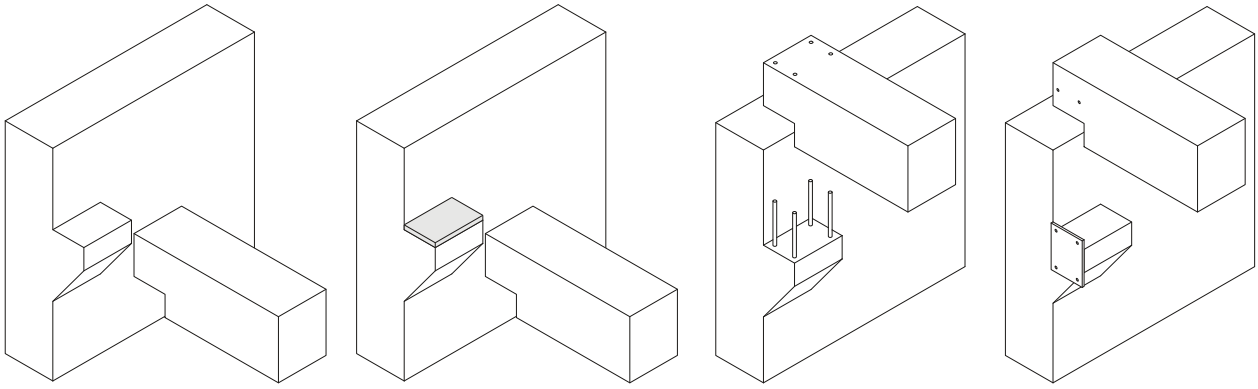
Graphic 54
Types of beams and joists for the system of structural walls in precast concrete.



Graphic 55
Types of consoles precast in concrete. FDB, Germany, 2013.



Graphic 56
Slabs in precast concrete. FDB, Germany, 2013.



Graphic 57
Joints with friction support between components.

Graphic 58
Connections through the continuity between reinforcements and a final casting of concrete to increase rigidity

Graphic 59
Joints between metallic elements embedded in the concrete, which are joined through metallic pins or through welding

Graphic 60
External metallic elements to join two or more precast elements

4.6.2.2. Joints

In structures of load-bearing walls, connections must comply with the provisions of Chapter C.16 of NSR-10. In the structures of load-bearing walls, joints are generally made between the slabs and the walls, between beams and walls and between beams and slabs. Sometimes the slabs are supported only on the beams or on the brackets, which have been joined beforehand to the walls that confine them. In structural wall systems, joints may be:

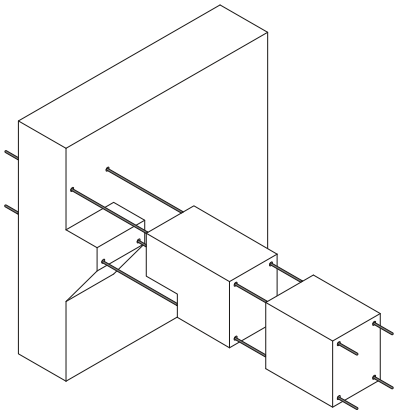
Simple support: These are used to join walls, beams and slabs in areas of low seismic risk and where structural elements are hardened through their geographic conformation. In simple-support joints or geometric assemblies, soft insulating materials such as neoprene are also used (Graphic 57).

Cast concrete: In this type of joint, the union of walls, beams and slabs is carried out with high-adherence or grouting mixtures. Sometimes metallic rods are used and in the cavities where the metallic reinforcements are installed, high-resistance concrete is cast to harden the movement of the reinforcements and ensure the structure's stability (Graphic 58).

Internal metallic elements: These joints are formed by metal strips that can be joined to each other through welds, metal rods, screws or bolts that are installed in the interior of the precast structural elements (walls, slabs and beams) to ensure their stability (Graphic 59).

External metallic elements: These elements are installed on the surfaces of two or more precast elements to ensure the stability of their union, which can be through welds or a third metallic element such as pins, bolts or screws. In their joint with the precast concrete elements, these plates may be complemented with the use of metal rods, screws or bolts that restrict the movements and ensure the stability of their fixation to structural elements (Graphic 60).

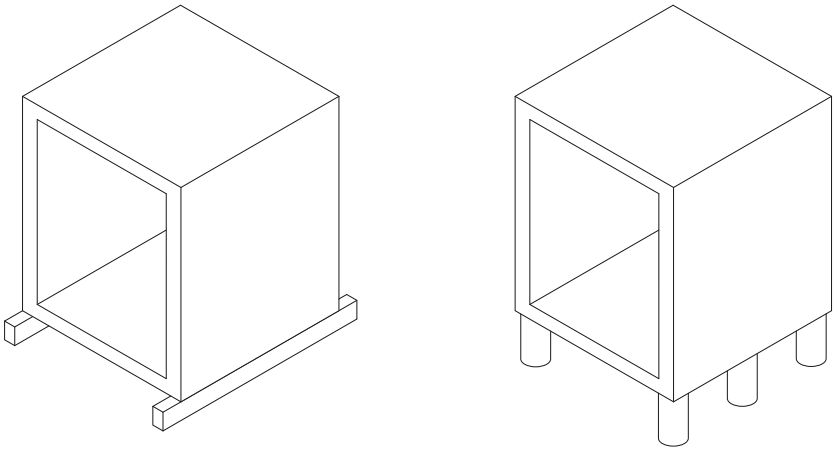
Post-tensioned joints: This system is used to horizontally join load-bearing walls to slabs or beams. The anchors located in the exterior part of precast elements are those in charge of supporting the metallic cables that are tensioned through the use of mechanical equipment. The post-tensioning is not done vertically along the walls, since they are submitted to compression forces (Graphic 61).



Graphic 61
Post-tensioned joints that stiffen after the installation of the precast elements.

4.6.3. Spatial cells

This system is composed of precast modules of integrated slabs and walls that form a living space delimited by these structural elements. They can be serially produced with a high degree of industrialization and with all technical installations integrated into the living space. They can be built in conventional concrete or with lightweight concrete. In this system, all the walls and slabs have a structural function. Their production must be made in formwork or molds designed to contain the concrete's lateral thrusts, since the casting must be done vertically with the reinforcements previously placed without joints in the element, which must have a monolithic behavior (Staib et al., 2008b, pp. 160-163). Through the production process, it is possible to control the quality of the concrete surface of walls and floors on both sides of the cell. For constructions that are two or more stories tall, the structural behavior of this system implies the continuity of the cells' walls along the entire height of the building. In its transport and installation, it is necessary that the measurements and weights of each element be within permitted limits (Staib et al., 2008b, pp. 160-163). According to the standards that regulate the installation of these elements, in the mounting process it is necessary to have specialized hoisting equipment with load capacities that exceed up to five times the weight of the precast cells.



Graphic 62
Foundations for precast spatial cells.

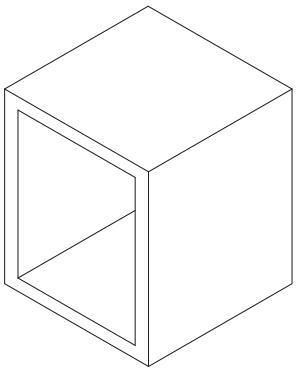
4.6.3.1. Elements

4.6.3.1.1. Foundations

The foundations of precast cells are generally continuous beams, precast concrete pilings or foundation slabs that are placed under the structural walls, which must conserve a vertical continuity throughout the height of the building. These beams, pilings or slabs are supported on the terrain and have some proportions and a depth defined by the geotechnical studies made before the project's construction (Graphic 62).

4.6.3.1.2. Cells

These monolithic elements, formed by walls and slabs constructed in solid or lightweight concrete, have structural reinforcements in metallic rods, which have thicknesses and weights that are defined in the structural designs. The union of walls and slabs generate monolithic elements that delimit living spaces. They are produced, transported and installed as a single unit (Graphic 63). The spatial cells present high conditions of structural stability, due to their geometric configuration and the technical processes used in their manufacture.



Graphic 63
Walls and slabs behave monolithically to generate unique, seamless elements.

4.6.3.2. Joints

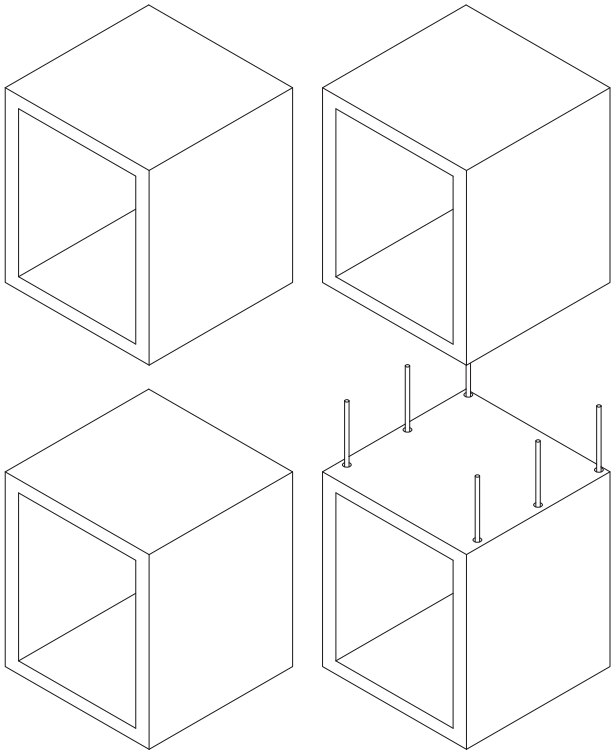
The design of connections for spatial cells uses mechanisms similar to those of the joints for skeletal structures and load-bearing walls, and is regulated in Chapter C.16 of NSR-10. They are also classified as simple support, cast concrete, internal metallic elements, external metallic elements and post-tensioned joints.

Simple support: These simple-support joints are used for spatial cells , which form buildings that are one or two stories tall. The cells can support each other without the need for another element that articulates them, using the stability and friction generated by their own weight. In this type of support, it is important to consider the terrain's load-bearing capability of and the characteristics of the seismic zone. The joints or geometric assemblies, soft insulating materials such as neoprene, high-density polystyrene, or insulation in flexible materials such as waterproof packaging, may be used (Graphic 64).

Cast concrete: To reinforce the union among cells, in the cavities where the metallic reinforcements are installed, high-resistance concrete is cast to harden the movement of the reinforcements and ensure the structures'. The number of rods per cell is determined according to the structural design, in relation to the height of the building, its geometry, the seismic zone and the load-bearing capability of the terrain (Graphic 65).

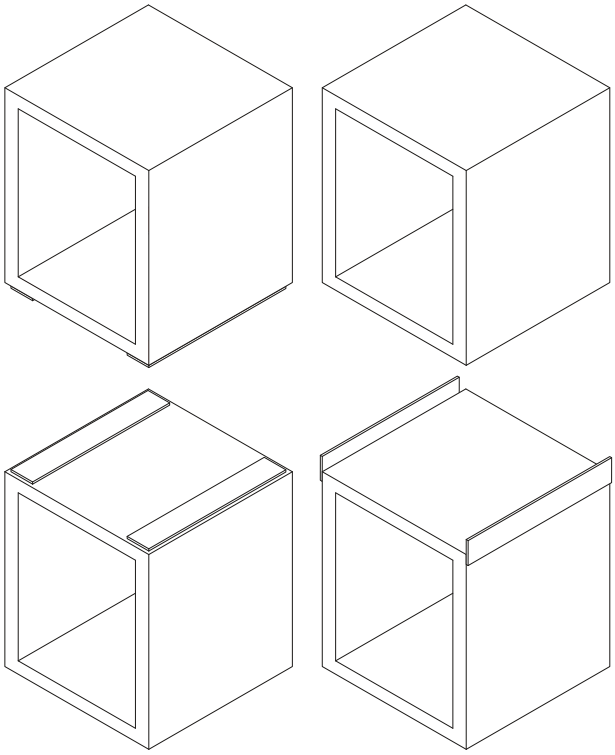
Internal metallic elements: In this type of joint, interior metallic connectors can join two or more spatial cells. These connectors are generally metallic plates joined by welding, metallic rods, screws or bolts (Graphic 66). The internal metallic joints can be installed in the production process or during the work itself. For this, the cavities specified for the installation of structural connectors must be provided from the spatial cells manufacturing process.

External metallic elements: Spatial cells may also be joined through metallic elements that may be embedded in the concrete since the manufacturing process. These exterior plates restrict the movements of precast elements and generate joints that are visible. Other connectors may be rods, bolts or screws, which are installed through holes that are usually made in the production site (Graphic 67).



Graphic 64
Joints with friction support between components.

Graphic 65
Connections between the reinforcements and a final casting of concrete to increase its rigidity.



Graphic 66
Joints between metallic elements embedded in the concrete, which are joined through metallic pins or through welding.

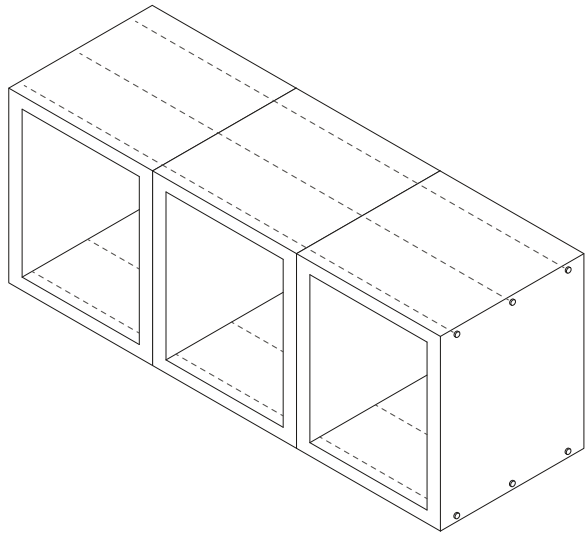
Graphic 67
Exterior metallic elements installed during the mounting process that stiffen the joint between precast elements.

Post-tensioned joints: This system is used to join the slabs or walls of two or more cells. They are used mainly as horizontal reinforcements because the compression stresses in the walls are generally attended with the mass of concrete that conforms them, and with conventional metallic reinforcements. The post-tensioned systems ensure the continuity of interior reinforcement in small or large-format elements, generating different aesthetic and technical possibilities in the prefabrication systems (Graphic 68). The post-tensioning joints maintain the continuity of reinforcements throughout all the precast pieces and can reduce volumes and weights by allowing the installation of smaller-sized elements.

4.7. NSR-10 Regulations for the joints of precast elements

The unions or joints define the continuity of the pieces that make up structural systems of prefabrication (skeletal, load-bearing walls, spatial cells or the combination of them). The union between these elements is made through different support, assembly or fixation mechanisms. In Chapter C.16 (which regulates construction with precast concrete), the Colombian Earthquake-Resistant Construction Regulations, NSR-10, proposes the technical specifications that must be followed in the design of the joints among the elements.

Point C.16.3 considers the distribution of stresses among the elements, an aspect in which the connections develop essential work to ensure structural continuity. In Section C.16.3.2.1, the path of the stresses must be continuous in



Graphic 68
Post-tensioned joints that stiffen after the installation of the precast elements.

the elements and in the connections located among them. When tension stresses are produced, a continuous path of the reinforced steel must be provided through the use of overlap splices, welded or mechanical splices or mechanical connections. Metallic connections can absorb the stresses and the concrete absorbs the shear and the compression. A continuous path of steel through a connection may include

bolts, welded plates, shear connectors or some other steel elements specified in the structural design. The tension stresses in the connections must be transmitted to the main reinforcement of the elements. The details of the connection must take into account the stresses and deformations due to retraction, plastic flow and thermal effects (*Comisión Sismorresistente & Minambiente,* 2010, pp. C-300-C-301).

Section C.16.5.1.2. explains that when the precast floor or roof elements form diaphragms, the connections between the diaphragm and the laterally supported elements must have a nominal tensile strength of not less than 4.4 kN per linear meter. In structural designs, the diaphragms are generally considered to be a part of the lateral load-resisting system. The stress on the tie is equivalent to the value of the service load of 3 kN/m, specified in the Uniform Building Code (*Comisión Sismorresistente & Minambiente,* 2010, p. C-302).

The NSR-10 Regulations explain each one of the connections that may be used for precast elements. They are described in Sections C.16.6.1.1. and C.16.6.1.2.

Point C.16.6.1.1 considers that the effectiveness of the connections to transmit stresses among the elements must be determined by analysis and testing. When the shear is the primary load of the structure, the provisions explained in Point C.11.6 may be used. These specifications should apply when it is appropriate to consider the transmission of the shear through a structural plane or element with the existing or potential shear, a contact surface between the different materials or a contact surface between two concrete elements installed at different times. The precast elements comply with this condition (*Comisión Sismorresistente & Minambiente,* 2010, p. C-302).

Point C.16.6.1.2 indicates that a connection that is designed using materials with different structural properties, their relative rigidity, resistances and ductile capabilities must be considered in the structural design. Different components of a connection (bolts, welded pieces, plates or inserts) have different properties that can affect the overall behavior of a connection (*Comisión Sismorresistente & Minambiente,* 2010, p. C-302).

Section C.16.6.2 explains the supports of precast elements of the roof or floor in simple supports, which must respond to what is indicated in points C.16.6.2.1 and C.16.6.2.2.

Point C.16.6.2.1 regulates the crushing stress admissible on the contact surface between the support element and the element supported, and the middle of any intermediate-support element may not exceed the crushing resistance of any of the surfaces or the support element (*Comisión Sismorresistente & Minambiente,* 2010, p. C-302).

Point C.16.6.2.2 proposes that, unless shown through analysis or tests, the behavior of the elements and their connections are not affected, the following two requirements of the NSR-10 Regulations must be met:

- After considering the tolerances, each element and its support system must have design dimensions so that the distance from the edge of the support to the end of the precast element in the direction of the light is at least $l_n/180$. The term l_n expressed in the NSR-10 Regulations means free light measured in millimeters between the supports' faces. These distances may not be less than 50mm for solid or alveolar (hollow-core) slabs, nor less than 75mm for beams or elongated t-shaped elements.
- The support pads or supports located on the non-reinforced edges of the precast elements must move toward the interior of the element a minimum of 13mm from the support face, or at least the dimension of the bevel on the edges that have these characteristics. This point differentiates the length of the support and the length of the end of the precast element located on the support. The support pads distribute loads and the reactions concentrated on the contact area and allow limited horizontal and rotational movements to decrease the magnitude of the stresses in structural elements (*Comisión Sismorresistente & Minambiente,* 2010, p. C-302). To prevent the flaking of the concrete elements under heavily loaded contact areas, the support pads should not extend to the edge of the support if it has not been reinforced. The edges may be reinforced with steel plates or angles. The tolerances must be considered to avoid the support in simple concrete, where there is no reinforcement continuity (*Comisión Sismorresistente & Minambiente,* 2010, p. C-17).

Section C.16.7.1 indicates that after the approval of the structural designer, it is possible that elements such as dowels or inserts that protrude from the concrete, or that are exposed for inspection, are introduced in the precast element while the concrete is in a plastic state, according to compliance with the following provisions:

- When it is not required that the embedded elements are hooked or tied to the reinforcement within the concrete (Point C.16.7.1.1).
- When the embedded elements are maintained in the correct position while the concrete is plastic.
- When the concrete is appropriately compacted around the embedded elements (*Comisión Sismorresistente & Minambiente,* 2010, p. C-305).

Prior to the mounting process, Section C.16.8 of the NSR-10 Regulations specifies the need to place identification markings in the precast elements to indicate their location, orientation in the structure and date of manufacture. The identification markings must correspond to the mounting plans. The identification codes correspond to each prefabrication firm and may vary from one project to another (*Comisión Sismorresistente & Minambiente,* 2010, p. C-305).

In Table 16, the technical specifications that must be complied with for the specification of joints between precast concrete elements are specified.

Regulation	Content
C.16.3.	Distribution of stresses among the elements
C.16.5.1.2.	Connections between the diaphragm and the laterally supported elements
C.16.6.1.1.	Connections to transmit stresses among the elements
C.16.6.1.2.	Supports of the precast elements of the roof or floor
C.16.6.2.1.	Crushing stress admissible on the contact surface between the support and supported element
C.16.6.2.2.	Behavior of the elements and their connections
C.16.7.1	Dowels or inserts in the precast element while the concrete is in a plastic state

Table 16
Technical specifications for joints between precast concrete elements, according to NSR-10.

4.8. New developments: Outlook

Academic research and the precast concrete industry have produced new ideas to improve its technical quality, diversify its geometries, increase surface finishes and develop new structural and non-structural elements. Complementary developments have improved the resistance of the material, explored the possibility of using other aggregates and generated new forms through the use of flexible formwork. These developments are found in the incorporation of other materials to the mix, to increase the resistance of materials and reduce the volumes of concrete in the reinforcements of structural elements and in the development of new formworks.

4.8.1. Bio-concrete (Self-Healing Concrete)

This research, developed by the Delft University of Technology in Holland, between 2006 and 2015, combines nature's microorganisms and construction materials. This type of concrete has the property of self-repair due to an addition of bacillus bacteria, which produces spores that can survive for up to five decades without food or oxygen and that can progressively repair some cracks and holes (Figure 41). As the pH value of concrete is very high, only the so-called alkaliphilic bacteria are able to survive. This prevents the passage of water and, thus, prevents corrosion of the reinforcing steel.

To perform the repair, the bacillus bacteria are stored inside the concrete in capsules made of biodegradable plastic, which open upon contact with water once the mixture has solidified. The bacteria store calcium lactate and then produce limestone, a material that repairs concrete. The use of bacterial concrete can, in theory, lead to substantial savings, especially in steel-reinforced concrete. It will also mean durability issues can be tackled in a new, more economical way when designing concrete structures.

Bacterial concrete is ideal for constructing underground retainers for hazardous waste, as no humans would have to go near it to repair any occurring cracks. For residential buildings, however, it does seem the traditional repairing of cracks will remain the most economically attractive solution for now. The team of researchers has tested the different capacities of the bacteria to respond to sulfate attacks or thermal oscillations, and with this material they hope to begin a new era of biological buildings. The Self-Healing Concrete Project is part of the TU Delft Self-Healing Materials Research program at the Delft Center for Materials (DCMat) (TU Delft, n. d.).



Figure 41
Bio-concrete (Self-Healing Concrete. Research developed by the Delft UT-wide Self-Healing Materials Research Program at the Delft Center for Materials (DCMat).

The team of researchers has tested the different capacities of the bacteria to respond to sulfate attacks or thermal oscillations, and with this material they hope to begin a new era of biological buildings. The Self-Healing Concrete Project is part of the Delft UT Self-Healing Materials Research program at the Delft Center for Materials (DCMat) (TU Delft, n. d.).

4.8.2. Concrete reinforced with natural fibers.

A research carried out by the *Universidad Pontificia Bolivariana* (UPB) in Medellín, Colombia, since 2008, has proposed the development of precast concrete elements reinforced with plantain and banana fibers obtained from recycling processes in crops that reach an extension of more than 360,000 hectares (Figure 42). These elements were mechanically evaluated using an Instron 5582 universal test machine and following the guidelines of the ASTMD 1037-99 Technical Standard with 150mm x150mm x4mm test pieces. The L/d ratio used in the test pieces was 16. The mechanical resistance corresponds to a mixture reinforced with 25% treated fiber, which allowed the elaboration of non-structural elements with mechanical performances capable of withstanding anchoring processes or mechanical joints, approved by the Colombian Earthquake-Resistant Construction Regulations, NSR-10. The fibers used as reinforcing elements were obtained through a mechanical extraction of the central veins of the leaves and the rachis –or pseudo stems– of the plantain and banana plants, all with different percentages of lignocellulosic fibers, constituted by cellulose, hemicellulose and lignin. To control the moisture of the fibers, mechanical-technical treatments have been

used on reinforces that are based on steam treatments at a temperature of 200ºC with time between four and eight minutes. The process was performed with a pilot reactor equipped with an expansion tank. The fibrous bundles were then washed with running water and dried until reaching an equilibrium moisture of nearly 7%, to bio-mineralize them and generate resistance to the alkalinity of the concrete mixture. After performing the thermal evaluation, alkalinity resistance and the tendency of moisture uptake of the steam-treated plantain fiber samples, it has been observed that the stability of the system is increased by reducing the absorption of moisture and resistance to alkalinity, which makes it possible to use these materials more comfortably as a reinforcement base for the production of these precast concrete elements. The tests were performed using TA Instruments 1600 DTA thermo-gravimetric analysis (TGA) equipment under an inert atmosphere of nitrogen at a heating rate of 10ºC/minute. According to these results, the steam treatment improves the mechanical performance of the materials developed, which is increased thanks to the presence of the concrete mixture, which improves the load transfer. According to the experience gained in the developmental stage, it is possible to indicate that precast non-structural elements may be manufactured in concrete reinforced with natural fibers obtained from the fibrous waste of the plantain agroindustry, useful for the production of non-structural panels of façades and interior walls, thus contributing to the solution of social and environmental problems. This system proposes the generation of new sources of employment and social development and uses natural resources that are renewed in periods of 12 months (Corona, 2009, pp. 46-49).

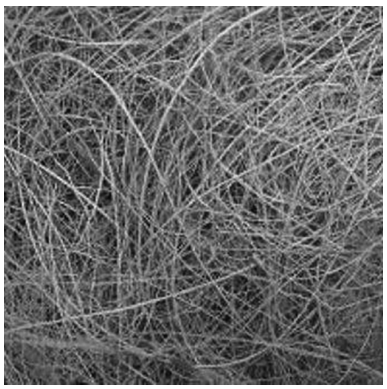


Figure 42
Concrete reinforced with natural fibers. Research developed by *Universidad Pontificia Bolivariana* (UPB) in Medellín, Colombia.

4.8.3. Concrete reinforced with nanoparticles.

Nanoparticles comprise another group of materials that may be added to the concrete mixture to increase its resistances and reduce the volume of material required for the construction of precast elements. Concrete reinforced with carbon nanotubes are classified in:

- Single-Wall Carbon Nano-Tubes (SWCNT) are composed of carbon atoms arranged in a cylindrical hexagonal network, so that its structure is the same as the one obtained if a sheet of graphite was rolled on it (Figure 43).
- Multi-Wall Carbon Nano-Tubes (MWCNT) have a structure similar to several concentric SWCNTs with different diameters (Figure 44) (Rivas, Ganzer & Cosme, n. d., p. 13).

In both cases, their main characteristic is a very high longitude/diameter ratio: their diameter is on the order of nanometers and their length can vary from a few microns to millimeters, or even centimeters. The mechanical properties of each type of concrete, reinforced with carbon nanotubes, depend on their dimensions (diameters and length) and the defects present in the nanotube (such as openings or impurities that can occupy the place of a carbon atom or some deformations or inclinations). This type of concrete can generate greater mechanical resistances in the mixture, and therefore, the volume to be used would be less, which would generate higher yields of the materials with lower consumptions (Rivas et al., n. d., p. 50).

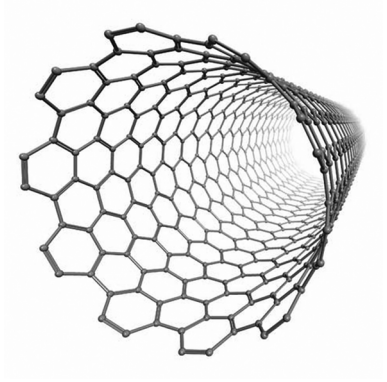


Figure 43
Single Wall Carbon Nano-Tubes (SWCNT) and Multi-Wall Carbon Nano-Tubes (MWCNT). Accessed December 11, 2015; available at: http://www.mdpi.com/sensors/sensors-15-01564/article_deploy/html/images/sensors-15-01564f3-1024.png.

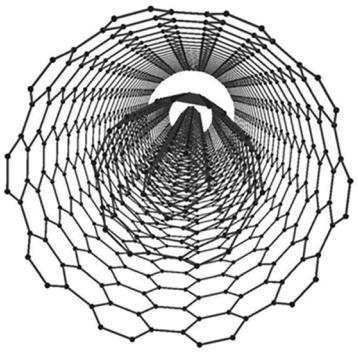


Figure 44
Single Wall Carbon Nano-Tubes (SWCNT) and Multi-Wall Carbon Nano-Tubes (MWCNT). Accessed December 11, 2015; available at: http://www.mdpi.com/sensors/sensors-15-01564/article_deploy/html/images/sensors-15-01564f3-1024.png.

4.8.4. Transformable (post-formable, cutting or graphic) concrete

This type of concrete can be bent, cut or have its surface modified. Curved concrete is a micromechanical material that has greater tensile and deflection stresses and is lighter than traditional concrete (Figure 45). Instead of using stony aggregates, polyvinyl-coated fibers and silica sand with diameters up to 0.2mm are incorporated into the mixture. By reducing the need for traditional metal reinforcements, the ability to post-form the precast elements (which can have up to 1cm of section in panels measuring 120cm x 240cm) is improved and seismic resistance is increased. Some types of this curved concrete are:

- Low-density curved concrete, which incorporates air bubbles, micronized glass, polymer spheres and light aggregates that allow achieving greater ductility than other lightweight concretes.
- Self-compacting concrete, that uses its own weight to increase its density without using vibrations to ensure the correct distribution of the mixture.
- Pulverized concrete, which is applied through sprays with air (spray-type) to make repairs on previously produced elements (Li, 2012, p. 24).

Cutting concrete (*Betonfräsen* in German) is one that can be transformed by manual or mechanical procedures similar to those used in the cutting processes of agglomerated particleboards or elements in dimensioned dry wood (Figure 46). These elements develop high resistance to compression with low densities, properties that maintain their mechanical stability and permit cutting according to the desired shapes. They are mainly used in exterior panels of façades or in non-structural interior walls.

Graphic Concrete combines silkscreens and photographic etching techniques on the surface of in-situ cast concrete or precast concrete elements (Figure 47). This type of concrete has an invention patent belonging to Finnish architect Samuli Naamanka since 2002. Its future developments could form a series of innovations aimed at improving some environmental conditions. The textures that can be designed on the surfaces of the concrete elements generate micro-shadows that reduce the temperature obtained by radiation and decrease caloric conduction toward interior spaces. A setting retarder is applied to the surface of the mold containing the recorded images and keeps the concrete in contact with these surfaces until it hardens. After the casting process, a pressurized hose removes the concrete from the area occupied by the image or by the desired texture, which is engraved in relief on the surface of the cast or precast concrete element (Petricone, 2012, p. 110).

4.8.5. Textile formworks.

Textile molds, for the construction of precast concrete elements, comprise a technology with the ability to transform architectural concrete in reinforced concrete structures. This type of mold is adapted to the form resulting from the weight of the mix and the deformations of the material. At the University of Manitoba, the Centre for Architectural Structures and Technology (CAST), Professor Mark West and his work team have explored different possibilities to produce

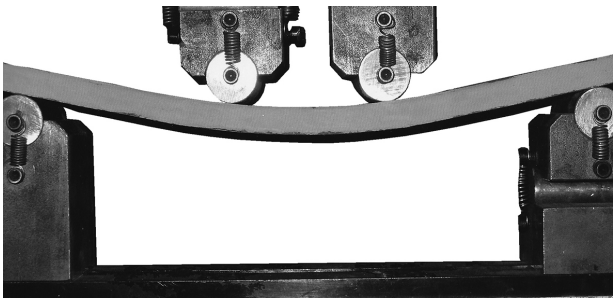


Figure 45
Curved concrete, a micromechanical material with resistances to tension and deflection stresses is more lightweight than traditional concrete. Photo: ACE-MRL, the University of Michigan. CONCRETE IDEAS. Edited by Pina Petricone - Thames & Hudson.



Figure 46
Cutting concrete, material that can be transformed through manual or mechanical procedures.

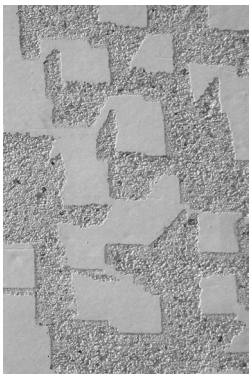


Figure 47
Graphic concrete, a material that combines silkscreens and photographic etching techniques on the surface of concrete elements. Photo: Graphic Concrete Ltda. CONCRETE IDEAS. Edited by, Pina Petricone. Thames & Hudson.



Figure 48
Structural elements obtained from the use of textile formworks. Photo: CAST Brochure. Accessed December 11, 2015; available at: http://umanitoba.ca/cast_building/

precast structural and non-structural elements using textile molds. The natural tensions of the geometries foreseen by the textile membranes generate lightweight and economical formworks, which use a lesser amount of materials in contrast to conventional formworks. These molds, which follow the forms of a funicular polygon, can reduce the unnecessary consumption of concrete in the production of structural and non-structural elements (West, n. d.). Through the tensions applied to the textiles, the pouring of concrete can generate different geometries in structural and non-structural elements (Figure 48). The costs of these textiles in local markets make this type of formwork an option for precast concrete structural and non-structural elements.

Summary

The structural system and the living space

Continuity

The precast-concrete elements for the construction of social housing must guarantee the structural, spatial and constructive continuity of the project. In structural continuity, the unions or joints between the precast elements must be the minimum necessary to maintain the stability of the system and define a uniform behavior among the parts that make it up. Spatial continuity defines the support structure according to the perimeter of the dwellings (load-bearing walls and floor or ceiling slabs) so that the living space has the least amount of structural elements in its interior; it can be read integrally and used in different ways. Constructive continuity permits the use of other materials in façades or interior walls from the prefabrication in concrete of the support structure, allowing the harmonious articulation between materials and processes at different time and with different characteristics.

Flexibility

Precast-concrete social housing should consider flexibility on four scales: urban, in the building, in the dwelling and with other constructive subsystems: On the urban scale, proposals should be adapted to flat or sloped topographies and shape the public space in different ways with courtyards, streets, residences or viewpoints. In the building scale, the precast elements can form different types of groupings between one to five stories tall, on terrains with different load-bearing capacities and with different urban and architectural languages. In the dwelling scale, the interior spaces must allow different habitable areas, spatial configurations and typological variations that permit the individualization of the dwellings from the needs, desires and number of members of the family groups. In the scale of other construction subsystems, industrialized housing with precast-concrete frames must allow the use of other materials, with different forms, textures and proportions, to resolve the non-structural elements, such as interior walls and façades. This condition permits increasing the versatility of the housing by finding diverse formal and functional solutions from the constructive system itself.

Prefabrication systems

The structural elements must propose a system of *partial industrialization*, in which the support structure must be prefabricated in concrete, with the highest standards of quality. The non-structural elements can use other elements or constructive systems traditionally used in the local context, such as brick or concrete-block masonry, allowing the incorporation of other industries or the local workforce into the process. Other systems and materials not commonly used in urban environments, but that may be specified in the designs of these houses, are wood panels, earthen walls, stone walls, walls with recycled elements, among others. This condition allows us to think of a partially prefabricated system, which industrializes only the support structure, but that permits the combination of this element with other materials and with other technical systems, to qualify and use in the process of the local workforce.

Precast-concrete components for the production of structural elements

The conformation of the concrete for the prefabrication of the support structure must consider the materials available in the local context, in order to reduce costs and guarantee the existence of the raw material necessary for the production of the frames. These elements are specified with local cement, stone aggregates, conventional structural reinforcements (steel metal bars or metallic mesh) and accelerating setting additives to form a mixture with components available in the local market. The minimum strengths of the precast-concrete frames will be determined by the structural designs for each project, based on the minimum standards established in the Colombian Earthquake-Resistant Construction Regulations NSR-10, which establishes 17 Mpa as the minimum resistance to compression for structural elements. This technology should allow for subsequent technical and industrial developments, through the use of other components to obtain lighter concrete (with expanded aggregates, wood particles, air to obtain cellular concrete) or with recycling processes to improve the environmental conditions of the material (fly ash, materials obtained from construction processes). Other developments, such as textile reinforcements, steel-fiber or fiber-glass reinforcements and the production of ultra high performance concrete can be used also for the production of the structural elements. Other reinforcements that the system must allow are prestressed elements and post-tensioned cables for the union among the pieces that make up the system. The formworks for the production of the prefabricated elements can be in metal, wood, polyester, fiberglass or materials that allow processes of reuse, to deduct the costs in the production stage.

Production

The production of the prefabricated structural elements can be done in industrial plants or field factories (at the work site), according to different factors, such as distance from the plant to the project site, accessibility to the lot, costs and time. If there is space in the project site for the production of the structural elements and if the distance from the plant to the lot exceeds 150km, it is possible to prefabricate in the worksite itself or in satellite plants that may be simultaneously producing the structural elements for different construction sites of the projects.

Transport

According to the Ministry of Transport of the Republic of Colombia, land transport in Antioquia (which is used to carry 95% of the products among its different zones) is conditioned by the size of the roads and vehicles used. This, in turn, conditions the sizes and weights of the precast-concrete structural elements, which can be up to 18.50m in length (or modular sizes at this distance to transport several elements simultaneously), up to 2.60m in width and up to 4.40m in height. The maximum weight allowed for the transport of these elements, so that they can reach the internal roads of each municipality, is 52 tons. To ensure efficient processes and maintain the desired costs, transportation can be done from the production plants (most of them located in the Medellín Metropolitan Area and its surrounding municipalities) to municipalities 150km away. The transport factor is a decisive

element in the implementation of the industrialization system of the housing support structure; therefore, it determines the geometries, sizes, weights and locations of the projects. If the distances between the production plant and the project sites are greater than 150km, or if the access roads to the lots are narrow and do not allow the movement of cargo vehicles, the possibility of having field factories on the project lots or having satellite prefabricating plants, which can simultaneously supply several municipalities far from the area of coverage of the industrial zones, should be studied.

Structural systems

The industrialization of the support structure of the dwellings must be done through the prefabrication of the concrete, material resistent in structural terms and culturally accepted by the community that inhabits urban territories. These precast elements must be designed as structural units that have the lowest possible number of joints, which standardize their industrial production so that only one of their typologies can be used in different ways, generating a flexible, versatile housing system and which maintains the structural stability necessary in buildings from one to five stories tall. The structural system that meets these requirements is the spatial cells, which are formed by the union between a slab and a wall (generating an L-shape), by a slab and two walls (generating U-shapes), or by two slabs and two walls (generating a closed frame, with the structure in the perimeter of the living space). The industrialization of these spatial cells as structural elements allows solving the structural joints from the industrial plant with all the technical conditions required by the regulations; it reduces the work of joints on site (improving the efficiency of the system) and stiffens the joints between the slabs and walls, generating hyper-static and self-supporting elements that permit reducing the processes on site, reducing the joints among the structural elements and permitting different designs in the plant and in the façade by eliminating structural elements from the interior spaces and on the façades.

Regulations from the Colombian Earthquake-Resistant Construction Regulations NSR-10 for prefabricated elements

In Title C (Concrete), Chapter C.16 (Prefabricated Concrete), the regulation defines all the technical details for the design, production, transport and installation of precast-concrete elements in buildings. All the structural designs for the construction of social-housing projects with this system must comply with the existing regulations for the definition of mix dosages, reinforcements, geometries, joints and other technical applications that must be present in the structural designs.



Case Studies

Systems and Projects 1948 – 2010

Official programs and private initiatives in different contexts resorted to industrialization, since the first decades of the 20th Century, to build social housing quickly, economically and with specific quality standards. With the precast concrete, architectural designs were rationalized and housing components were standardized, allowing a reduction in the housing deficit in shorter periods of time and with lower costs than those used by traditional construction systems like in-situ cast concrete or structural masonry. Although the reduction in time and costs was demonstrated through processes of precast concrete, aspects such as the quality of living, the repetitiveness of architectural solutions and the reduction of expressions of individuality generated different reactions. Some of them associated precast concrete with a totalitarian political view and with a housing condition lacking functional and formal variants. When precast concrete buildings obeyed a political condition, they showed a utopian vision of universal equality by establishing it in their homes (Groys, 2014, p. 40). Some of the housing principles understood it as an open, potentially variable combination of standardized elements, where some industrial systems were taken as models for the design and construction of buildings. Instead of traditional houses, apartments that could be grouped into housing projects were conceived (Groys, 2014, p. 41).

In *Panel Buildings: Stations on the Way to Utopia (Edificios de paneles: estaciones camino a la utopía)*, Boris Groys argues that precast concrete housing in Eastern Europe, Western Europe, Asia and America was inspired by the Russian avant-garde and the German Bauhaus. His architects planned housing projects for workers (*Arbeitersiedlungen*) that were economical, functional, free of any architectural pretension and that allowed rapid construction. Industrialization in the construction of residential buildings was one of the main objectives at that time. Thus, in 1924, Mies Van der Rohe wrote: "If we achieve this industrialization, then social, economic and artistic problems could be easily solved" (Richter, 2006, as cited in Groys, 2014, p. 43).

In other contexts, housing was simultaneously designed and built with *in situ* cast concrete (skeletal or structural walls), skeletal structures with metallic profiles and structures of structural walls with structural masonry. These buildings, conceived with some housing, urban, political and technical conditions, different from those in precast concrete, expressed other ideas to address the housing problem. The construction technique was not only a mechanism for the realization of projects; it was associated with the functional conception of the building, the reading of urban space, the relationship with the physical context, the ideological expression of the unit or diversity, and the relationship of the living space with its inhabitants. Boris Groys argues that, in the design of mass housing for workers, an aesthetic attitude was connected with a political one. After the reunification of Germany, the specialized criticism of former West Germany considered the buildings of the German Democratic Republic (GDR) as "inhumane manifestations of totalitarian mistreatment of the population, condemned to live in identical apartments".

The *Plattenbau* was considered an act of the GDR against the beauty of traditional German architecture. In the former Union of Soviet Socialist Republics (USSR) and in the Eastern European countries that formed the Iron Curtain after the fall of the Berlin Wall, rationalist architecture was subjects to a very similar criticism. The standardization of the construction elements in prefabrication obeyed the desire to provide as many houses possible for the working population, an aspect that was later replicated for technical, economic, social and political reasons in several countries in Eastern Europe, Western Europe, Asia and America (Groys, 2014, pp. 44-45).

The architectural debates between socialist housing versus the architecture of housing in Western Europe and North America showed that humanist notions were associated with political and ideological contexts. The speech of rationalization and standardization faced diversity and individuality.

With precast concrete, new housing typologies were designed and built; building components were industrialized, new procedures were developed to install the components and housing was conceived as a political and social expression of equity and efficiency to provide the population as many houses in the shortest possible time. The aesthetic value of precast concrete architecture had different interpretations, from political and social aspects. It was not just about aesthetic interpretations or individual tastes.

Contrary to standardization, the speech of diversity corresponded to an aesthetic taste for heterogeneity, for difference and for convergence. The expression and desire for individuality in housing seems to move away from anything uniform, repetitive or reductionist. The aesthetic sensibility of the houses' users moved away from the monotonous, massive appearance of precast concrete buildings. Boris Groys argues that the speech and policies of diversity and cultural differences should not be seen or interpreted without relating them to the market-driven practices of diversification and the cultural differentiation of the second half of the 20th Century. The Communist aesthetic, that related the political context to collective housing buildings, was not diverse enough and confronted the pluralist taste or a part of society (Groys, 2014, pp. 45-46).

Precast concrete housing generated –from the processes of design, production and installation of its elements– a series of industrial procedures, technical developments, housing typologies and aesthetic conditions that influenced ways of living.

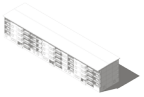
In the historical line of collective housing, standardization architecture and the architecture of diversity have shared spaces and characterized their time. They have been means to express the political, social, technical, economic and living conditions of the context where they have been located. Under different views and concepts, both have understood collective housing as a manifestation of life in community, of technology as an expression of industrial progress, and of political conditions.

Different housing constructions in Eastern Europe, Western Europe, North America and Latin America, built between 1948 and 2010 with precast concrete structures or enclosures in concrete, were studied in order to understand the relationship between each of the elements that make up the support structure, the living space and the language expressed through their forms. In each series of prefabrication or in each project, the structural system and its components, the assembly process of its components and the spatial and volumetric results are illustrated.

Precast concrete



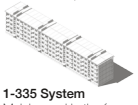
Andrew Melville Hall
Saint Andrews, Scotland, 1964
James Stirling



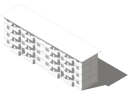
IMS System - Latin America
Mainly used in Cuba, 1960
CTVU (Centro Técnico de la Vivienda y el Urbanismo)



PREVI
Lima, Perú, 1966
E. Montagne, C. Morales



1-335 System
Mainly used in the former Soviet Union, 1959
Vitaly Lagutenko and the DSC Soviet System



Large Panel IV System (Sistema Gran Panel IV)
Mainly used in Cuba, 1959
The DSC Soviet System



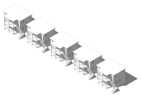
PREVI
Lima, Perú, 1966
Atelier 5



K-7 System
Mainly used in the former Soviet Union, 1958
Vitaly Lagutenko and the DSC Soviet System



Large Soviet Panel System
Mainly used in Cuba, 1965
Hugo D'Acosta



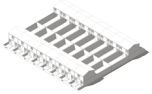
Novoa-Sandino System
Patented and mainly used in Cuba, 1950
José María Novoa



IMS System - Europe
Mainly used in the former Yugoslavia, 1957
Institute for the Testing of Materials (IMS)



VAM System
Mainly used in The Netherlands, 1961
A private Dutch company



Muzú Neighborhood (Barrio Muzú)
Bogotá, Colombia, 1949
J. Gaitán, Á. Ortega, G. González, Instituto de Crédito Territorial ICT.



1-510 System
Mainly used in the former Soviet Union, 1957
SAKB Specialized Architectural and Design



G-57 System
Mainly used in the former Czechoslovakia, 1957
Bata: Bohumil Kula & Hynek Adamec



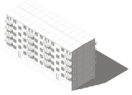
Larsen & Nielsen System
Mainly used in Denmark, 1960
R. A. Larsen, A. Nielsen



Camus System
Patented and mainly used in France, 1948
Raymund Camus

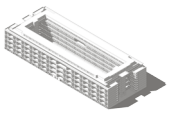


Quiroga Neighborhood
Bogotá, Colombia, 1951
G. Solano, Á. Ortega, G. González

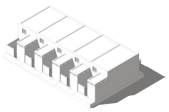


1-464 System
Mainly used in the former Soviet Union, 1960
The DSC Soviet System

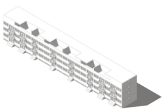
20-30



Immeuble Villas
Project, 1922
Le Corbusier

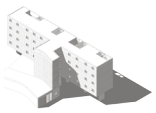


Weißenhofsiedlung
Reihenhäuser, Stuttgart, Germany 1927
Pankokweg 1, 3, 5, 7, 9
J. J. P. Oud

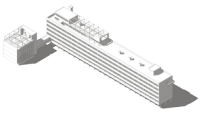


Weißenhofsiedlung
Wohnblock, Stuttgart, Germany 1927
Am Weißenhof 14-20
Mies van der Rohe

30-40



Swiss Pavilion
Paris, France, 1931
Le Corbusier

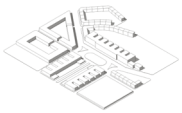


Narkomfin
Moscow, Former Soviet Union, 1932
Moisei Ginzburg, Ignaty Milinis



Cité de la Muette
Drancy, France 1932
Eugène Beaudouin, Marcel Lods, Vladimir Bodiansky, Jean Prouvé

40-50



El silencio
Caracas, Venezuela, 1945
Carlos Raúl Villanueva



Prefeito Mendes de Moraes (Pedregulho)
Rio de Janeiro, Brasil, 1947
Affonso Eduardo Reidy, Francisco Bolonha

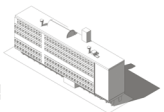


Presidente Alemán
Mexico City, Mexico, 1949
Mario Pani

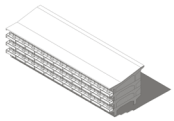
50-60



Copan Building
São Paulo, Brasil, 1951
Oscar Niemeyer

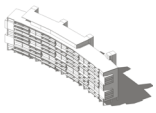


Unité d'Habitation
Marseille, France, 1952
Le Corbusier

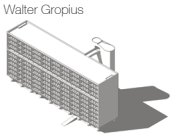


Tuscolano III Neighborhood
Roma, Italy, 1954
Adalberto Libera

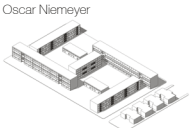
60-70



Hansa Viertel
Händelallee 1–9, Berlin, Germany, 1960
Walter Gropius



Hansa Viertel
Altonaer Straße 4-14, Berlin, Germany, 1960
Oscar Niemeyer



Exequiel González Cortés Neighborhood
Santiago de Chile, Chile, 1964
Hegedus, Carballo, Bravo / Grupo TAU

In situ cast concrete, masonry and other construction systems



Habitat 67
Montreal, Canada, 1967
Moshe Safdie



Southgate Estate Residential Complex
Runcorn New Town, Cheshire, England, 1977
James Stirling



Martinsviertel
Cologne, Germany, 1977
Schürmann Architekten



PREVI
Lima, Perú, 1966
James Stirling



Precast Affordable Housing
Mainly used in Chile, 1975
The Government of Chile



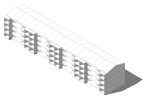
PREVI
Lima, Perú, 1966
E. Llanos - M. Mazzarri



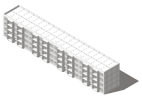
Residential Building
Monza, Italy, 1972
A. Mangiarotti



Genter Straße Residential Complex
Munich, Germany, 1972
O. Steidle, R. Thut, D. Thut



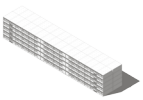
Skarne S66 System
Mainly used in Sweden, 1966
Ohlsson & Skarne



Soviet KPD System (Krupnopanelnoye Domostroyenie)
Mainly used in Chile, 1972
Vitaly Lagutenko



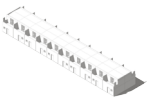
Niza Residential Complex
Pereira, Colombia, 1980
System designed by Pablo Cortina



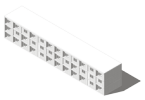
Jugomont 61 System
Mainly used in former Yugoslavia, 1961
B. Budimirov, Ž. Solar, D. Stilinović



Men´s residences in the Olympic Village
Munich, Germany, 1971
G. Eckert, and W. Wirsing



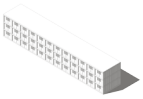
Women´s residences in the Olympic Village
Munich, Germany, 1971
Heinle, Wischer and Associates



Bachué City III
Bogotá, Colombia, 1980
P. Samper, L. Tapias, C. Moreno and G. Marín



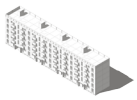
WBS-70 System
Mainly used in the former German Democratic Republic, 1970
Deutschen Bauakademie, TU Dresden



Bachué City II
Bogotá, Colombia, 1980
P. Samper, L. Tapias, C. Moreno and G. Marín



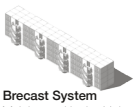
Residential and comercial Building
Rathenow, Germany, 1997
K. Sill, J. Keim



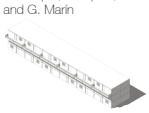
Ital-Camus System
Italian adaptation of the Camus series, 1960
Original idea by Raymond Camus



Large Panel 70 System
Mainly used in Cuba, 1970
Osmundo Machado, Grupo Nacional de Viviendas



Brecast System
Mainly used in the United Kingdom, 1970
Building Research Establishment (BRE)



Bachué City I
Bogotá, Colombia, 1980
P. Samper, L. Tapias, C. Moreno and G. Marín

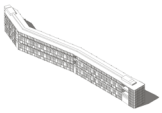


Official Social Housing
Alcobendas, España, 1995
Manuel de las Casas

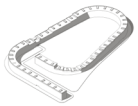


Elemental - Milan House Prototype
Milan, Italy, 2008
Elemental – Chile

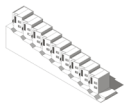
70-80 | 80-90 | 90-00 | 00-10



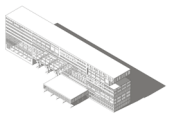
Robin Hood Gardens
London, England, 1972
Alison & Peter Smithson



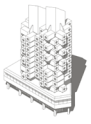
"El Ruedo" M-30
Madrid, Spain, 1986
Francisco Javier Sáenz de Oiza



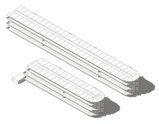
Atlantida 1
Medellín, Colombia, 1994
Ana Elvira Vélez



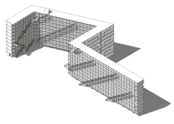
Silodam
Amsterdam, The Netherlands, 2002
MBM (Martorell, Bohigas, Mackay) and MVRDV (Maas, van Rijs, de Vries)



Nagakin Capsule Tower
Tokio, Japan, 1972
Kisho Kurokawa



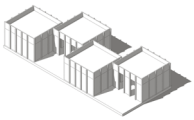
Nemausus
Nimes, France, 1987
Jean Nouvel



Gifu Kitagata
Motosu, Japan, 1998
Kazuyo Segima



Quina Monroy
Iquique, Chile, 2003
Elemental - Chile



PREVI
Lima, Perú, 1978
Knud Svenssons

Graphic 69
Collective housing seen from its history and from the construction technique, as a response to the political, social, technical, economic and housing conditions of their contexts.

5.1. 1940s and 1950s

5.1.1. Camus System. France, 1948



Graphic 70
Exterior view

Camus System. France, 1948	
Type of structure	Structural walls
Type of prefabrication	Closed
Architect, inventor or designer	Raymond Camus
Average areas per home (in square meters)	35, 45, 70
Number of housing units (on average, per building)	20
Average height of the buildings (in number of stories)	5
Number of types of precast elements	87
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	1
Beams	1
Facade panels	19
Interior walls	19
Mezzanine slabs	29
Types of structural elements or slabs for rooves	11
Special elements (ducts, joints, common areas, awnings)	5
Stairs	2
Structural spatial cells	0
Types of joints	Steel bars and *in situ* cast concrete

Table 17
Camus System, France, 1948. Information taken from: Alonso and Palmarola, 2014, pp. 216-217, 257, 306-309.

System and building

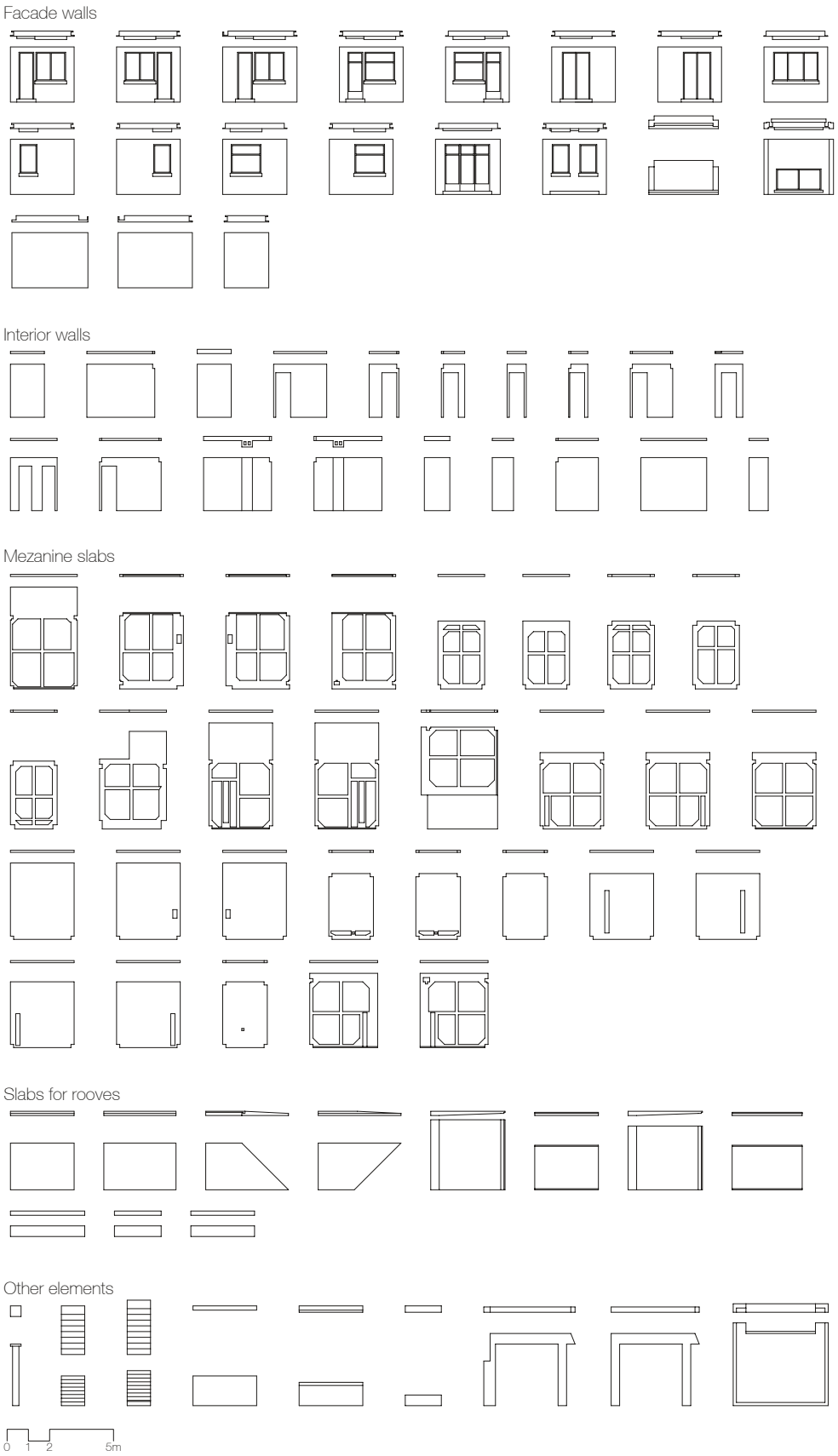
Patented in 1948 by Raymond Camus, this system of structural walls was used in France and later in other countries in Europe, Asia and America. In the 50s and 60s, new developments were incorporated to use it in the construction of five-story high-rise residential buildings for the working class in the USSR and in some Eastern European countries. The joints were resolved with steel bars and reinforced with *in-situ* cast concrete to produce a rigid, homogeneous unit (Alonso & Palmarola, 2014, p. 217). In Western Europe, its use was highlighted in Italy, where it was adapted by means of some modifications that later originated in the Ital-Camus structural system. Years later, it was also adapted in Cuba as the Soviet Great Panel System and in Chile as the Great Structural Panel System (KPD), which had the influence of Soviet technology in the design and construction of social housing buildings (Alonso & Palmarola, 2014, pp. 216-217).

The Camus System was considered as a "heavy prefabrication" process, which denoted that the industrialization system of some buildings comprised load-bearing walls and slabs in structural concrete, produced in series in a type of closed prefabrication that did not permit its combination with other technical, material or structural systems. The system solved all the elements and components necessary to create a complete, closed building. Complete because it developed all the necessary components for the construction of a building; closed because the geometric configuration of the elements and the details for their connections were specifically created for this building, incompatible with other systems.

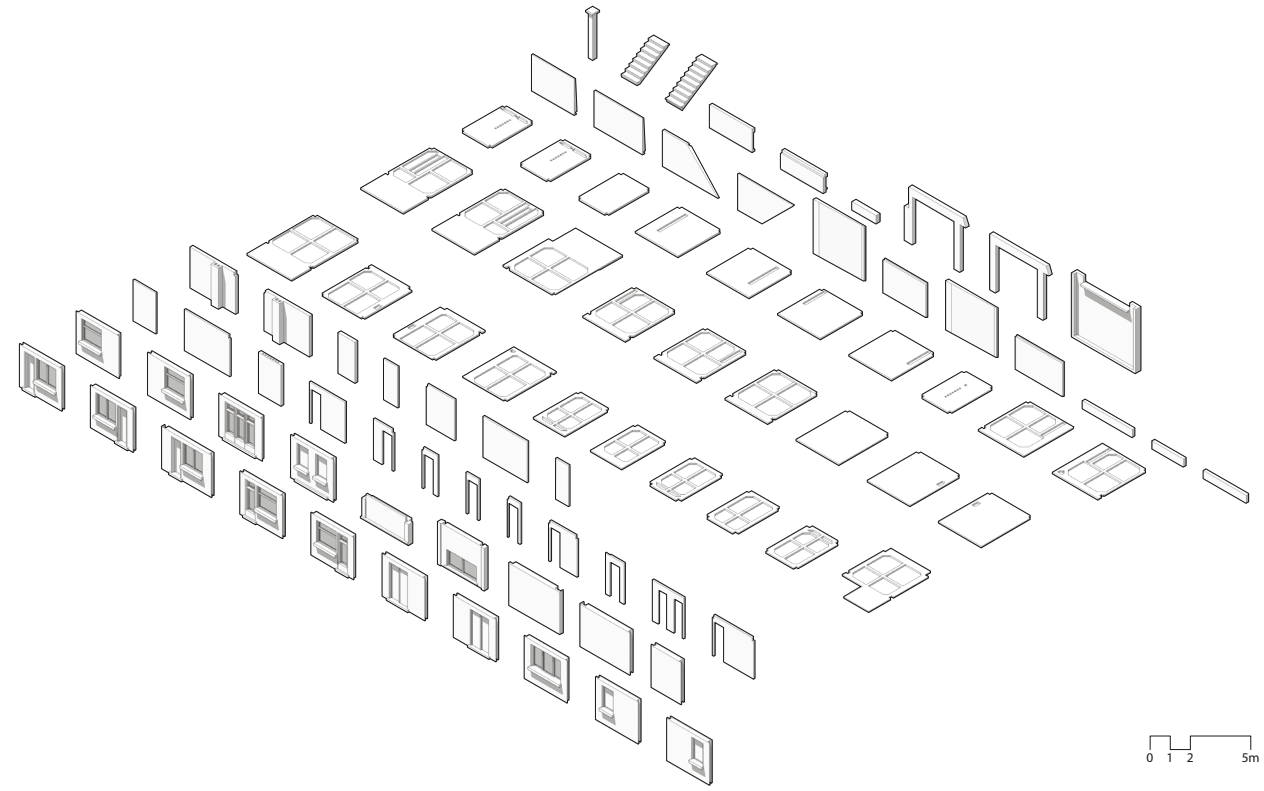
Through these systems, it was possible to assemble different numbers of parts, with few types and modifications among them to standardize their components as much as possible. In compensation for these limitations, the Camus System offered economic and logistical advantages. The economy in the system installation was one of the principal advantages of these heavy-prefabrication systems. Also, installation time were lower through the use of a smaller amount of specialized labor, which increased the financial benefits of the process. The design and construction processes had to be adapted to the system, so that the elements that formed the building could be adapted to the characteristics of the elements. The reduced flexibility of this system and the requirement of a minimum number of housing units were two important determinants in its use.

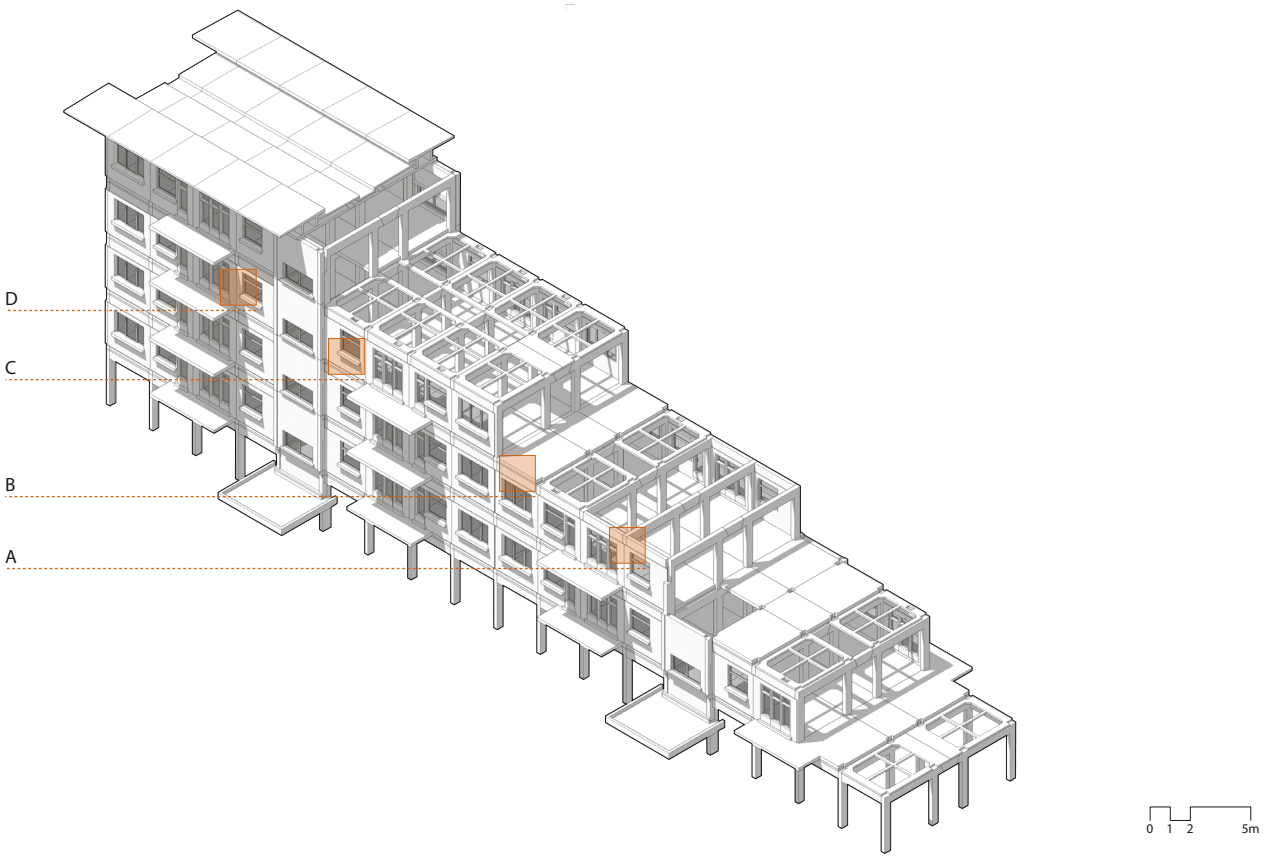
The Camus System was approved as a patent in 1949 by the French Scientific and Technical Centre for Building (*Centre Scientifique et Technique du Bâtiment,* CSTB). Applied massively, it was necessary for the French Government to achieve its goal of building nearly 20,000 homes per month in the early 1950s. The Camus System became a symbol of heavy prefabrication in Western Europe. In the middle of 1969, it had six factories in France and 16 factories in other countries including the United Kingdom, Germany, Italy, Russia and Algeria.[25]

25 Heavy Prefab Systems. Camus System. Accessed May 29, 2017; available at http://postwarbuildingmaterials.be/material/heavy-prefab-systems/.



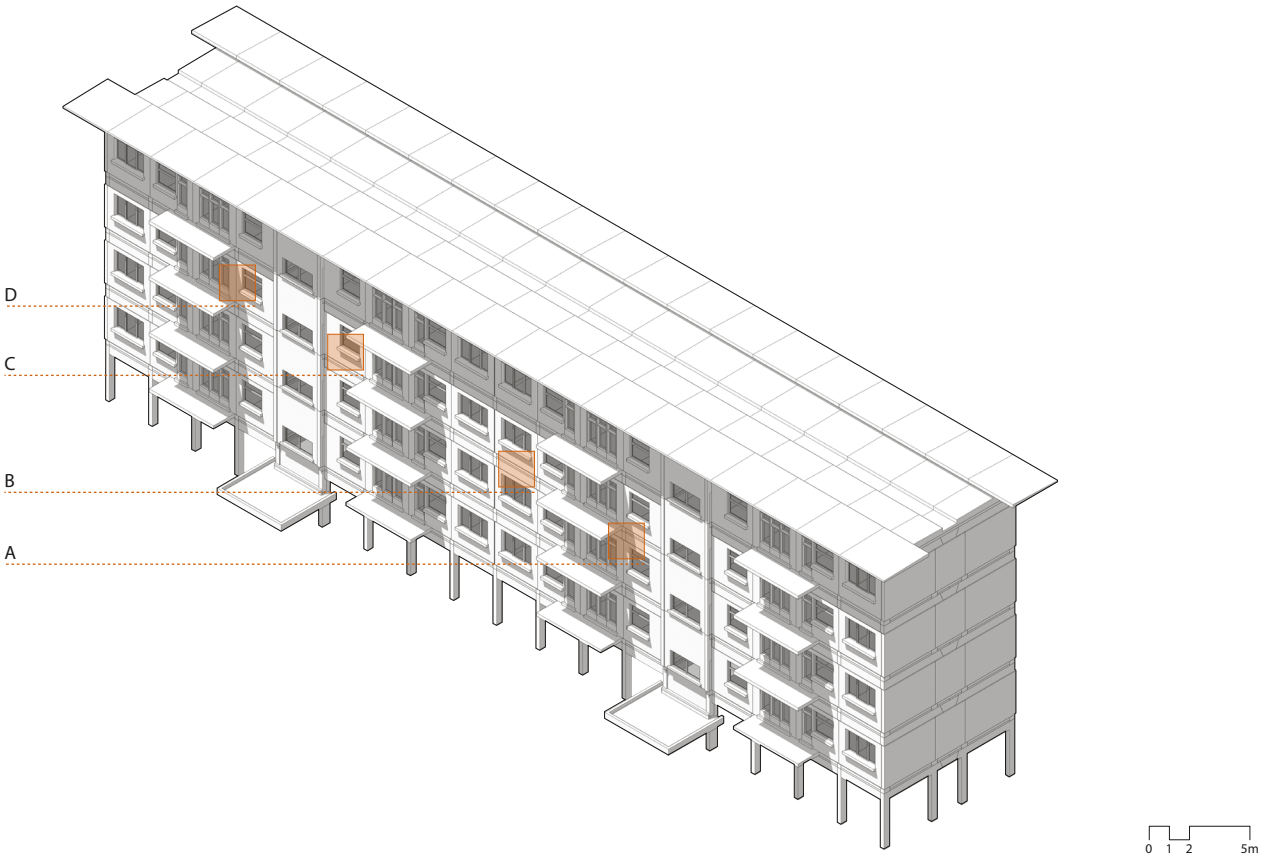
Graphic 71
Components: floor plans and façade





Graphic 72
Components: axonometry

Graphic 73
Construction process



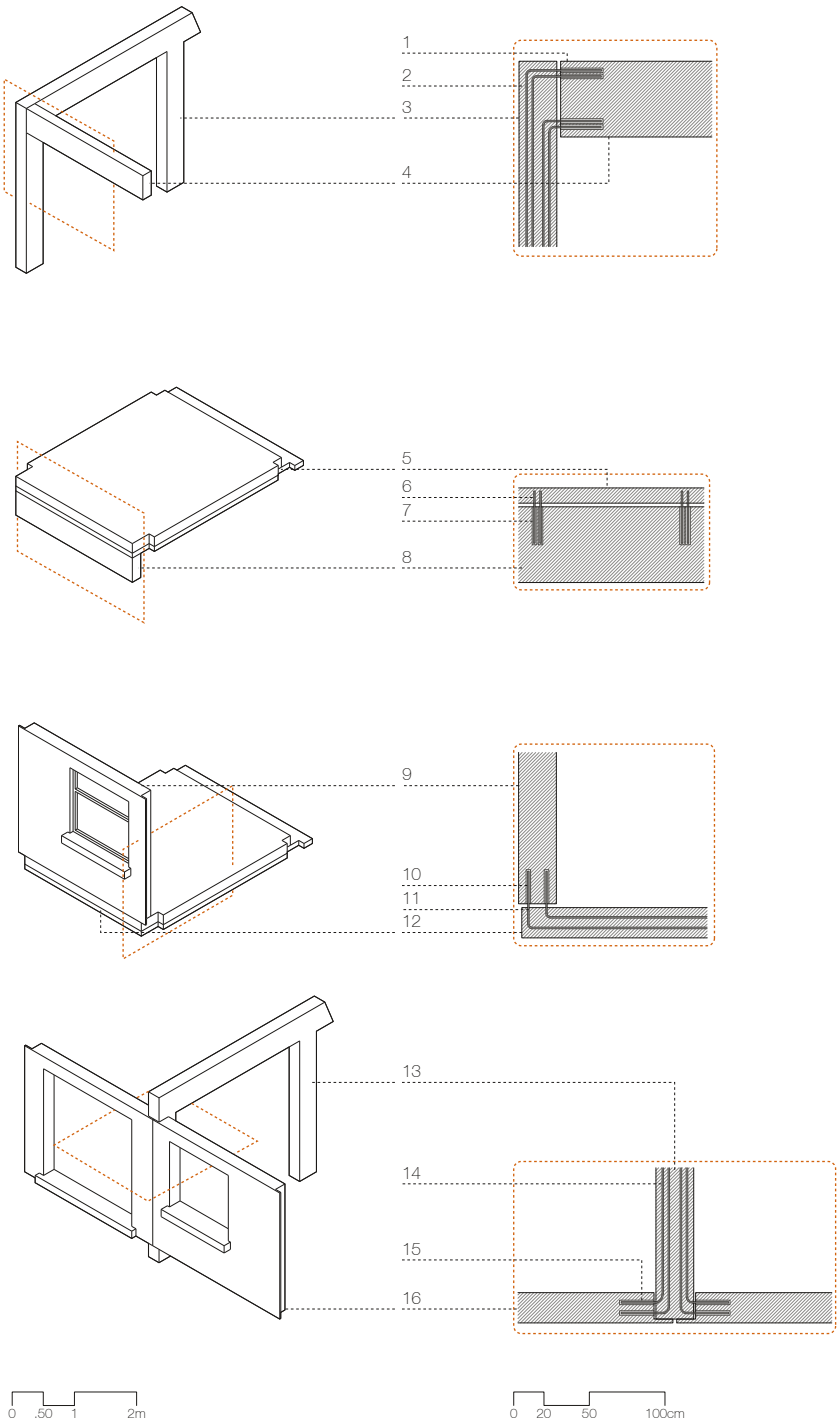
Graphic 74
The technical system and the architectural language

Advantages

- The system proposed modular developments with dimensions among the structural elements that permit different combinations for housing units.
- Different buildings could be made in short periods of time and with control of costs in different contexts, due to the dimensional coordination among their pieces. This condition allowed the construction of 20,000 housing units per month in France other countries in Europe, Africa and America.
- The proportions of the elements permit their transport from the production plants to the project site.
- The versatility of the system in its geometries and in its principles of dimensional coordination allowed it to be adapted to different cultural and geographic contexts.
- The joints and the geometries of the elements allowed its replicability in short periods of time.
- The system generates different types of housing and comfortable uses of the interior space. Architectural designs must consider cross-ventilation and orientations to respond to the geographical context.

Disadvantages

- It is necessary that the system have elevators or ramp systems to allow accessibility to each of its levels. The dimensions of the doors, interior corridors and free spaces in common areas do not allow a comfortable accessibility of people with different disabilities.
- The foundation systems, such as the load beams to receive the structural walls, could require depths similar or greater than conventionally systems.
- The elements that make up the system belong to a type of closed prefabrication, in which other types of elements or materials cannot be used in the construction process. Some of the structural elements form part of the interior space, which does not allow different architectural design in the same living space. The location of structural elements within the space conditions its use and its transformation over time.
- Having the façade panels previously defined, the possibility of incorporating cultural traditions or individualizing the language in each project is restricted. Thus, it is a system that considers few variations in its aesthetic aspect and does not generate variations in its language according to the communities that inhabit it and in agreement with the cultural traditions. By having structural walls in its façades and interior spaces, the systems restricts the incrementality over time or the transformation of living spaces according to the requirements of families.



1. In-situ cast concrete
2. Steel bars
3. Precast concrete column
4. Precast concrete beam
5. Precast concrete slab
6. Steel bars
7. In-situ cast concrete
8. Precast concrete beam
9. Precast concrete facade wall
10. In-situ cast concrete
11. Steel bars
12. Precast concrete slab
13. Precast concrete column
14. Steel bars
15. In-situ cast concrete
16. Precast concrete facade wall

Graphic 75
Constructive details

5.1.2. Novoa - Sandino System, Cuba, 1950



Graphic 76
Exterior view

Novoa - Sandino System. Cuba, 1950	
Type of structure	Mixed: skeletal and structural walls
Type of prefabrication	Open
Architect, inventor or designer	José María Novoa
Average areas per home (in square meters)	44, 60, 75
Number of housing units (on average, per building)	1 (individual homes)
Average height of the buildings (in number of stories)	2
Number of types of precast elements	14
Precast foundations for columns	1
Precast foundation beams for walls or mooring beams	1
Precast foundation slabs	0
Columns	2
Beams	2
Facade panels	2
Interior walls	2
Mezzanine slabs	2
Types of structural elements or slabs for rooves	2
Special elements (ducts, joints, common areas, awnings)	0
Stairs	0
Structural spatial cells	0
Types of joints	Assemblies, steel bars, cast concrete

Information taken from: Cabrera, 2011. Also taken from: Segre, 2005, p. 172.

Table 18
Novoa - Sandino System, Cuba, 1950.

System and building

The system was created by Architect José María Novoa en 1950. It was initially recognized as the Novoa System and was widely used in Cuba between the 1950s and the 1970s to build social housing quickly and with low costs. Later, it was known as the Sandino System. It is a mixed structural system that combines elements belonging to skeletal systems and structural walls. The precast concrete columns were designed to be assembled to the foundations, joined to the metallic reinforcements and stiffened with an *in-situ* casting of concrete. These columns (with an "H" section) were also designed as guides for the installation of the five precast concrete panels that conformed the height of the house, joined together by simple supports. Each of the panels weighed 65 kilograms, allowing them to be installed by two people and without the need of special equipment. The façade panels were joined by a simple support to the sub-floor and mezzanine slabs through the overlapping and mooring of their metallic reinforcements. At the end of the process, the joint between these modulated elements was reinforced every 0.94m with an *in-situ* casting of concrete at the knots. Its use permitted building one- and two-story residences, with an average area of 60 m² in rural settings in periods of four weeks (Segre, 2005, p. 172).

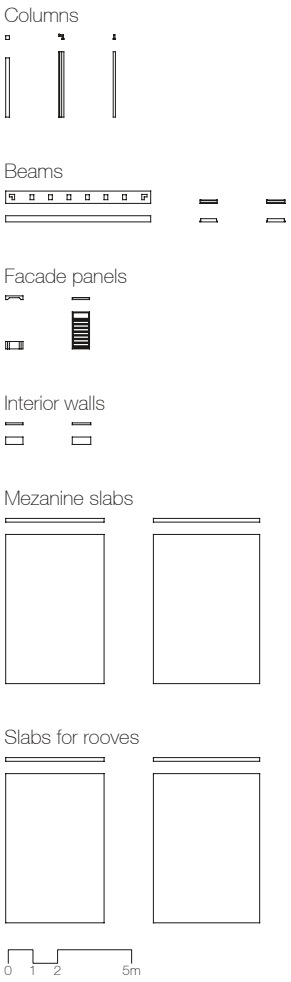
This System was widely used in rural areas because of the simplicity of the elements and the assemblies among them, which could be done with the participation of unskilled labor from the same sectors in which the housing complexes were built. These elements could be prefabricated at the project site, since the plant producing the structural elements was mobile and could be moved to different places. The simplicity of handling and the technical components of the mobile prefabrication plant, the easy handling of the structural parts and the reinforced-concrete closure panels that could be installed by one or two men, their ease of adaptation to different variable-plant schemes due to the reduced size of the basic 94-cm. structural module allows this system to be widely used even in rural environments with one- and two-story dwellings. The housing groups built with the system had at least 20 to 25 houses. The rural village of *Ciudad Sandino*, built in the 60s, had 3,000 homes and was intended to house 15,000 inhabitants.

The urbanizations assumed different configurations from linear schemes, paired houses along tree-lined streets that converged in social areas where community services were concentrated. This system facilitated self-construction processes in which relationships among the rural people were fostered to progressively promote the abandonment of isolated housing. Although the experimentation on this scale was restricted, the compaction of the housing blocks and the solution of apartments on two floors (some units in *Ciudad Sandino* were up to four-stories tall), the intermediate link between the traditional rural dwelling and the urban communities emerged after 1968.[26]

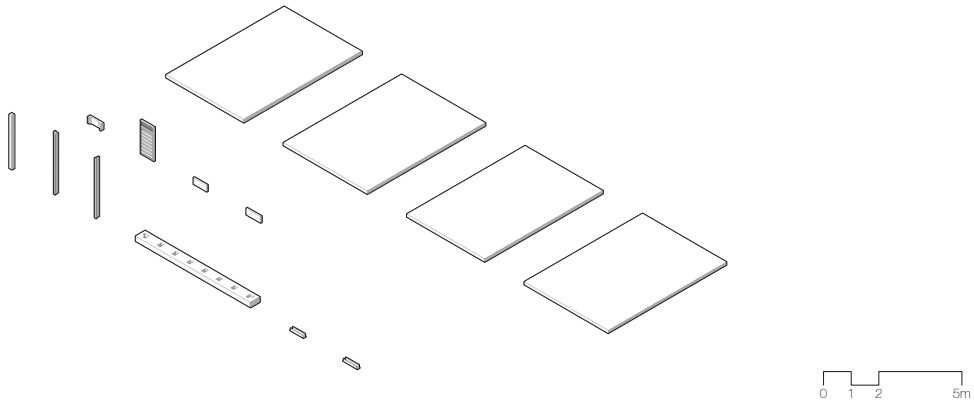
The flexibility of the system and its adaptability to different urban focuses allowed the design of dispersed housing (for example, the *Las Terrazas* Community in Pinar del Río) and compact urban-housing structures (such as the Managua Community, in the province of Havana). In some of them, cultivation plans were proposed for terraces; in others, the houses were adapted to the geometries and slopes of the land, forming a harmonious whole with the landscape.[27]

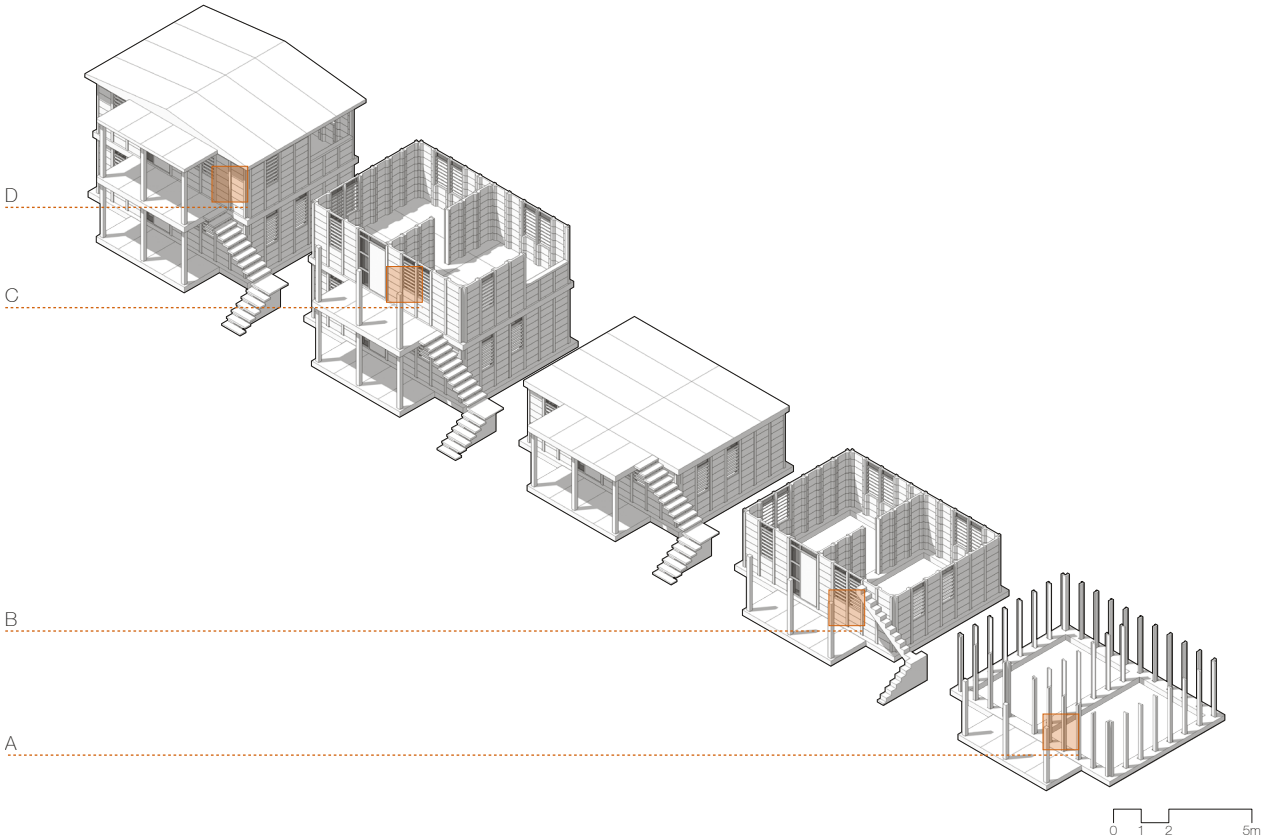
26 Amneris Vergani, "Ciudad Sandino" in: *Arquitectura / Cuba,* No. 334, Havana, 1965, p. 1

27 Segre, Roberto. Three decades of reflections of the Latin American habitat. National University of Colombia, 2005, 171 p.



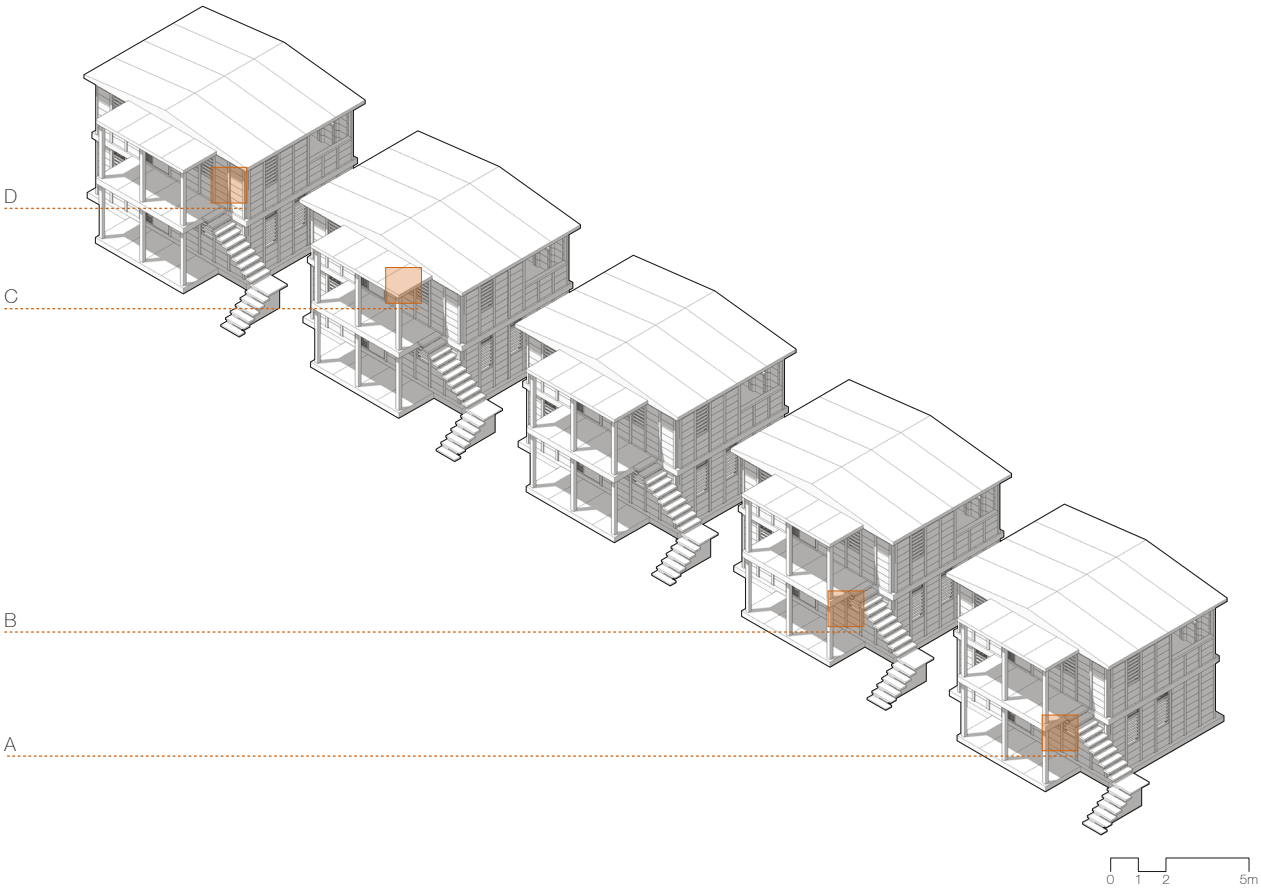
Graphic 77
Components: floor plans and façade





Graphic 78
Components: axonometry

Graphic 79
Construction process



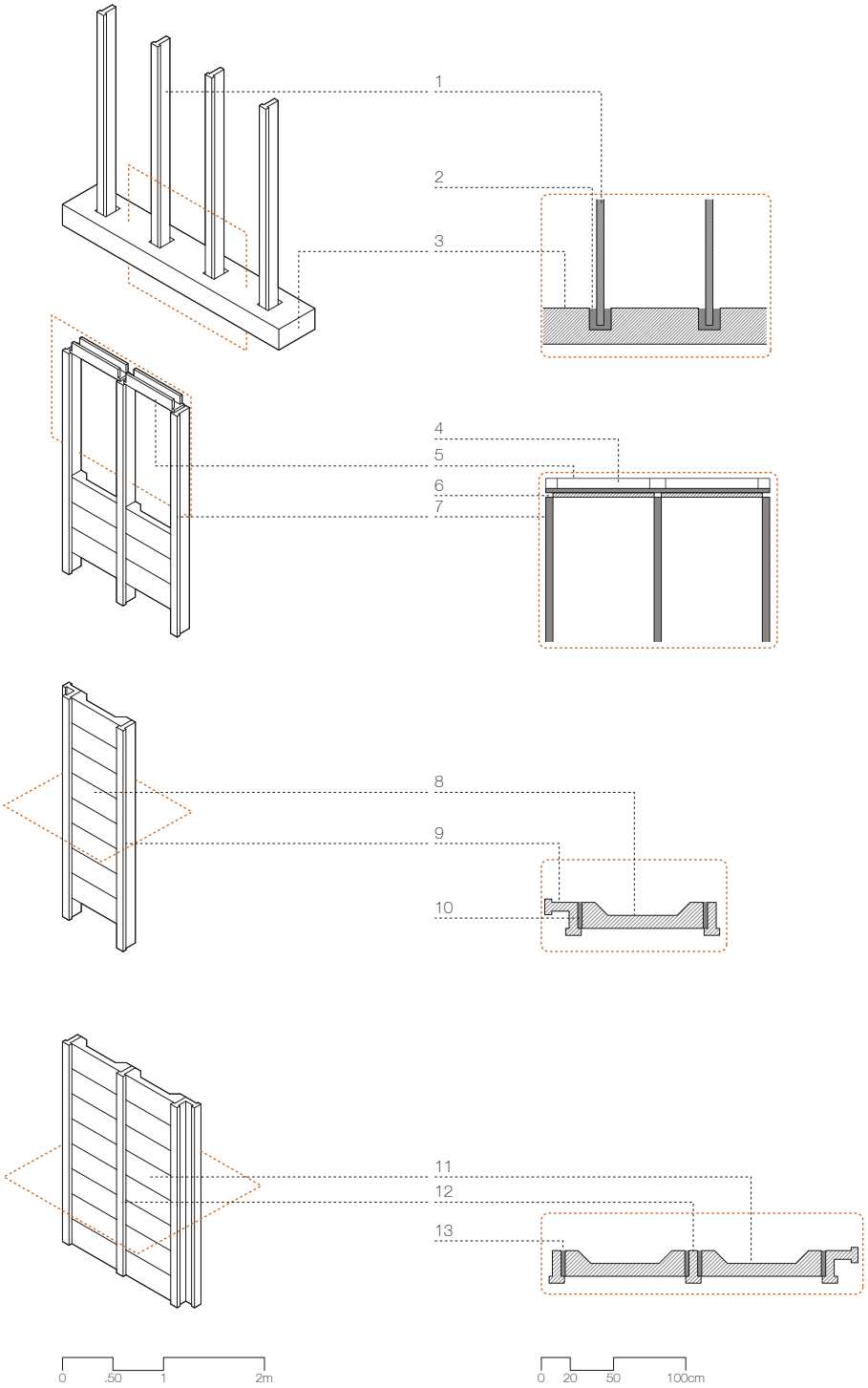
Graphic 80
The technical system and the architectural language

Advantages

- The proportions of the elements, their geometry and their joints allow this system to conform modular spaces, to be transported and used on flat and sloped terrains, to configure isolated or collective housing.
- The system can be used in different climatic zones (according to the use of open or closed panels) and for different cultural and social contexts, since part of the construction process involved the communities that will later occupy the homes.
- The configuration of the dwellings and the proportions of the elements allow disabled people to move around.
- A reduced number of structural parts permits different architectural designs and occupations of the territory. These elements have proportions that allow their handling on side without specialized tools: that are fixed by means of geometric fittings between the wall modules and columns, or with structural joints between foundations and columns with metal rods and concrete castings. The system resolves the joints with the use of conventional materials and tools, with the use of labor from the place where the project is located.
- The location of the columns and wall panels can be modified according to the characteristics of the topography, proposing different types of housing and responding to the context with different languages.
- The location of the structural wall modules allows cross-ventilation in interior spaces. The modular coordination allows different proportions in the living space with different designs according to the conditions of the context or the number of family members.
- The façade solutions can be related to the climatic or cultural conditions of the context, with the wishes or tastes of its inhabitants.
- Through the localization of non-structural division elements, the interior space can be modified according to the needs of its inhabitants. The wall modules can be manipulated by one or two people without the need for specialized tools.

Disadvantages

- This type of solution can lose efficiency in massive projects that require greater construction speeds. The structural elements should consider other large sizes, which allow the system to be used in urban settings and solve a larger number of houses in shorter time.
- The configuration of this system conditions the installation of elevators and ramps and functioned better in one- and two-story dwellings than in massive high-rise solutions.



1. Precast concrete column
2. In-situ cast concrete
3. Precast concrete foundation slab
4. In-situ cast concrete
5. Precast concrete beam
6. Steel bars
7. Precast concrete column
8. Precast concrete facade wall
9. Precast concrete column
10. In-situ cast concrete
11. Precast concrete facade wall
12. Precast concrete column
13. In-situ cast concrete

Graphic 81
Constructive details

5.1.3. G-57, Former Czechoslovakia, 1957



Graphic 82
Exterior view

G-57. Former Czechoslovakia, 1957.	
Type of structure	Structural walls
Type of prefabrication	Closed
Architect, inventor or designer	Bata: Bohumil Kula y Hynek Adamec
Average areas per home (in square meters)	35, 50, 65
Number of housing units (on average, per building)	40
Average height of the buildings (in number of stories)	5
Number of types of precast elements	33
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	20
Interior walls	5
Mezzanine slabs	8
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	0
Stairs	0
Structural spatial cells	142
Types of joints	Welded metal hooks

Information taken from: Alonso and Palmarola, 2014. pp. 240-241, 269, 334-335. Also taken from: Panelové Domy, n. d.

Table 19
Former Czechoslovakia, 1957.

System and building

In 1957, Architects Bohumil Kula and Hynek Adamec from the company Bata developed this series, conformed by structural walls that were specified for the design and construction of residential buildings with average heights of five stories. The most-repeated layout was the one that placed the groups of stairs between two housing units, thus reducing common areas and circulation (Panelové, n. d.). Different finishes could cover the exterior surface of the structural panels installed on the façades. These were a monolayer of ceramics or of paint applied on the concrete, allowing different appearances in the buildings. The joints between their components were specified through welded metal hooks, allowing the production of precast concrete panels without interior reinforcements. Given the efficiency in steel consumption and versatility in the façade finishes, this was the prefabrication series with the largest number of units built in the Republic of Czechoslovakia where the system was designed (Alonso & Palmarola, 2014, pp. 240-241).

The evolution of the structural-panel technology in the former Czechoslovakia was different from that in the former Soviet Union, as these elements reached other developments in dimensions, joints and finishes, while in the former Soviet Union, it was proposed that the typification and standardization of structural elements be extended. This series proposed the use of two structural axes in the housing buildings, located on the social area with a service area integrated into a bathroom without natural lighting or ventilation and a kitchen facing the exterior façade.

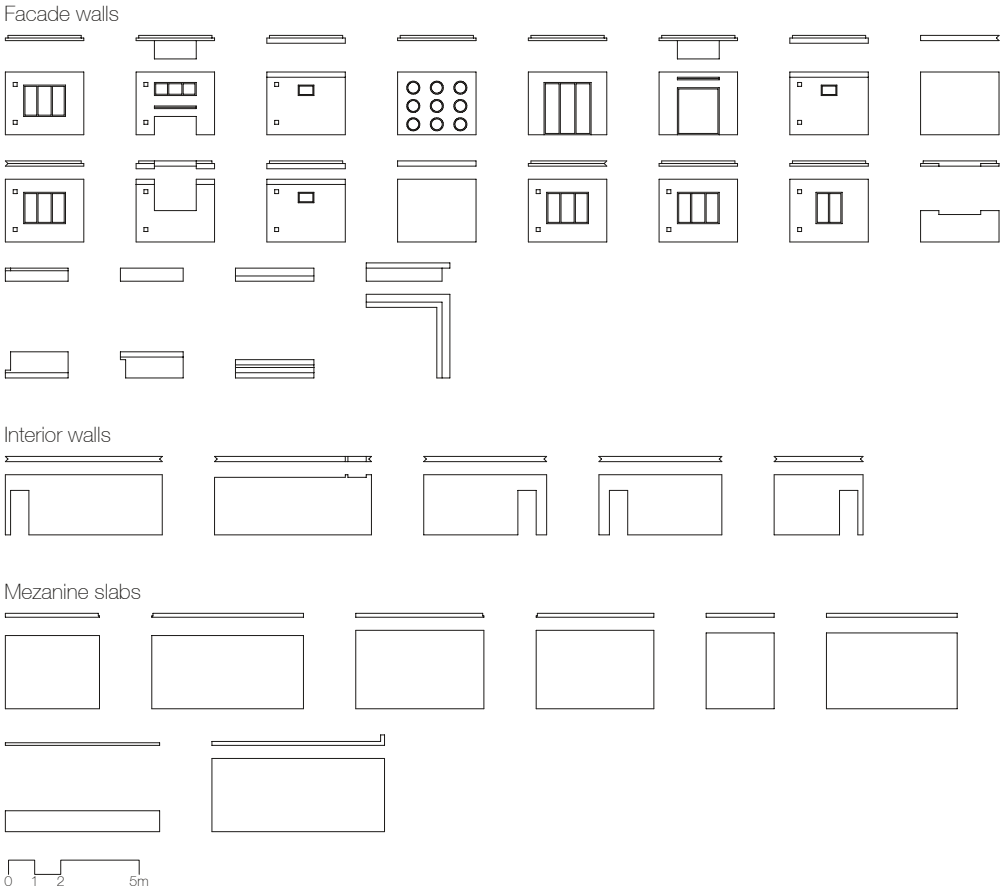
The buildings, with average heights between four and five stories, with architectural plans that modulated spaces with similar dimensions among them, reduced the number of types of panels necessary for the construction of the building. The façade designs were made under the principal of a universal orientation toward the principal fronts, which permitted the towers of dwellings to be located in different contexts, with open façades toward any of its longest sides, which was known as "universal orientation toward the front." The interior walls conceived as non-structural elements in other materials or in precast concrete were considered for the subdivision of the interior spaces.

The evolution of the system toward the series G-58 and G-59 allowed the use of lighter-weight structural and non-structural panels, prefabricated in concrete with cement and plastic mixtures or with industrial-process residues. Interior steel columns were also incorporated in these two series, to create greater flexibility in the interior space. The evolution of the system also experimented with the exterior expression of the buildings, including panels with different colors and finishings and windows with circular patterns.[28]

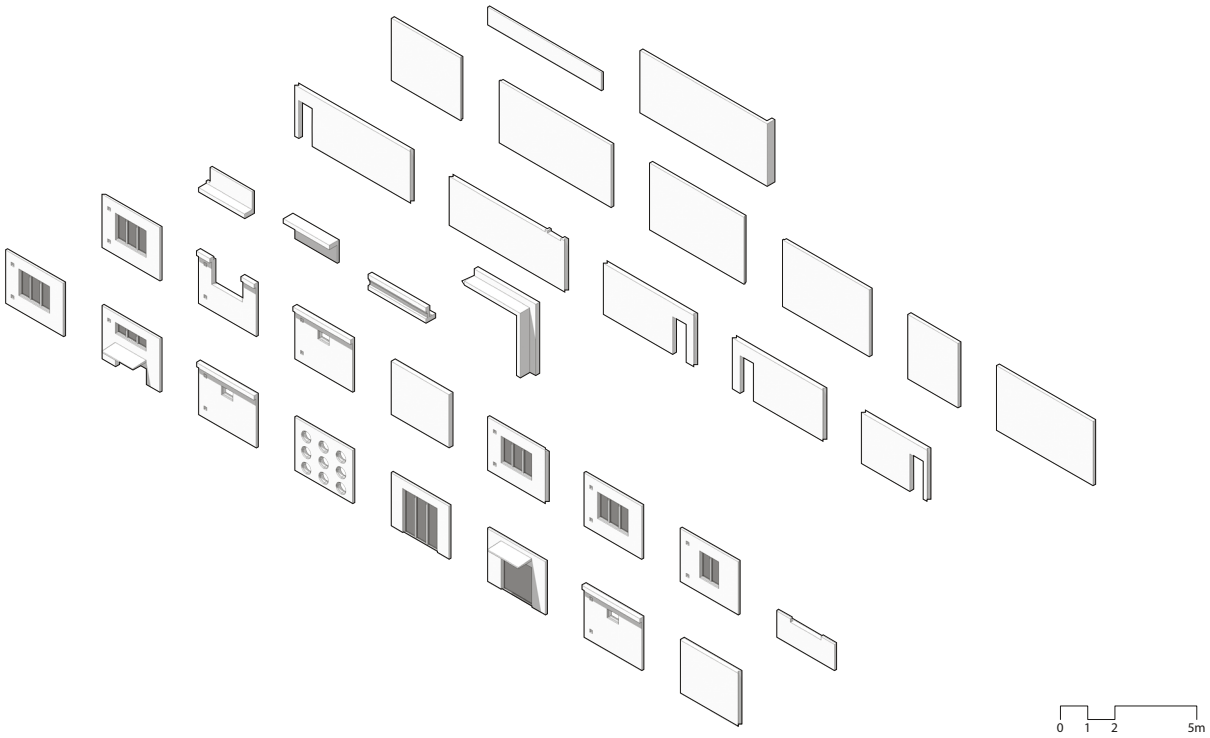
In 1961 in his book *New Techniques and Architecture in Czechoslovakia*, Karel Storch described the technology of the G-57 System as a structure of panels consisting of four elements: interior load panels, exterior load panels, partitions between spaces and floor slabs. The load panels formed a rigid system transversally and longitudinally. The stiffness and stability of the elements was resolved with weldings between the panels and a casting of concrete on these points. The floor panels were joined by welding and mortars in their longitudinal joints, forming a monolithic slab that spatially stiffens the structure.[29]

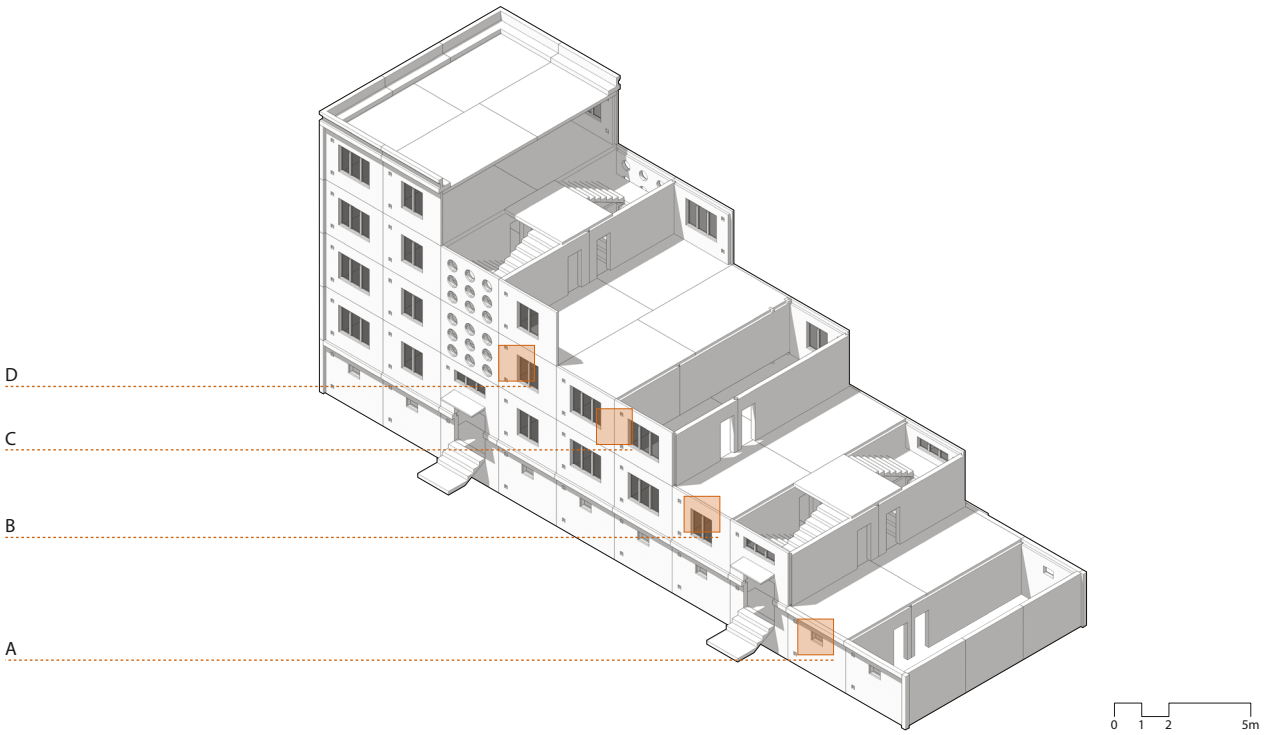
28 Zarecor, Kimberly Elman. Manufacturing a Socialist Modernity: Housing in Czechoslovakia, 1945-1960. University of Pittsburgh Press. 2011, 480 p.

29 Storch, Karel. New Techniques and Architecture in Czechoslovakia. Union of Architects of Czechoslovakia. 1961. 154 p.



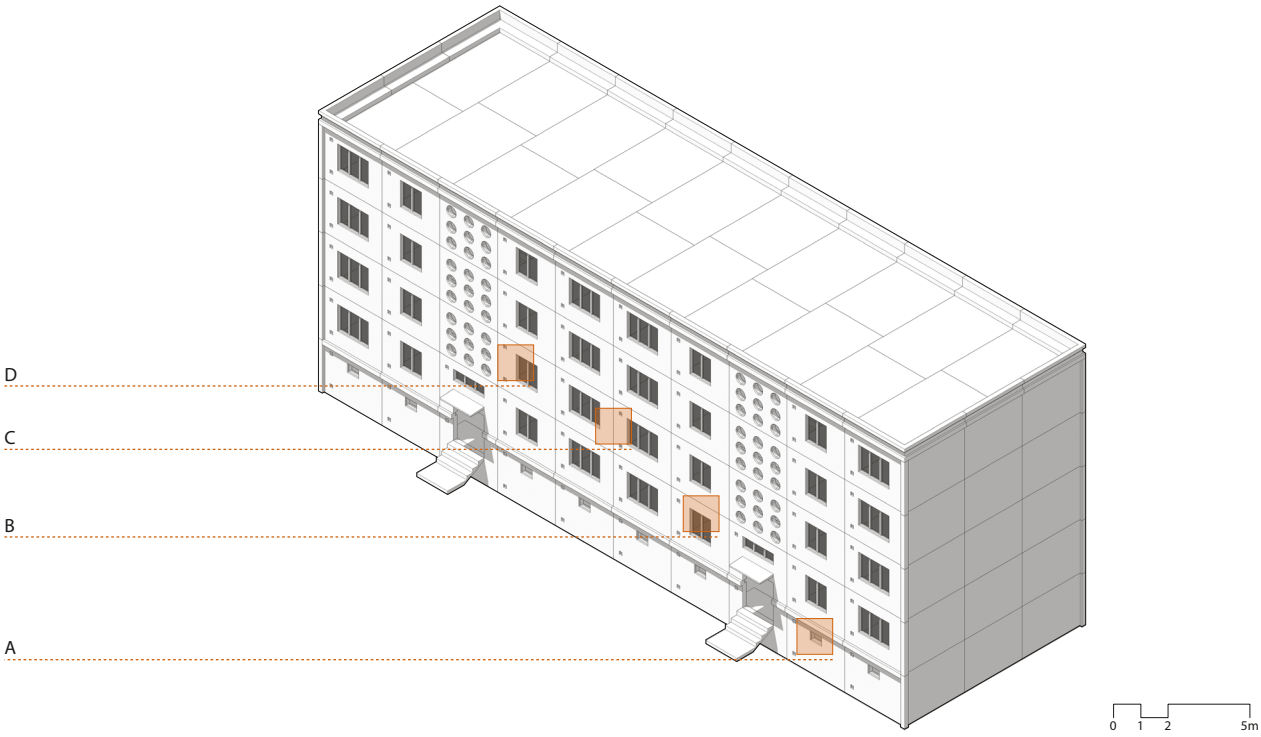
Graphic 83
Components: floor plans and façade





Graphic 84
Components: axonometry

Graphic 85
Construction process



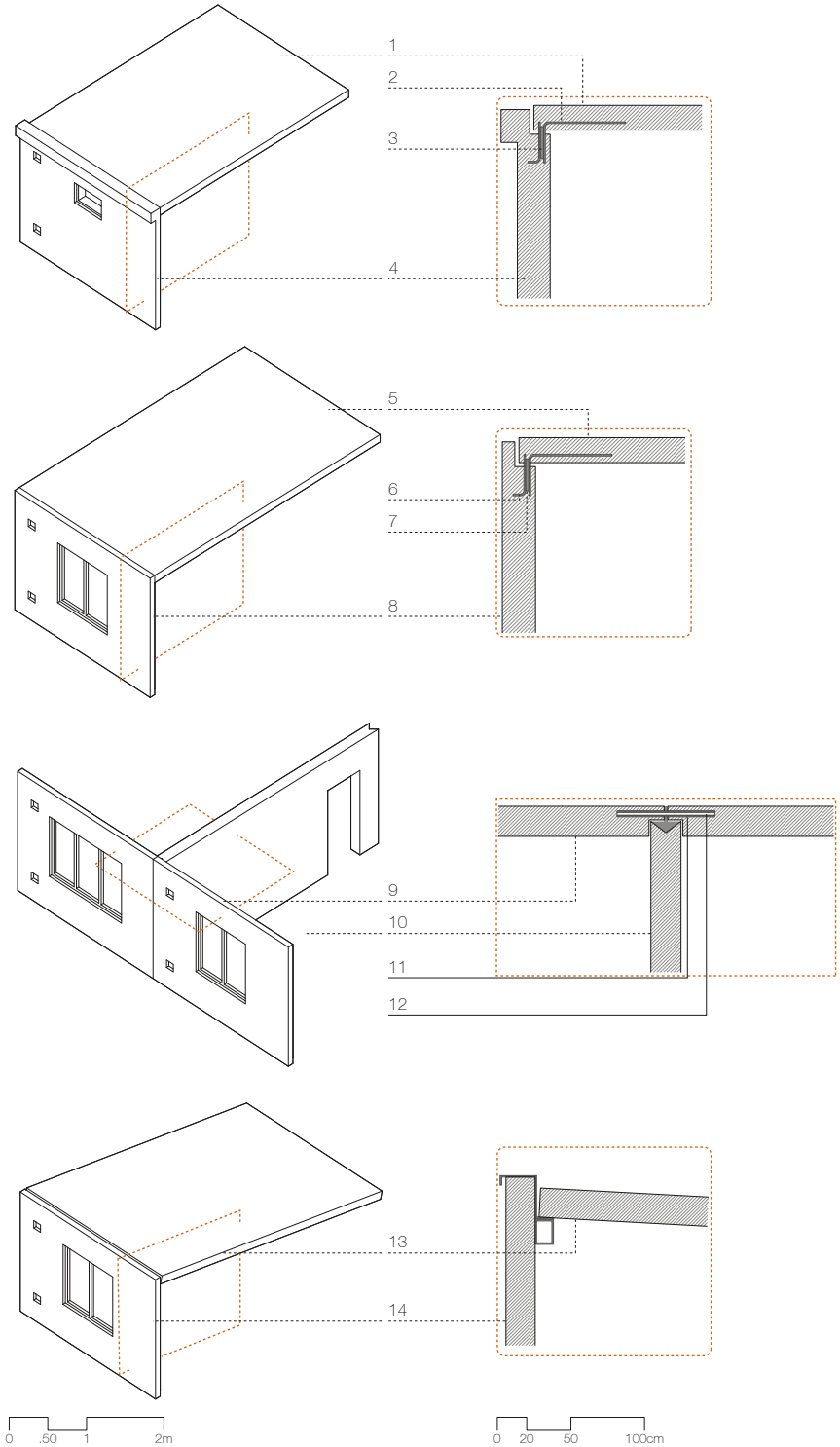
Graphic 86
The technical system and the architectural language

Advantages

- A defined number of façade panels, interior panels and slabs make up a modularly coordinated system that allows different designs.
- The types of panels and the assembly systems allow the massive and rapid construction of housing buildings.
- The dimensions of the panels allow them to be transported from the production plants to the building. They may be produced in the project site itself.
- The architectural designs, based on the geometries of the interior and exterior panels, make the building configuration have open façades toward its longest sides, which allows the project to be located with the most favorable visual or location conditions in different contexts.
- The system proposes non-structural divisions that allow modifying or adapting the interior space to the needs of its inhabitants.

Disadvantages

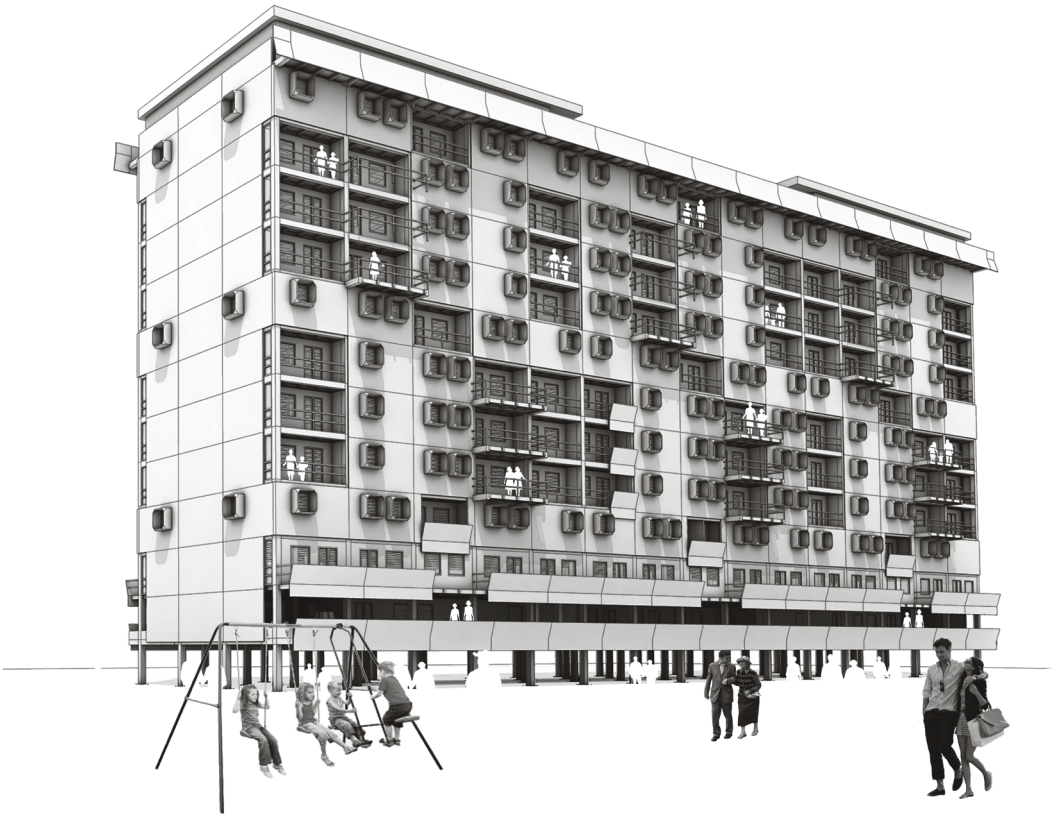
- The first floors, which are accessed by stairs, make the homes inaccessible to people with disabilities.
- The system consists of individual slabs and panels that must be joined one to another in the process of constructing the building. To improve efficiency in the installation process, the largest possible number of joints must be solved from the material-production plant and reduce their quantity to reduce time and processes at the assembly site.
- The system proposes the possibility of considering different typologies of façade panels. However, because these are structural panels, the modifications that can be made are geometric, or in the color or texture of their finishings. The building, which conditions its structure to make it part of the façades, loses possibilities of expression and respond to the context in different ways.
- The structural and spatial configuration of the interior space presents a bathroom unit without natural lighting or ventilation, with a kitchen facing the façade, but without relation to the social area.
- The aesthetics of the building can be modified according to the finishes of its façade panels, but since they are structural elements, their geometry nor their location on the façades cannot be modified, which limits the beauty of the project to the correct location of the panels or their design, to the variants in their geometry or to the characteristics of their finishes.
- Even when the non-structural interior divisions allow the modification of some spaces of the dwelling, the presence of structural elements in the façades means that the building has a limited number of responses of its language to the social, cultural and environmental contexts.



1. Precast concrete slab
2. Metal hooks
3. Welding
4. Precast concrete facade wall
5. Precast concrete slab
6. Metal hooks
7. Welding
8. Precast concrete facade wall
9. Precast concrete facade wall
10. Precast concrete interior wall
11. Metal hooks
12. Welding
13. Precast concrete slab
14. Precast concrete facade wall

Graphic 87
Constructive details

5.1.4. IMS System, Former Yugoslavia, 1957



Graphic 88
Exterior view

IMS System. Former Yugoslavia, 1957.	
Type of structure	Skeletal or structural walls
Type of prefabrication	Open
Architect, inventor or designer	Institute for the Testing of Materials (IMS)
Average areas per home (in square meters)	From 38 to 95
Number of housing units (on average, per building)	From 12 to 120
Average height of the buildings (in number of stories)	From 3 to 25
Number of types of precast elements	34
Precast foundations for columns	2
Precast foundation beams for walls or mooring beams	2
Precast foundation slabs	0
Columns	2
Beams	2
Facade panels	7
Interior walls	5
Mezzanine slabs	8
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	4
Stairs	2
Structural spatial cells	0
Types of joints	Post-tensioning joints

Information taken from: Petrovic, 2000, p. 5. Also taken from: Dimitrijevic and Gavrilovic, 2000, pp. 3-12.

Table 20
IMS System, Former Yugoslavia, 1957.

System and building

Developed in 1957 by Engineering Professors Branko Zezelj and Bosko Petrovic in the Institute for the Testing of Materials (IMS) of Belgrade in the former Yugoslavia, this skeletal system also used some structural walls. Their designs specified columns, beams, slabs and façade panels or precast, pre-tensioning interior walls, which increased their strength before the installation process. When the foundations of the building are completed, the precast columns are anchored to them and are fixed with the help of clamps. The post-tensioned joints in two directions, between the columns and the floor slabs or between the columns and edge beams, were specified with *in-situ* cast concrete fillings to increase the stiffness of the joints. After this was done, the clamps that held the columns were loosened. Subsequently, the support capitals were moved to the upper floor and the operation was repeated. With the IMS prefabrication series, buildings up to 25 stories were built using structural and non-structural elements from other construction techniques, which emphasized their open nature (Petrovic, 2000, pp. 4-8).

Between 1960 and 1975, the IMS System was used for the annual construction of an average of 7,000 apartments in the former Yugoslavia (Jovanovic, Grbic & Petrovic, 2004, pp. 179-183). Since then, it has had new technical developments, which have allowed it to improve efficiency in the production of the prefabricated elements and in their installation process. In Eastern Europe, Western Europe and some African countries, the IMS System has been successfully replicated for high-rise housing (Dimitrijevic, 1994, pp. 4-12).

In Latin America, this system was also used for the modular, rapid and economic construction of social housing. In the 70s and 80s in Cuba, it was used from a structure of separate columns, each 4.2m. Prefabricated columns up to three-stories high and slabs lightened in precast concrete were used and joined together through post-tensioning processes.

The floor slabs were finished with edge beams or cantilevered slabs. The primary elements of the system (columns, beams and prefabricated plates) were compatible with other secondary elements (bathroom and kitchen units, partition walls, veneers and other finishes), which could be built with different materials or belong to other construction systems.

The evolution of the system allowed the design of new structural and façade elements, maintaining among them the post-tensioned joints. The elements could be built *in situ* or in material-production plants. The versatility of the system allowed the design of different housing typologies from the same structural elements, which marked a difference with the different systems used in Europe after the II World War, which, from the same pattern of designs, repeated the housing units and their languages located in different contexts.[30]

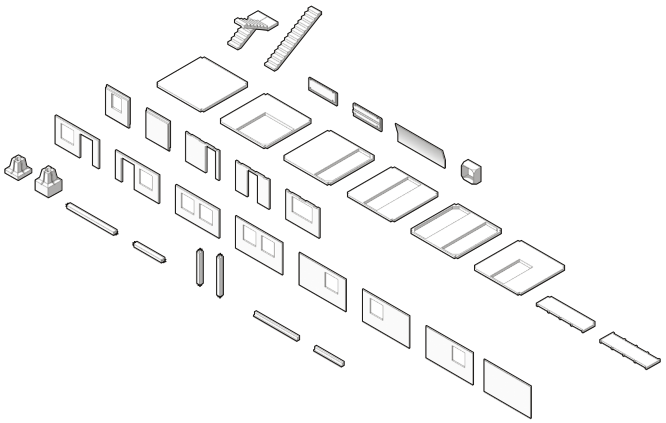
In the IMS System, the structural elements were arranged according to the architectural requirements. From the constructive point of view, it was desirable to have double symmetry in the design, especially in seismic zones, although the system allowed the asymmetric distribution of the partition walls of the stairs. The IMS Institute in Belgrade stated that with this system, housing of different costs and heights had been built in Europe and in developing countries as well as commercial, pubic or industrial buildings. The versatility of the system allowed it to be used in different contexts and with different uses.[31]

30 Dimitrijevic, Radovan. "Prestressing technology in housing – Yugoslav experience", XII FIP Congress, IMS Institute Proceedings, 2 (Vol. XXI, 1994), Belgrade.

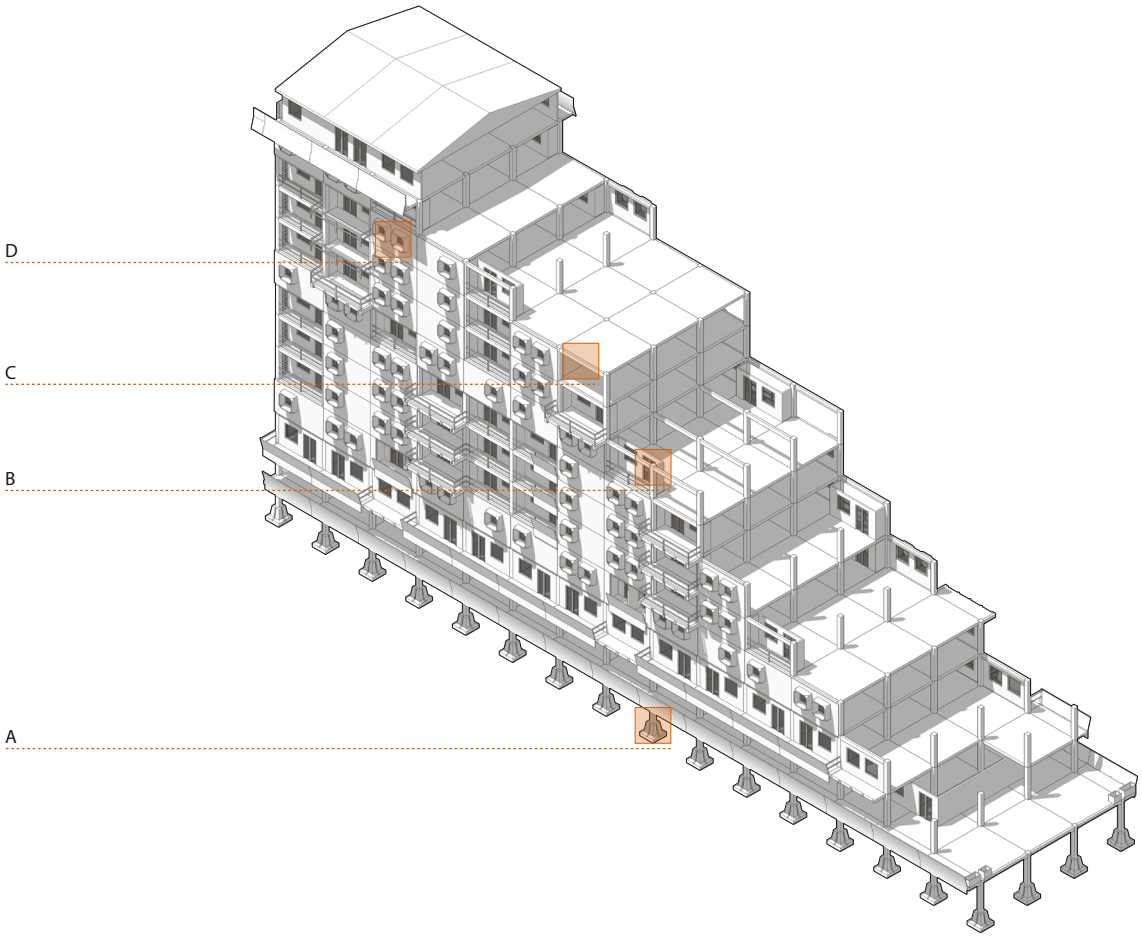
31 Dimitrijevic, Radovan and Gavrilovic, Branka. *Precast prestressed concrete skeleton in contemporary building - IMS system*. Belgrade: IMS Institute, 2000.



Graphic 89
Components: floor plans and façade



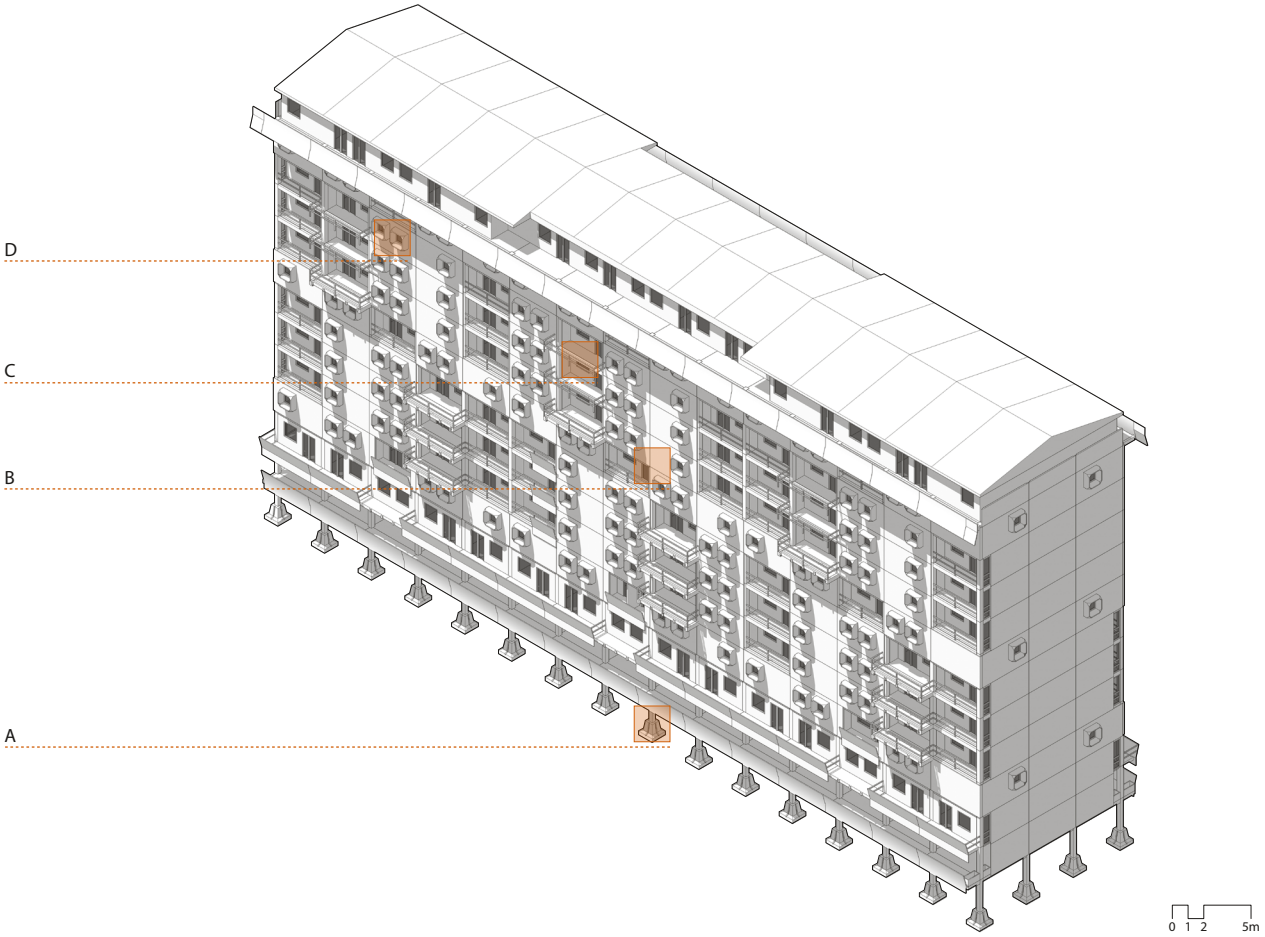
0 1 2 5m



0 1 2 5m

Graphic 90
Components: axonometry

Graphic 91
Construction process



Graphic 92
The technical system and the architectural language

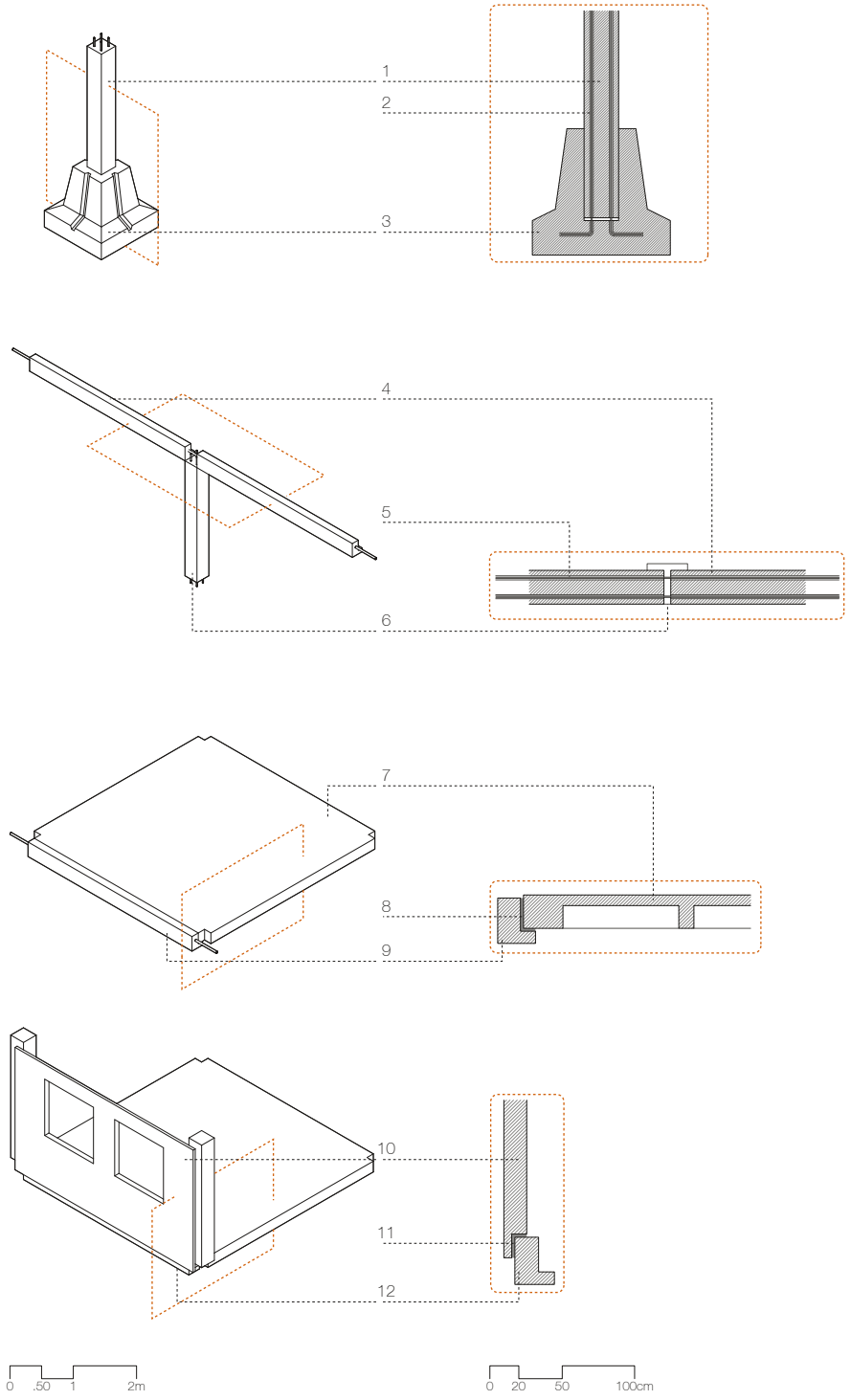
Advantages

- The system operates with criteria of modular coordination through its primary structural elements (columns, beams, slabs, walls and stairs). Secondary elements, such as façade panels or partition walls, can be specified in other materials.
- Due to the weights of the elements, the versatility of their use, adaptability to different contexts and costs, housing constructions have been built in Europe, Africa and America.
- According to the IMS catalogue[32], the maximum weight of the precast elements of the system is seven tons. This condition allows access to urban and rural settings, with cargo vehicles with capacities and proportions adjustable to different contexts. Given the conditions of the production technology of these elements, they can also be produced at the work site.
- The geometries of the support structure and the configuration of various buildings with the same structural elements allow the system to adapt to different geographic, cultural and climatic contexts.
- The system allows the localization of houses on the first floors and through elevators on the upper floors. The doors and circulation areas permit access to the different spaces that comprise the house.
- The designs of the structural elements are presented with reduced variants to control the number of alternatives and propose their union through post-tensioning cables, which are continuous reinforcements that integrally stiffen the support structure. These post-tensioning cables are installed through workable tools that can be operated in the construction process and that ensure efficient fixation among the structural elements. Reinforcements through the post-tensioning process reduce the need for castings in the joints, weldings or moorings of metallic elements.

Disadvantages

- The foundation systems for the columns generally are deep elements, which increases costs and time and reduce the efficiency in the social-housing building process. The load-bearing capacity of the terrains available in Antioquia is not high and the soils available have the least resistant in the table of values.

32 IMS RD Institute Belgrade. IMS Building Technology: Precast Prestressed Concrete Skeleton in Contemporary Building. Belgrade. Accessed May 31, 2017; available at www.institutims.co.yu.



1. Precast concrete column
2. Post-tensioned strand
3. Precast concrete foundation
4. Precast concrete beam
5. Post-tensioned strand
6. Precast concrete column
7. Precast concrete slab
8. Joint
9. Precast concrete beam
10. Precast concrete facade wall
11. Joint
12. Precast concrete beam

Graphic 93
Constructive details

5.1.5. 1-335, Former Soviet Union, 1959



Graphic 94
Exterior view

1-335. Former Soviet Union, 1959.	
Type of structure	Mixed: Structural walls and skeletal system
Type of prefabrication	Closed
Architect, inventor or designer	Vitaly Lagutenko and the DSC Soviet System
Average areas per home (in square meters)	30, 45, 60, 75
Number of housing units (on average, per building)	40
Average height of the buildings (in number of stories)	5
Number of types of precast elements	42
Precast foundations for columns	2
Precast foundation beams for walls or mooring beams	4
Precast foundation slabs	4
Columns	3
Beams	4
Facade panels	7
Interior walls	4
Mezzanine slabs	7
Types of structural elements or slabs for rooves	8
Special elements (ducts, joints, common areas, awnings)	0
Stairs	2
Structural spatial cells	0
Types of joints	Assemblies

Information taken from: Alonso and Palmarola, 2014. pp. 198-199, 248, 286-287.

Table 21
1-335, Former Soviet Union, 1959.

System and building

Conceived in the former USSR, in 1959, the 1-335 mixed structural system combined precast concrete elements from the system of structural walls with elements belonging to the system of skeletal structures. With this series, residential buildings on an average of five stories tall were constructed between 1959 and 1966. The assembly of the panels with the beams and columns accounts for the complexity of this mixed system, articulated through metal hooks joined by welding and *in-situ* cast concrete. Due to the problem of thermal insulation between the construction elements, it was recognized as the most unfortunate of all the prefabrication series of residential buildings developed under the government of Nikita Khrushchev. Subsequently, the 1-335K, 1-335A, 1-335AK and 1-335D series were produced until the end of the 1980s. There were at least 26 variations, but none of them included elevators or garbage chutes, which generated adverse conditions in the occupation of the houses (Alonso & Palmarola, 2014, pp. 198-199).

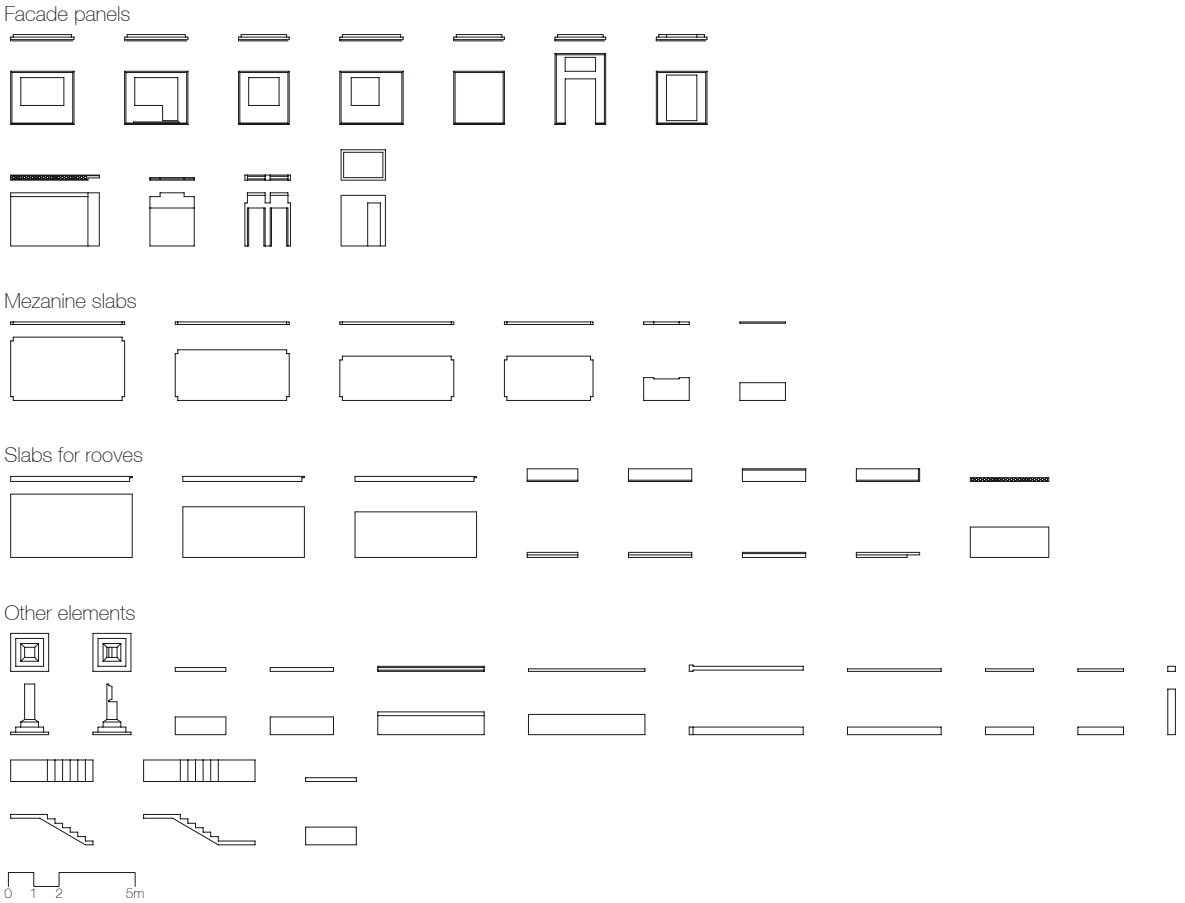
Having analyzed the advantages and disadvantages of the system, Soviet prefabrication continued to produce large panels and aimed to continue the search for an architecture that would achieve greater efficiency, showing a certain lack of interest in national artistic traditions and the historical styles of Russian housing.

The main objective was to establish solutions to design problems through new technological advances in the production of large-scale prefabricated elements, such as façade panels and floor slabs, which were combined with elements belonging to skeletal systems, such as precast-concrete columns and beams. The repetitiveness of the structural elements, which formed façades and interior spaces, served to form complete neighborhoods that were built with this system and over time which were partially modified by their inhabitants with interventions in their façades or in the non-structural elements of the interior space.

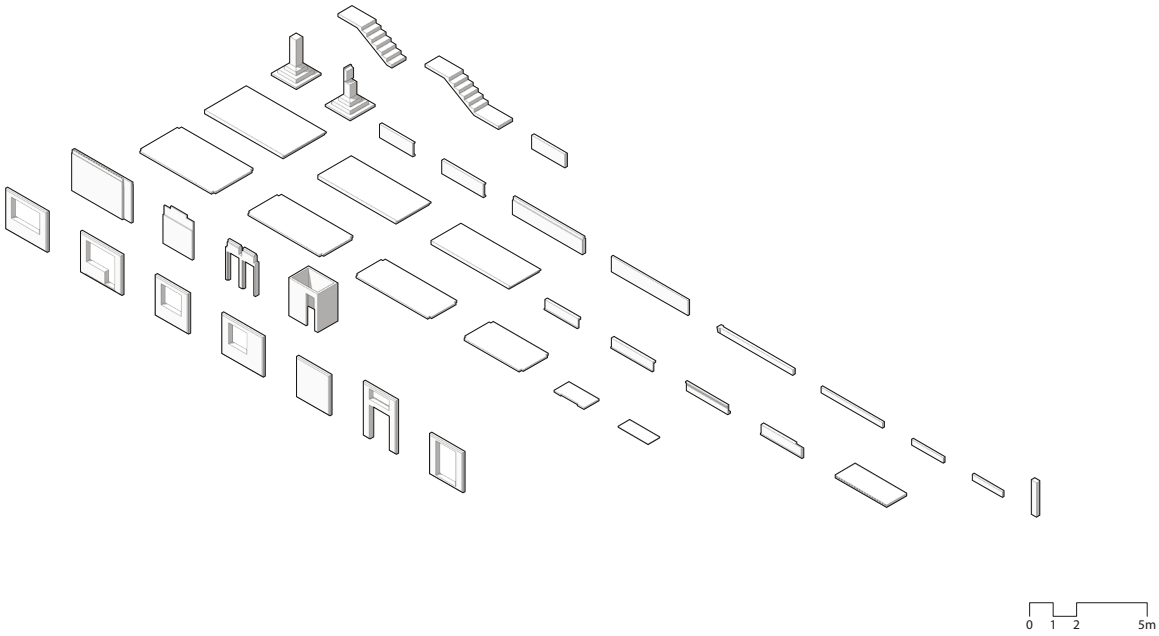
In this system and its subsequent developments, three principles associated with the efficiency that was wanted to be transmitted from the designs and the construction processes were evidenced: an increase in productivity, the promotion of equality among the working class, and satisfaction of the desire of the workers to own a home. In this context, where artistic speculation and political debate were united, the diversification of language and the typological richness of these houses was a relatively unexplored field in its subsequent developments.[33]

The largest number of buildings constructed with this series of prefabrication is found in St. Petersburg because its climatic conditions are not as extreme as those of Moscow. There is a structural rehabilitation program for these buildings and others have been demolished.

33 Alonso, Pedro. From Abstract to Concrete (*De Abstracto a Concreto*). ARQ 82: Manufacturing and Constructing. December 2012. Accessed May 31, 2017; available at: http://www.edicionesarq.cl/2014/de-abstracto-a-concreto/.



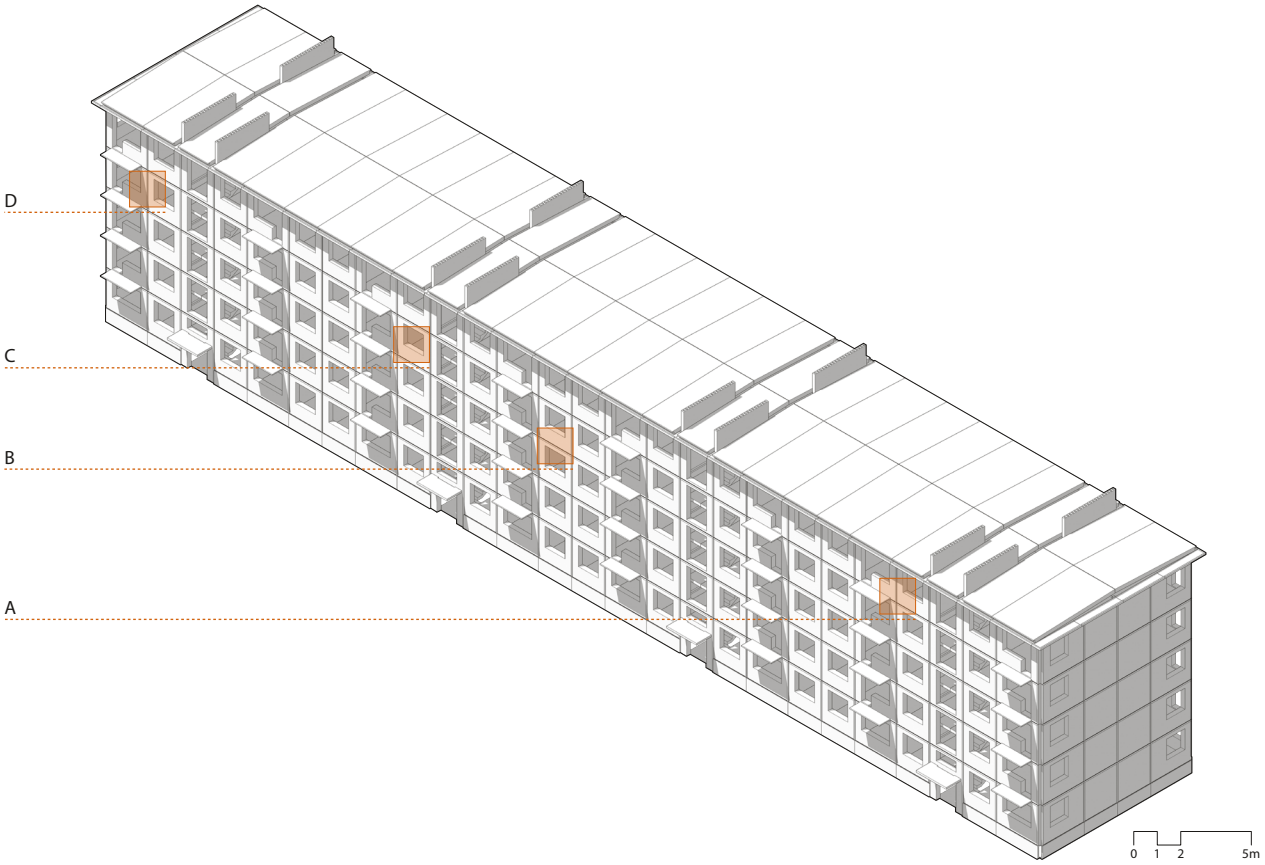
Graphic 95
Components: floor plans and façade





Graphic 96
Components: axonometry

Graphic 97
Construction process



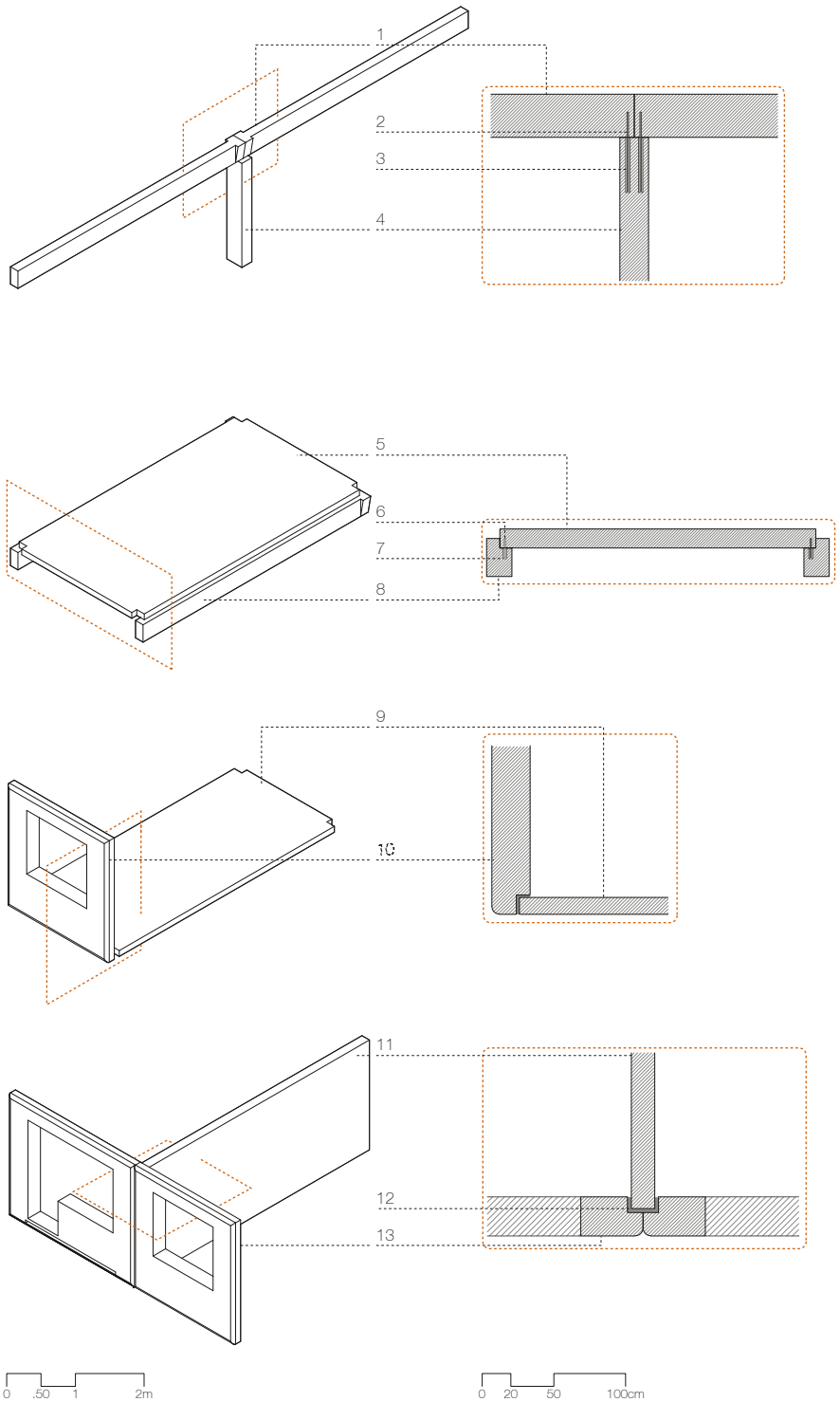
Graphic 98
The technical system and the architectural language

Advantages

- Each one of the elements has dimensions and proportions compatible with each other, which generated dimensional coordination among the floor slabs, façade panels, interior walls, columns and beams.
- The dimensions of the panels, slabs, beams and columns allowed their transport from the plant to the worksite and the construction of some of these elements *in situ*.
- The joints were made through geometric assemblies and cast in concrete that served to stiffen them. This permitted combining load-bearing wall systems with girder elements, which reduced the system costs compared to other prefabrication systems previously used. The installation speeds were also more efficient that those of other systems, due to the simplicity of their joints, which allowed the massive construction of buildings controlling the costs and their time.
- Some parts of the interior spaces could be modified by the users once they occupied the dwellings. All the interior walls were not conceived as structural elements, which allowed the variation in the program of houses, according to the needs of the users.
- Incrementality in the area of the homes was not possible due to its height configuration, but the interior space was modified by replacing, modifying or eliminating some of its lower divisions, originally conceived as non-structural elements.

Disadvantages

- The technical characteristics allowed the system to be built in other contexts, but without fully adapting to its climatic conditions or to the urban characteristics of the setting.
- In different contexts, the system did not have the same response in environmental or bioclimatic terms because of the joints between its walls and the characteristics of its insulations. Most of these buildings were constructed in St. Petersburg, where climatic conditions were less extreme than in Moscow.
- These buildings were fundamentally conceived in groups of up to five stories, in which elevators were not installed, which restricted the possibility of some people to access each of their levels.
- The system was conceived for contexts in which temperatures were not very extreme. Interior insulations and air leaks in their joints saw most of the houses being built in St. Petersburg, where climatic conditions were not as extreme as in Moscow.
- The structural panels of the façade had few variations among them, which generated similar languages for the system in different contexts.



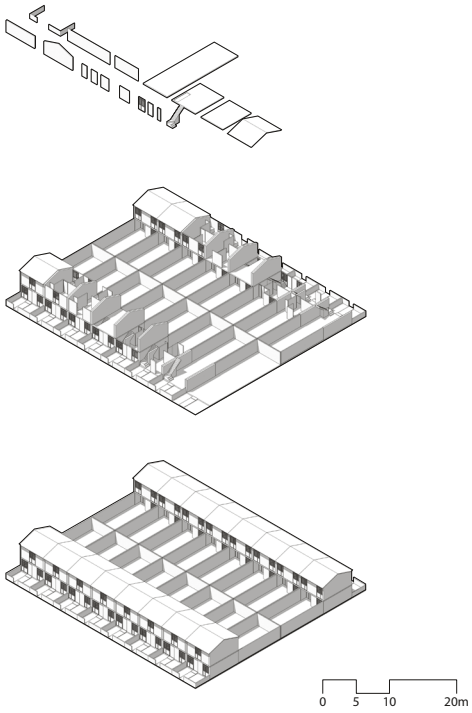
1. Precast concrete beam
2. Steel bars
3. In-situ cast concrete
4. Precast concrete column
5. Precast concrete slab
6. Steel bars
7. In-situ cast concrete
8. Precast concrete beam
9. Precast concrete slab
10. Precast concrete facade wall
11. Precast concrete interior wall
12. In-situ cast concrete
13. Precast concrete facade wall

Graphic 99
Constructive details

5.1.6. Other projects

5.1.6.1. Muzú Neighborhood Unit (Unidad Vecinal Muzú). Bogotá, Colombia, 1949

The Muzú Neighborhood Unit, designed with the system of structural walls by Architect Jorge Gaitán Cortés and the Institute for Territorial Credit's (*Instituto de Crédito Territorial*, ICT) architectural team, has the technical advice of Álvaro Ortega and Engineer Guillermo González Zuleta. Since 1946, Architect and Inventor Alvaro Ortega had adapted the "vacuum concrete" patent to the local context, which increased the resistance of this material and reduced the consumption of cement (Piñeiro, 1953, as cited in Escovar, 2006, p. 89). The system consisted of applying a vacuum to the cast concrete mixture through an air pump (Escovar, 2006, p. 89). With this principle, precast elements for the construction of some social housing in Colombia were designed and produced (Villazón, 2001, as cited in Escovar, 2006, p. 89). This residential complex was made up of 1,216 two-story homes. The urban proposal considered modules with four, six and eight houses grouped in courtyards, with gardens and exterior green areas, which reduced the initial occupancy density. In order to improve and optimize the social housing construction resources, the project experimented with the combination of precast concrete with different materials, such as ceramic pieces to increase their resistance and reduce thicknesses in walls, mezzanines and rooves. The precast elements were joined together with metal bars and *in-situ* cast concrete. The ITC proposed the progressive use of precast concrete structural and non-structural elements for its neighborhood units since that moment.

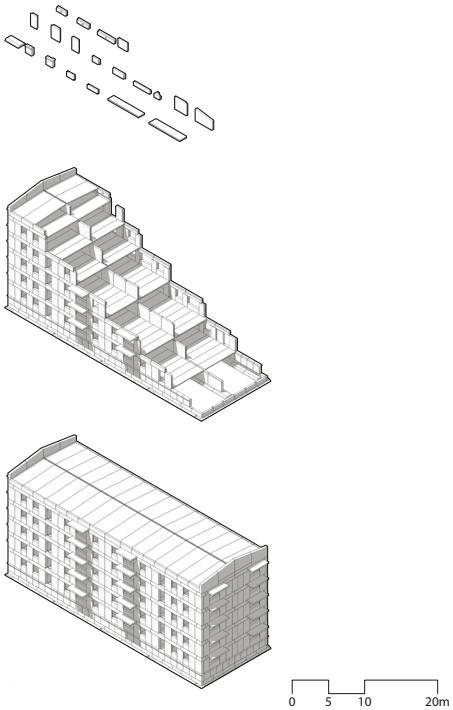


Graphic 100
Muzú Neighborhood Unit (Unidad Vecinal Muzú). Bogotá, Colombia, 1949. Construction process

5.1.6.2. 1-510, Former Soviet Union, 1957

Developed by SAKB, the Specialized Architectural and Design Institute, this series formed by structural walls was produced and used in the former USSR between 1957 and 1968 for the construction of residential buildings with average heights of five stories. It was used for worker housing in Moscow with typologies of one, two and three rooms, and with areas between 32 and 55 m². Each one had a balcony beginning on the second floor.

The interior walls were not structural and, therefore, they could be removed, moved or modified. The façade panels were specified with mineral wool in their interior for thermal insulation. The union between the prefabricated elements was designed with metallic connectors stiffened with *in-situ* cast concrete between the joints. In a period of eleven years, approximately 3.7 million m² were built for working-class residences in the former USSR and some Eastern Europe countries (Alonso & Palmarola, 2014, pp. 194-195).



Graphic 101
1-510, Former Soviet Union, 1957. Construction process

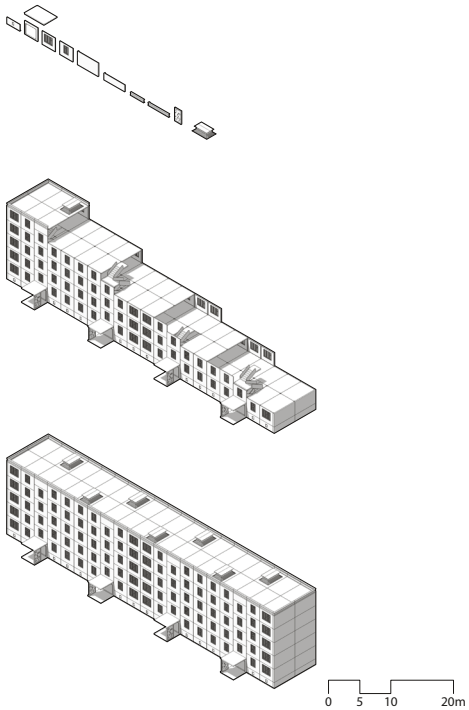
5.1.6.3. K-7, Former Soviet Union, 1958

After four years of experimentation, Engineer Vitaly Lagutenko, the chief planner of Moscow since 1956, designed –together with the Soviet technical group DSC (ДСК)– the K-7 large-scale industrialized construction process. This series, consisting of structural walls, was characterized by its laminar construction, prioritizing the structural collaboration between the flat and lighter elements than those used by the previous series of prefabrication, in order to distribute the loads in the least possible amount of material. The joints between the elements were made through welded metal bars that were concreted to stiffen the joints.

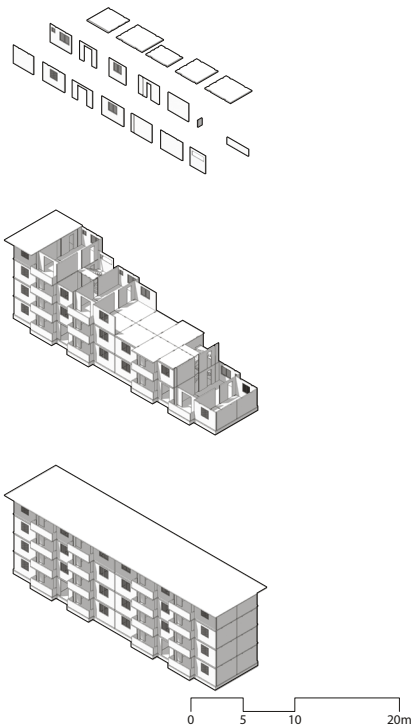
Almost all the buildings constructed with this system were five-storeys tall because Soviet health and safety regulations established this when the housing units did not have an elevator. The typical apartments of the K-7 series were conceived with a total area of 30 m² (one room), 44 m² (two rooms) and 60 m² (three rooms). The bathrooms and kitchens were produced in industrial plants and later connected to the installations arranged in the construction (Condo Madness, n. d.). Also known as *Khrushchyovka*, this type of apartment building was replicated some 70,000 times in the former USSR and in some Eastern European countries (Alonso & Palmarola, 2014, pp. 192-193).

5.1.6.4. Large Panel IV (Gran Panel IV). Cuba, 1959

From 1959 to 1969, Cuba's government began experimenting with and developing reinforced precast concrete panels in Cuba with the assistance of Soviet technicians. The Large Panel IV was the first industrialized system conceived and produced in Cuba. It was made up of structural walls and was used to build four- and five-story residential buildings. To adapt it to the Cuban context, the original thickness of the façade panels had to be reduced to 12cm, almost a third of the original thickness of the panels produced in the USSR. The most repeated architectural distribution was the one that arranged the volume of the stairs in the middle of two housing units, reducing common areas and allowing to reach each one of the apartments directly. Inside, the service areas (kitchens and bathrooms) were located beside the common areas to make the routes of electrical and hydro-sanitary installations more efficient. The union between the structural prefabricated elements was made by metallic connectors and concrete castings to stiffen the joints. The highest point was reached in 1970, when 22 factories produced nearly 10,750 homes. However, the buildings constructed with the Large Panel IV were widely criticized for the quality of their construction, for the repetitive language of their façades and for the lack of structural continuity between the exterior and interior panels with the mezzanine slabs (Alonso & Palmarola, 2014, pp. 206-207).



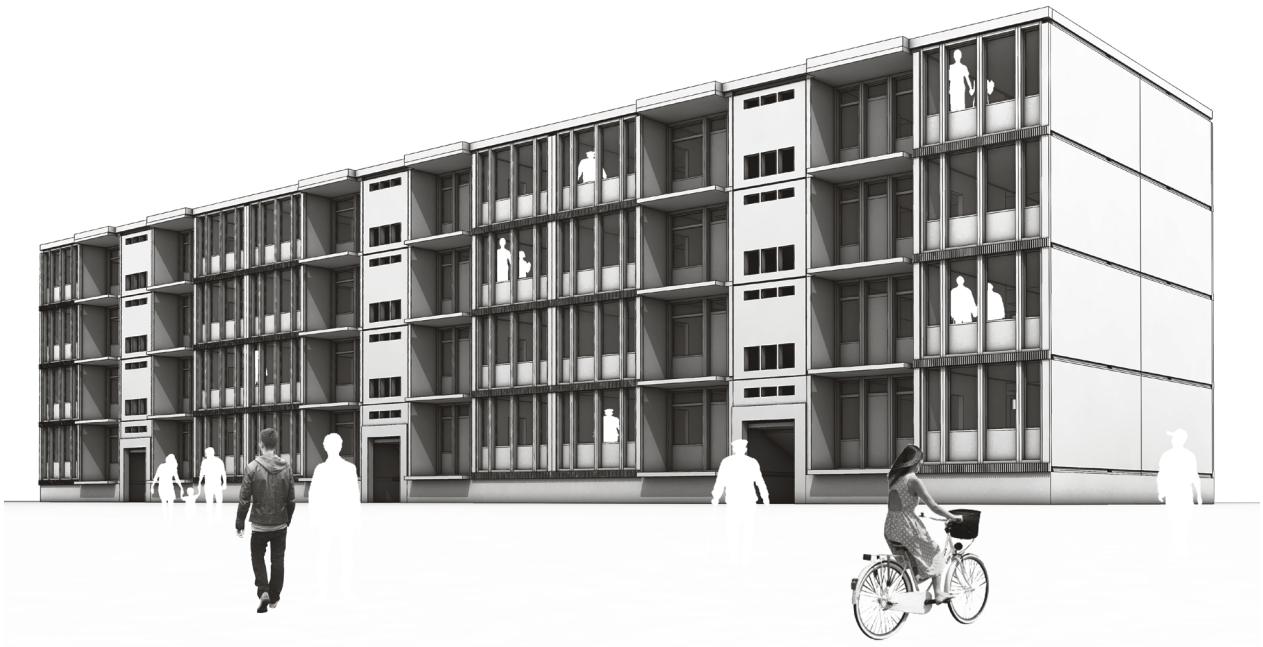
Graphic 102
Large Panel IV (Gran Panel IV). Cuba, 1959. Construction process



Graphic 103
Large Panel IV (Gran Panel IV). Cuba, 1959. Construction process

5.2. 1960s

5.2.1. VAM, The Netherlands, 1961



Graphic 104
Exterior view

VAM. The Netherlands, 1961.	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	A private Dutch company
Average areas per home (in square meters)	45, 70, 90
Number of housing units (on average, per building)	24
Average height of the buildings (in number of stories)	4
Number of types of precast elements	24
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	8
Interior walls	5
Mezzanine slabs	5
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	5
Stairs	1
Structural spatial cells	0
Types of joints	Assemblies, welded metal bars, concrete

Information taken from: Alonso and Palmarola, 2014, pp. 212-213, 255, 302-303.

Table 22
VAM, The Netherlands, 1961.

System and building

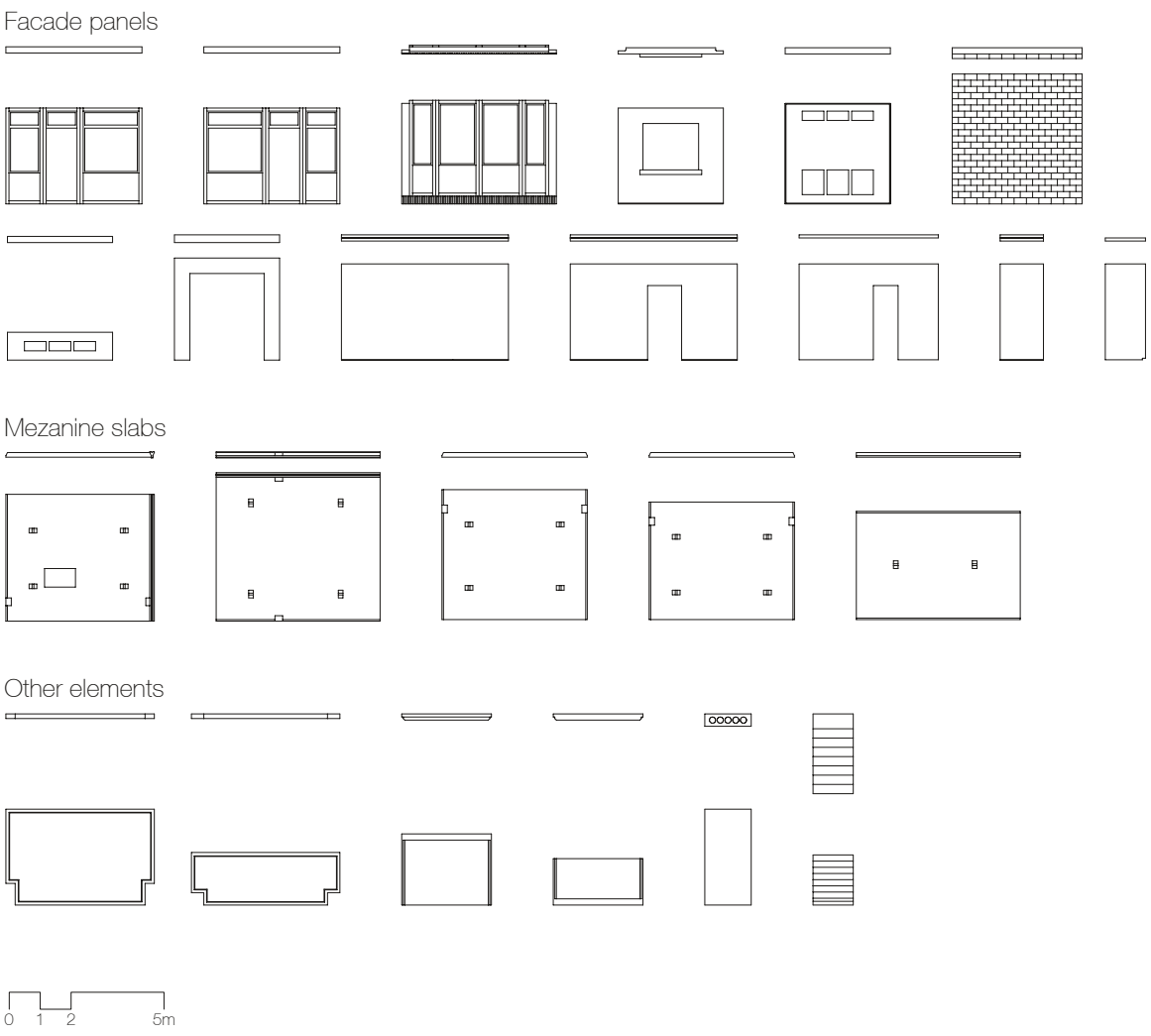
This series was conceived in Holland and Western Germany in 1961. It is a system of structural walls in which buildings with an average height of four stories were constructed; they were supported on the first floor built with traditional techniques (*in-situ* cast concrete or structural masonry). The first floor's public usages complemented the built housing units. The façade panels were specified with an exterior layer of pre-stressed concrete, usually veneered with other finishing materials (stones, brick or gravel), an intermediate layer of thermal insulation made up of mineral wool and an interior wall in lightweight concrete. The joints were maid by assemblies or by knots between metallic bars, which were stiffened with *in-situ* concrete castings. The mezzanine slabs were produced with recesses and assemblies to fasten the interior walls or façade panels. These panels were carefully produced to give the appearance of a traditional construction of finished walls, giving the homes a language that differed from prefabrication (Alonso & Palmarola, 2014, pp. 212-213).

Given the characteristics of the system, it was used for the construction of housing that was not necessarily aimed at the European working class. The first floors raised a relationship with the public space so that the housing units were located on the upper floors. The technical specifications, which plastered and decorated the façade panels with different appearances allowed the languages of the housing projects to be modified through the same prefabrication system.

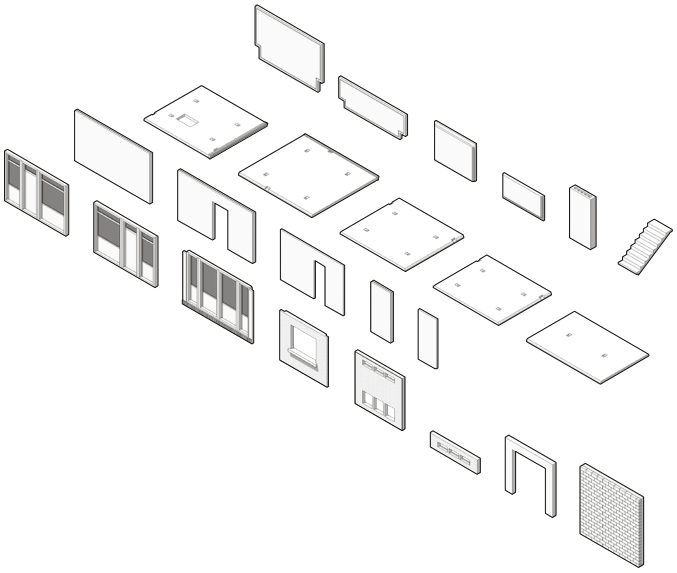
This system was not used massively in which housing was built with the series of the former Soviet Union, but generated other aesthetic conditions to prefabrication in the search for an individuality dreamed of by different social classes. The design of its support structure permitted having different architectural configurations, as the structural elements were located on the façades (panels designed with different types of openings) and only in some points of the interior space, where the families could redistribute their needs according to the areas available.

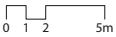
The houses built with this series have served to form neighborhoods with densities lower than the massive prefabrication systems of dwellings, in which the public spaces have complemented the collective habitation of the families.

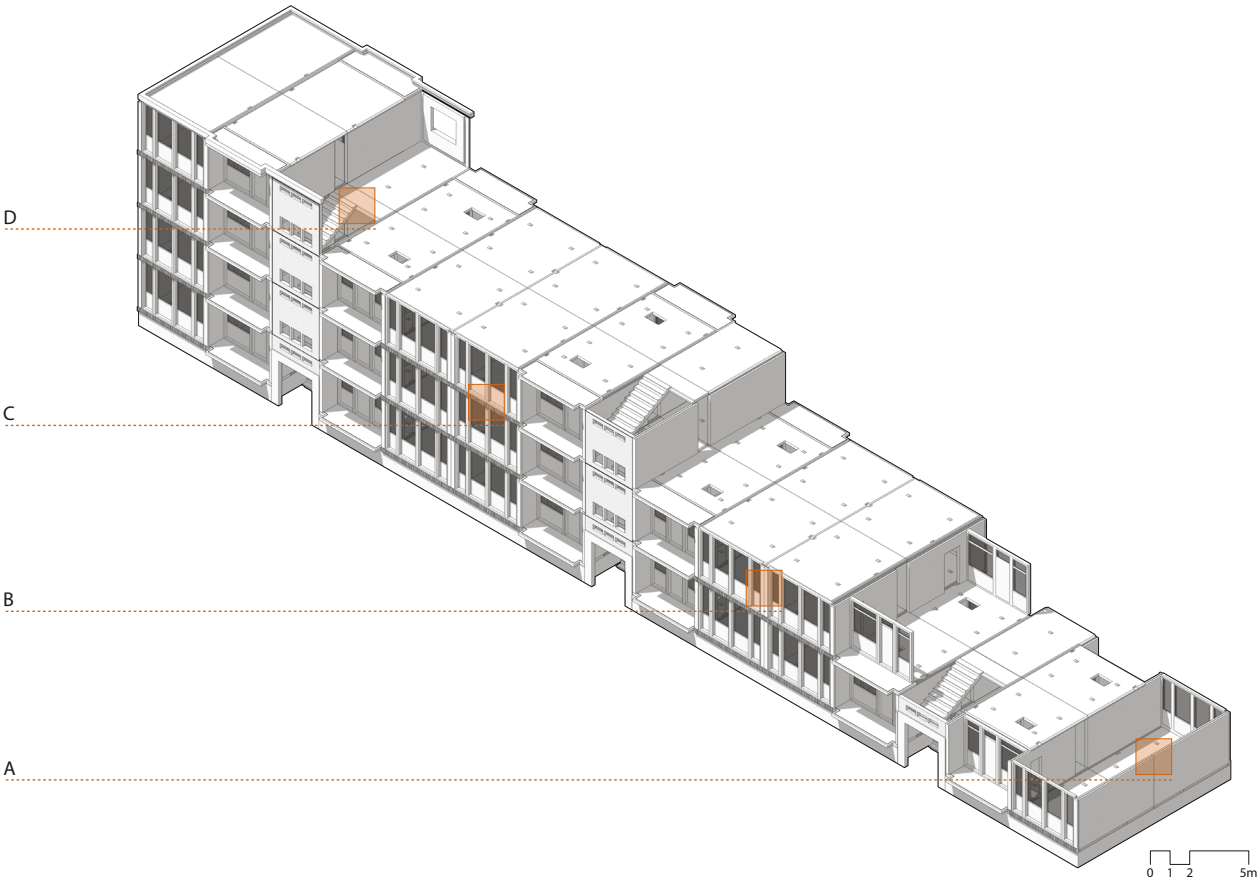
This open system of prefabrication also permitted the use of other materials or systems in the construction of the façades or in the interior spaces of the housing units, a situation that increased their versatility in the design of the interior space and in the appearance of the projects, associated more to traditional construction techniques than to conventional prefabrication systems with massive, closed façades and without variations in their surface appearances.



Graphic 105
Components: floor plans and façade

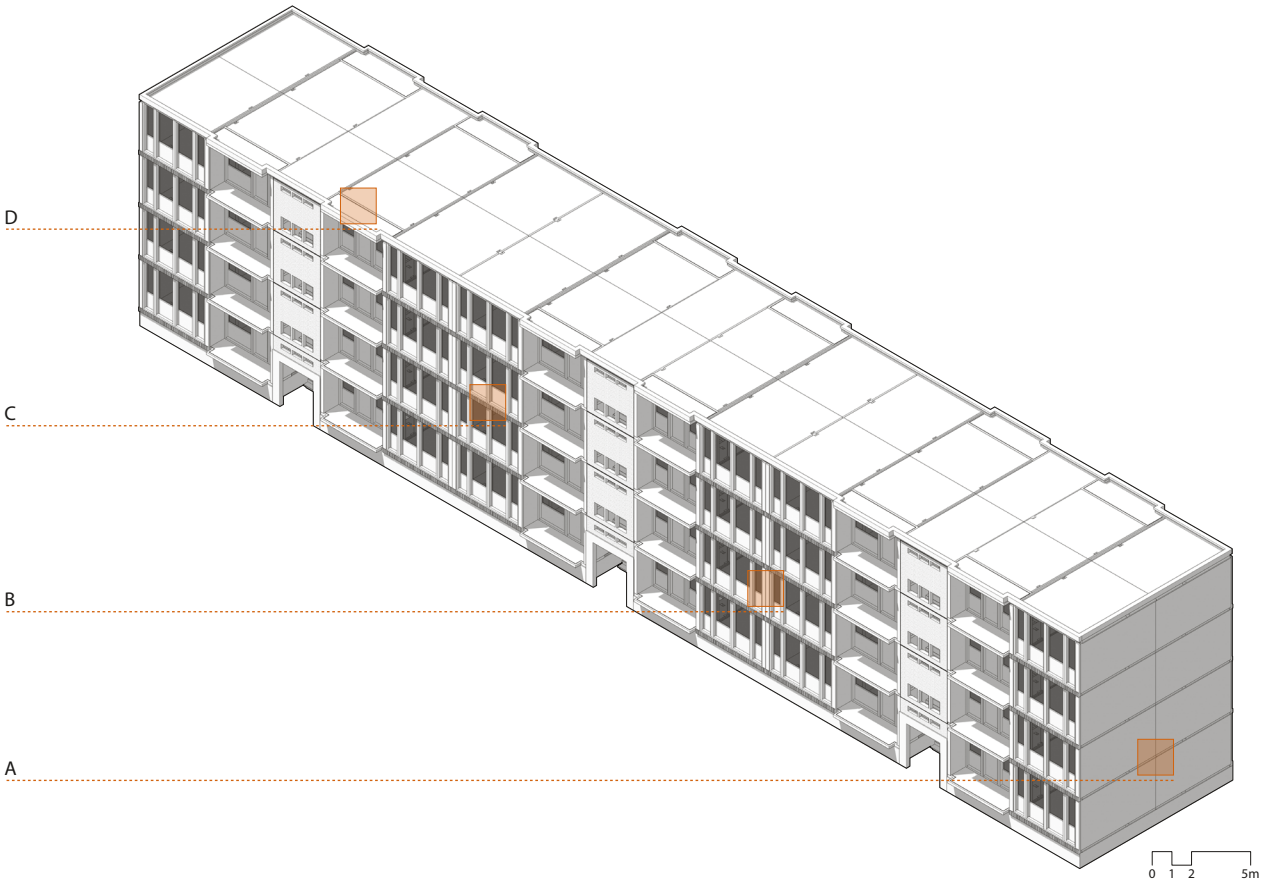






Graphic 106
Components: axonometry

Graphic 107
Construction process



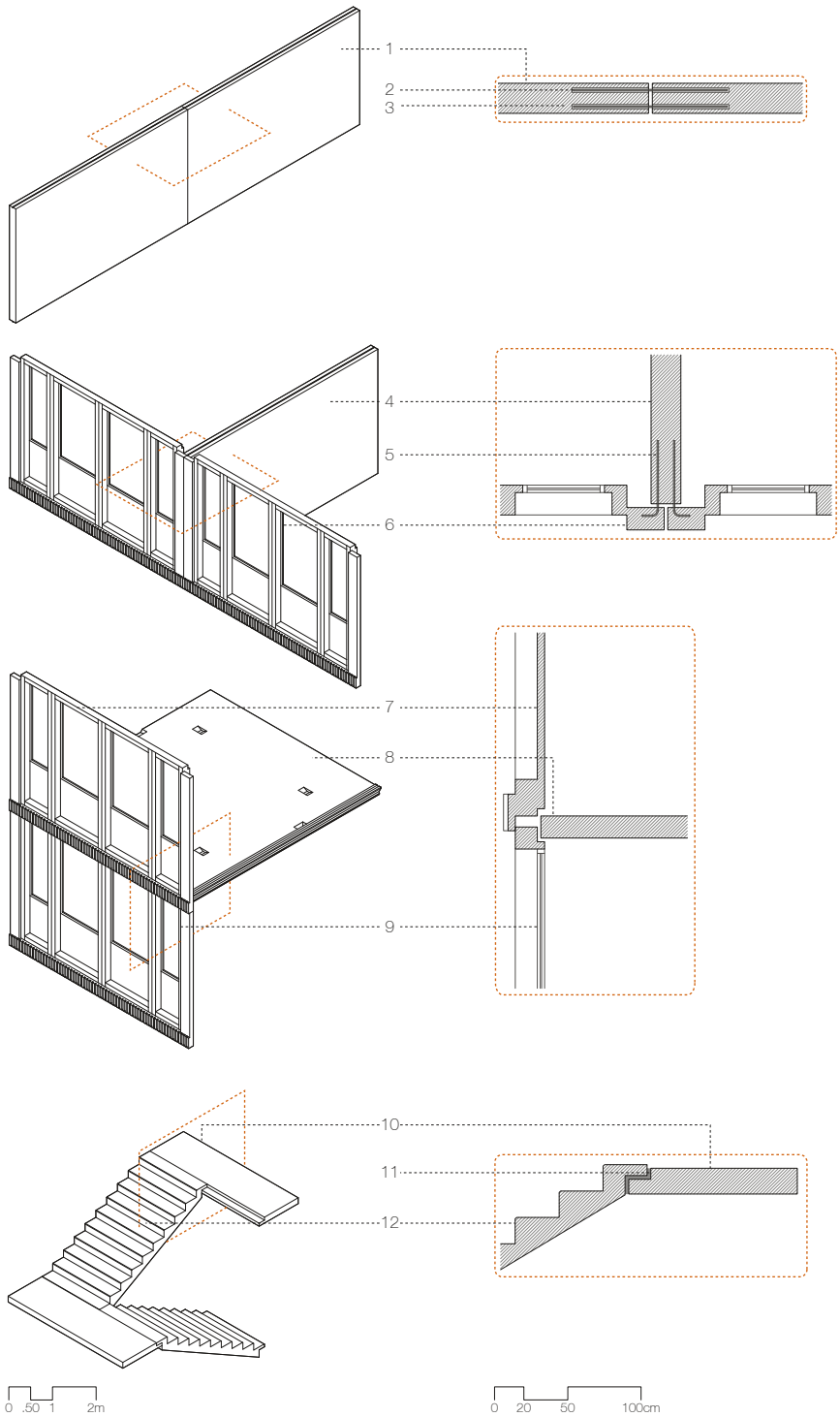
Graphic 108
The technical system and the architectural language

Advantages

- A reduced number of precast panels in the façade and floor slabs make up this system. The combination of these elements can generate different types or architecture.
- The reduced amount of structural elements and the variation their aesthetic appearance can have allowed the system to be used in architectural projects conceived for different social classes.
- The size and weight of the elements (none exceeds 5m in length or 7 tons) allows transport from the production plant to the project site and their on-site manipulation with mechanical instruments does not require high specifications.
- The load-bearing walls allow their construction with different geometries.
- The lower floors, generally conceived as extensions of the public spaces, generate places for activities complementary to the use of the dwelling. Most of the projects constructed with the system were four-stories high, with interior dimensions and collective spaces that allowed the mobility of the disabled.
- From the design of the façades (which, with the same prefabricated elements, allow the use of different finishings), interior spaces (that can be designed in different ways or transformed by the inhabitants), the system can be replicated maintaining its basic conditions, but modifying the living areas, the language of the façades and the geometries of the volumes. This generates conditions of typological variations through the use of the same elements.
- The configuration of the living space with the elements that make up the system allow having different proportions of use and respond to the different environmental conditions of the context. Open and closed façades, added to the configuration of the living space, permit having a relation with the environment that favor the well being of the housing space.
- The versatility in the language of the façade panels through the different finishings on the concrete surfaces permit having different aesthetic responses according to the social context, the cultural context, the climate and with the appearances desired for the project. The possibility offered by the panels to be coated or plastered with other textures or appearances of different materials diversifies the aesthetic condition of the project.
- The presence of non-structural elements in the interior space allows modifying its use according to the needs of the family groups.

Disadvantages:

- Although the fixation systems among the structural elements use metallic and cast-concrete elements and materials used in the construction process of the panels, in some cases the joints among the metallic elements require weldings to stiffen their joints, which complicates the assembly system.



1. Precast concrete facade wall
2. Metal bars
3. Welding
4. Precast concrete interior wall
5. Metal bars
6. Precast concrete facade wall
7. Precast concrete facade wall
8. Precast concrete slab
9. Precast concrete facade wall
10. Precast concrete slab
11. Assemble
12. Precast concrete stair

Graphic 109
Constructive details

5.2.2. Saint Andrews Dormitory, Scotland, 1964



Graphic 110
Exterior view

Saint Andrews Dormitory. Scotland, 1964	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	James Stirling
Average areas per home (in square meters)	20
Number of housing units (on average, per building)	126 and 198
Average height of the buildings (in number of stories)	6
Number of types of precast elements	46
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	24
Interior walls	3
Mezzanine slabs	8
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	10
Stairs	1
Structural spatial cells	0
Types of joints	Metal bars and *in situ* cast concrete

Information taken from: Alonso and Palmarola, 2014, pp. 228-229, 263, 322-323.

Table 23
Saint Andrews Dormitory, Scotland, 1964.

System and building

Also known as Andrew Melville Hall, this structural-wall building was designed by Architect James Stirling in 1964 in Saint Andrews, Scotland.

The project was designed with a central core containing most of the common areas, with two adjacent staggered blocks that were six stories tall. A central stairway solved access to the two buildings, each of which had 32 bedrooms per floor, looking over the Scottish coast, with a central circulation. The third floor had only 16 bedrooms, because the common areas were located toward the façade overlooking the courtyard located between the two buildings.

The precast concrete elements were conceived with different geometries, a situation that generated diverse textures in the façades from the orientation of the bedrooms overlooking the coasts.

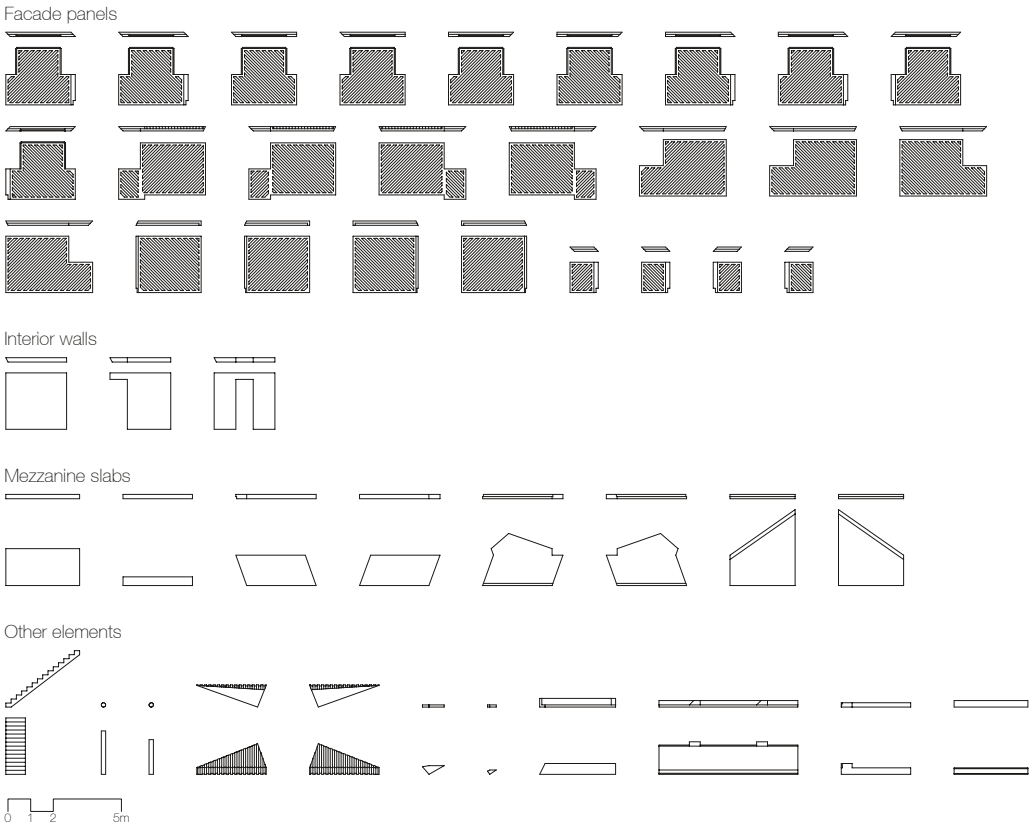
The assemblies between the prefabricated elements were made through rigid metallic connectors with welds and *in-situ* cast concrete. The entire project was conceived in four stages, but only one was built (Alonso & Palmarola, 2014, pp. 222-223).

This building, which offers individual rooms for students, was configured with a geometry that, when turning the modules on the axis of circulation, can be seen in the space of the rooms. The complex, originally designed with more residential blocks, was finally constructed in two blocks that can be occupied by up to 270 people. Noteworthy is that in its different levels complementary activities to dwelling configure the life in community.

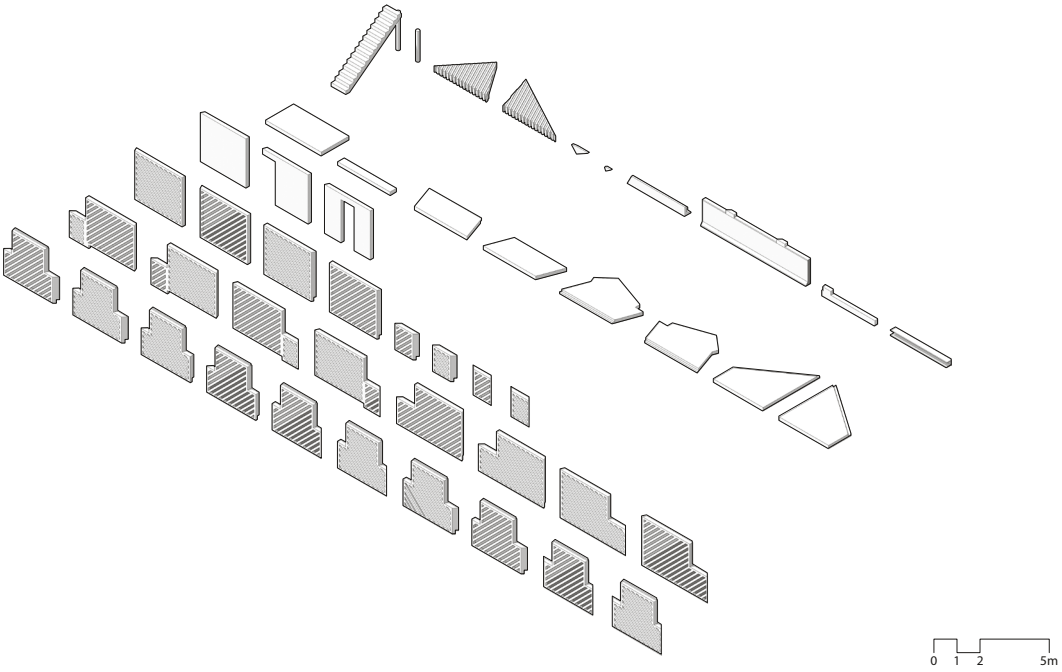
The prefabrication and layout of the façade elements generated a style known as "New Brutalism," in which the texture of the pieces and the configuration of the volume were the principal characteristics in its language. The articulation among the façade panels required great precisions in its edges, since the angles designed for the building façades were not conceived all to 90º. The angled arrangement of the rooms toward the landscape is one of the façade elements of the project in its relationship with the setting. The layout of these façade elements defined structural criteria and principles for the support of the building.[34]

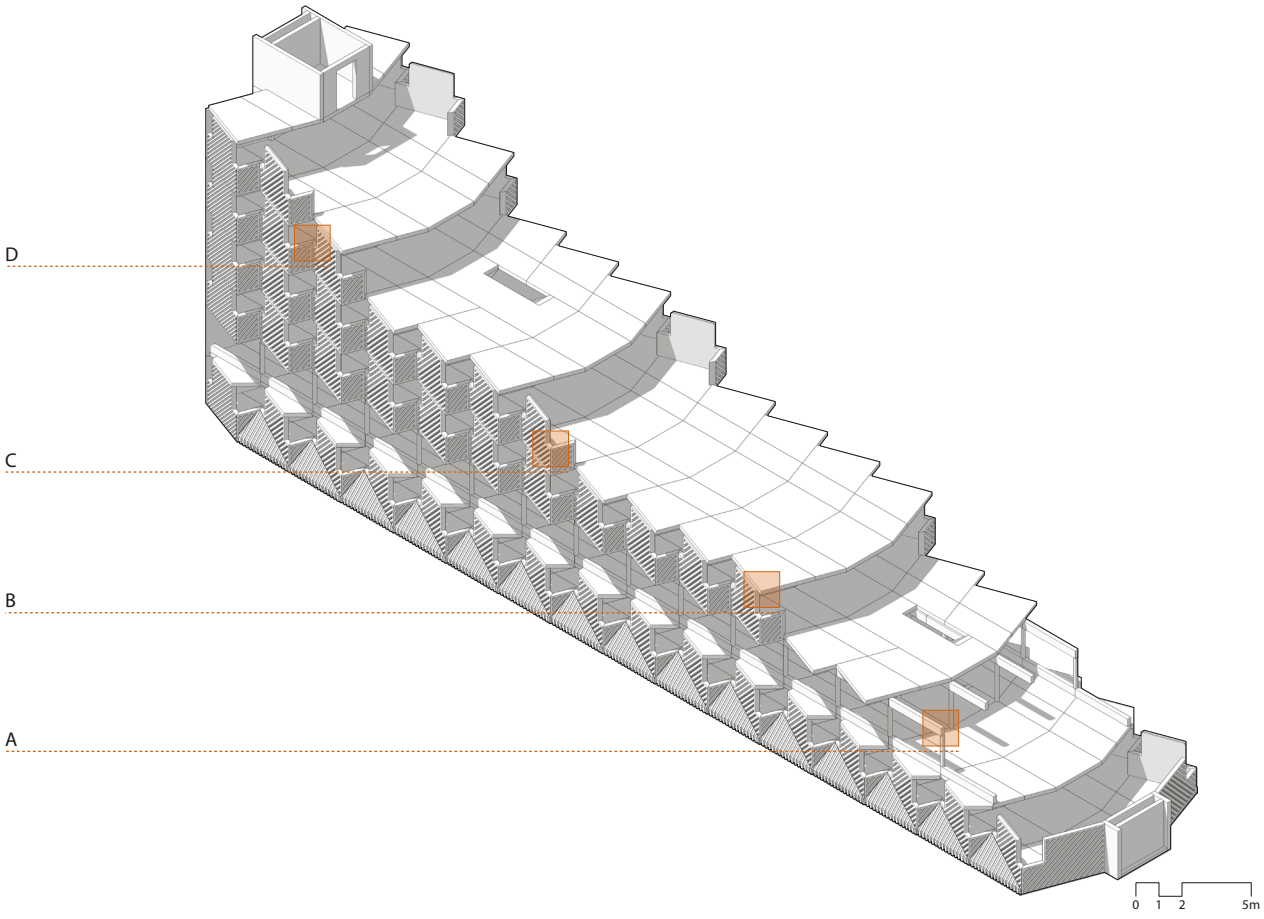
The project is located on a slightly inclined terrain, and its structural panels permit scaling the volume and separating the private life from social life around the circulations and the courtyard that articulates the two residential blocks.

34 Stirling, James, Michael Wilford and Associates. James Stirling, Buildings and Projects. p. 107



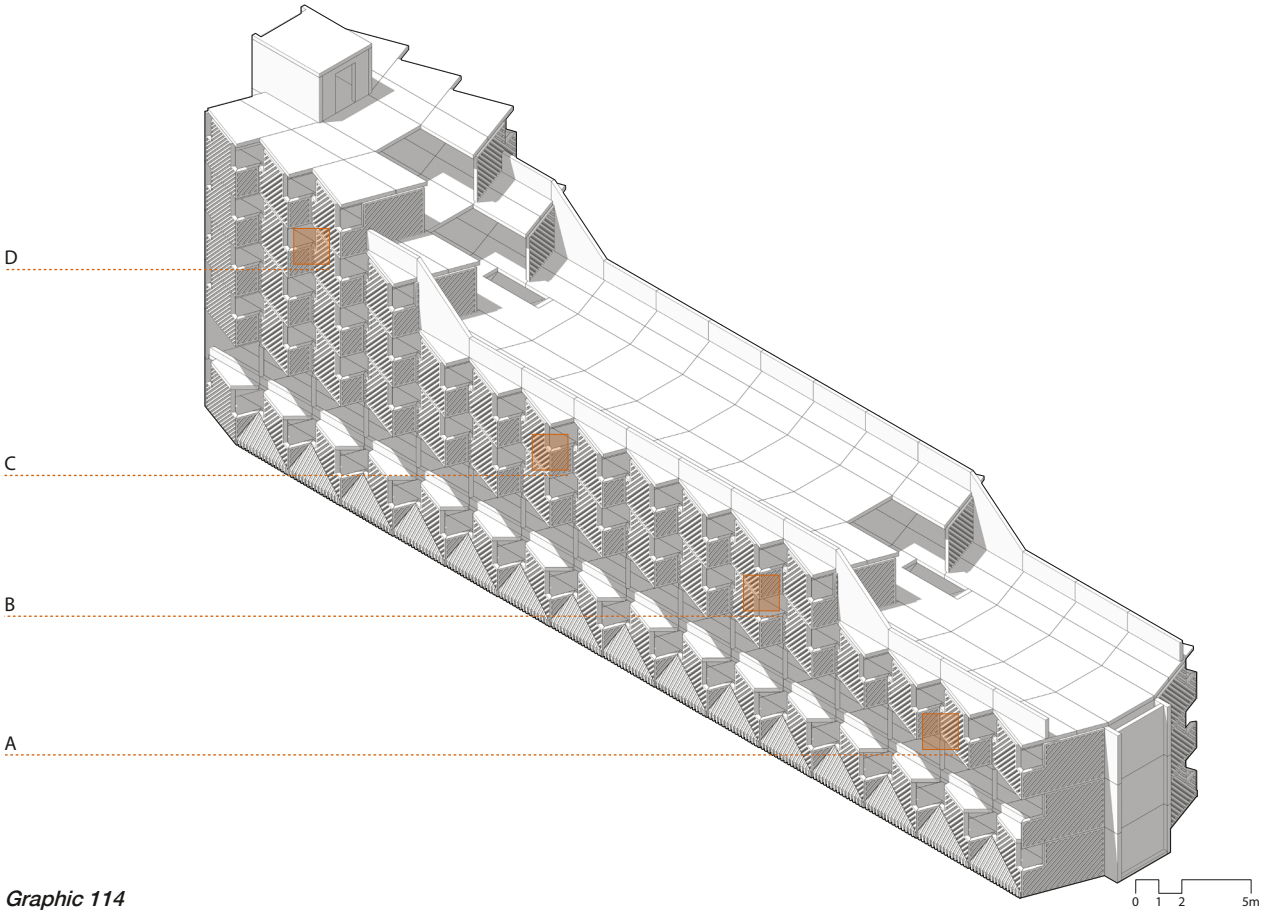
Graphic 111
Components: floor plans and façade





Graphic 112
Components: axonometry

Graphic 113
Construction process



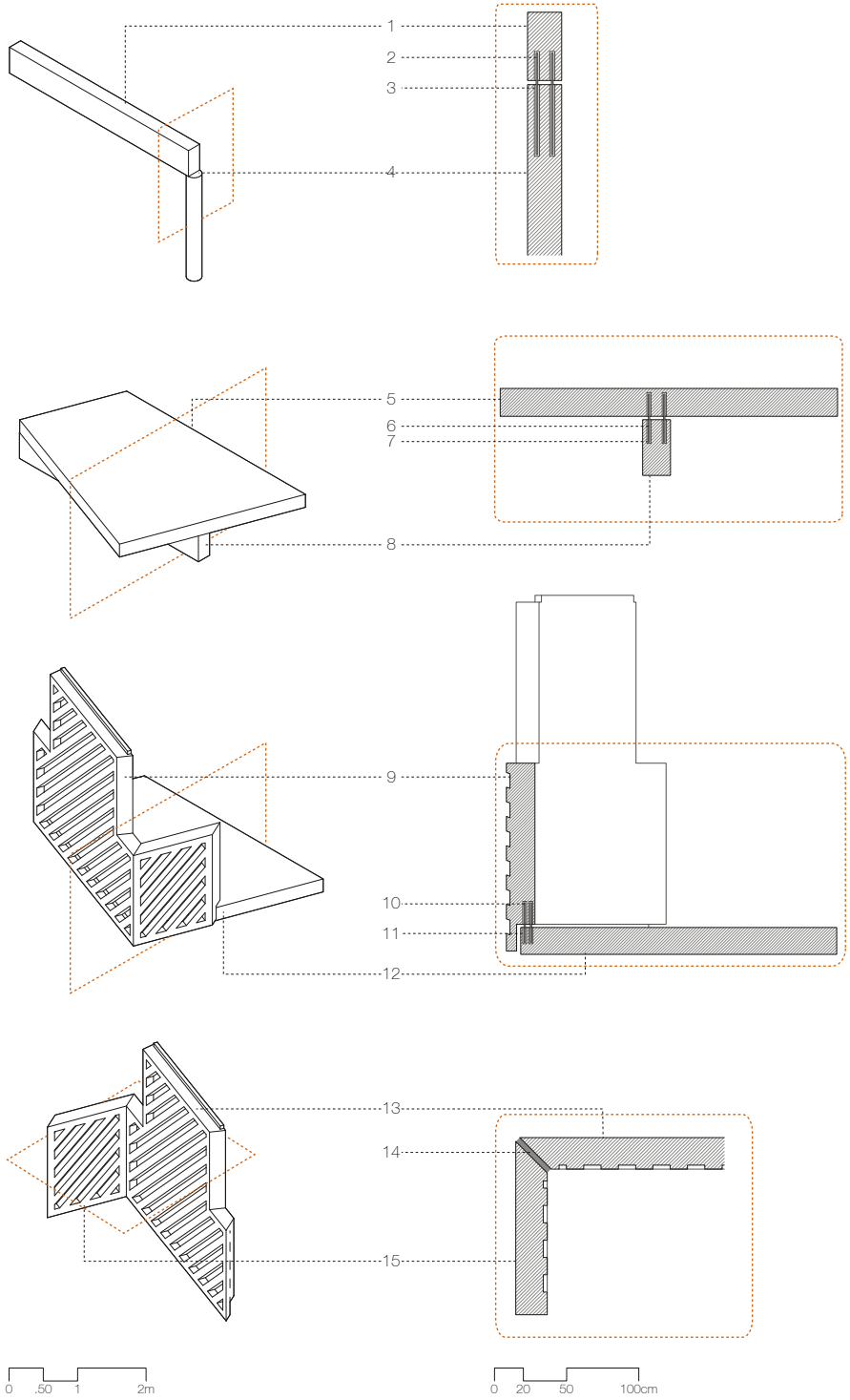
Graphic 114
The technical system and the architectural language

Advantages

- The size of the precast panels permits reaching the location site and its installation in the building.
- The configuration of the building in structural panels allowed the volume to adapt to the existing topography, generating a modulated staggering according to the slope and the proportions of the precast elements.
- A system of exterior ramps allows access to some of the floors. The dimensions of the rooms and the corridors permit the disabled to move about.
- The relationship with the setting, windows oriented to the best visuals and the possibility of receiving direct radiation in the colder seasons or protection from the sun in summer months gives the interior space conditions of well being.

Disadvantages

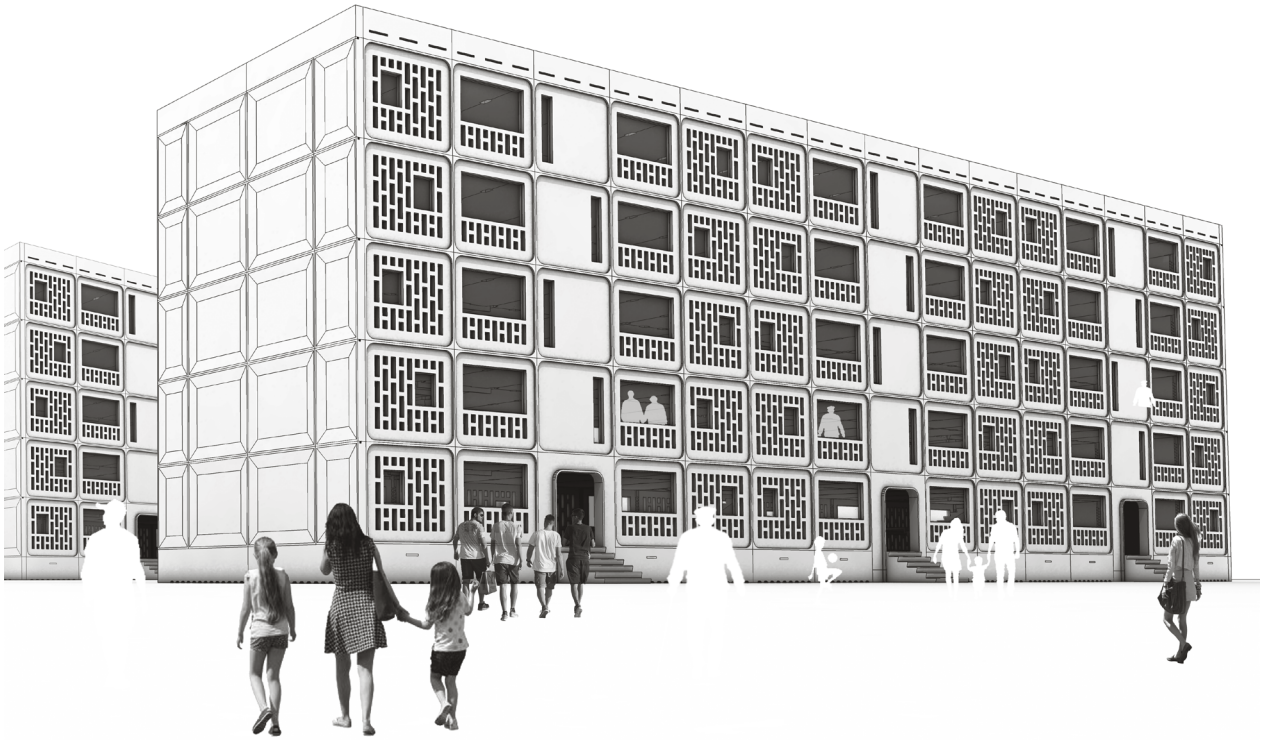
- Although the dimensions of the elements are coordinated with each other, the number of types of precast elements (46 in total) makes the standardization of the building not optimal.
- The building, originally designed to be built in more blocks, was finally constructed in two. No other buildings were constructed form the designs of these student housing units and, therefore, the model was not replicated.
- The number and variety of façade panels does not allow a more-efficient standardization in the production of the pieces. Although the building was not designed to be produced massively, the complexity in the geome try of the living space and the structural panels would run counter to the efficient industrialization of popular housing in the Department of Antioquia.
- Because of the specificity of the design and the typology of the panels and the areas of the rooms, the interior space does not have many variants in its occupation or its uses. The areas proposed and the geometric arrangement of the panels do not allow a series of variants in the use of the interior space.
- The brutalist style is not a current identified with massive housing construction. Therefore, the geometry and texture of the panels, the invariability of their façades and the monochromatic finish, distance it from the desired housing conditions in tropical regions.
- The specificity of the façade panels, the location of each one in the housing project and the areas of the rooms result in these units not allowing modifications after their occupation, a situation that should be contemplated in the local context, as families have the tradition of appropriating the living space to their needs and desires.



1. Precast concrete beam
2. Metal bars
3. In-situ cast concrete
4. Precast concrete column
5. Precast concrete slab
6. Metal bars
7. In-situ cast concrete
8. Precast concrete beam
9. Precast concrete facade wall
10. Metal bars
11. In-situ cast concrete
12. Precast concrete slab
13. Precast concrete facade wall
14. Joint
15. Precast concrete facade wall

Graphic 115
Constructive details

5.2.3. Large Soviet Panel, Cuba, 1965



Graphic 116
Exterior view

Large Soviet Panel. Cuba, 1965	
Type of structure	Structural walls
Type of prefabrication	Closed
Architect, inventor or designer	Hugo D'Acosta
Average areas per home (in square meters)	45, 60, 75
Number of housing units (on average, per building)	40
Average height of the buildings (in number of stories)	5
Number of types of precast elements	23
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	9
Interior walls	10
Mezzanine slabs	2
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	0
Stairs	2
Structural spatial cells	0
Types of joints	Metal bars and *in situ* cast concrete

Information taken from: Alonso and Palmarola, 2014, pp. 204-205, 251, 294-295.

Table 24
Large Soviet Panel, Cuba, 1965.

System and building

In October 1963, Hurricane Flora left more than 1,200 people dead and destroyed several homes in Cuba. Moved by the magnitude of the tragedy, Nikita Khrushchev, the President of the Council of Ministers of the Soviet Union, decided to donate a factory for the large-scale production of concrete panels, which was installed in 1965. The plant could produce elements for the construction of 1,700 homes per year (Alonso & Palmarola, 2012, p. 299).

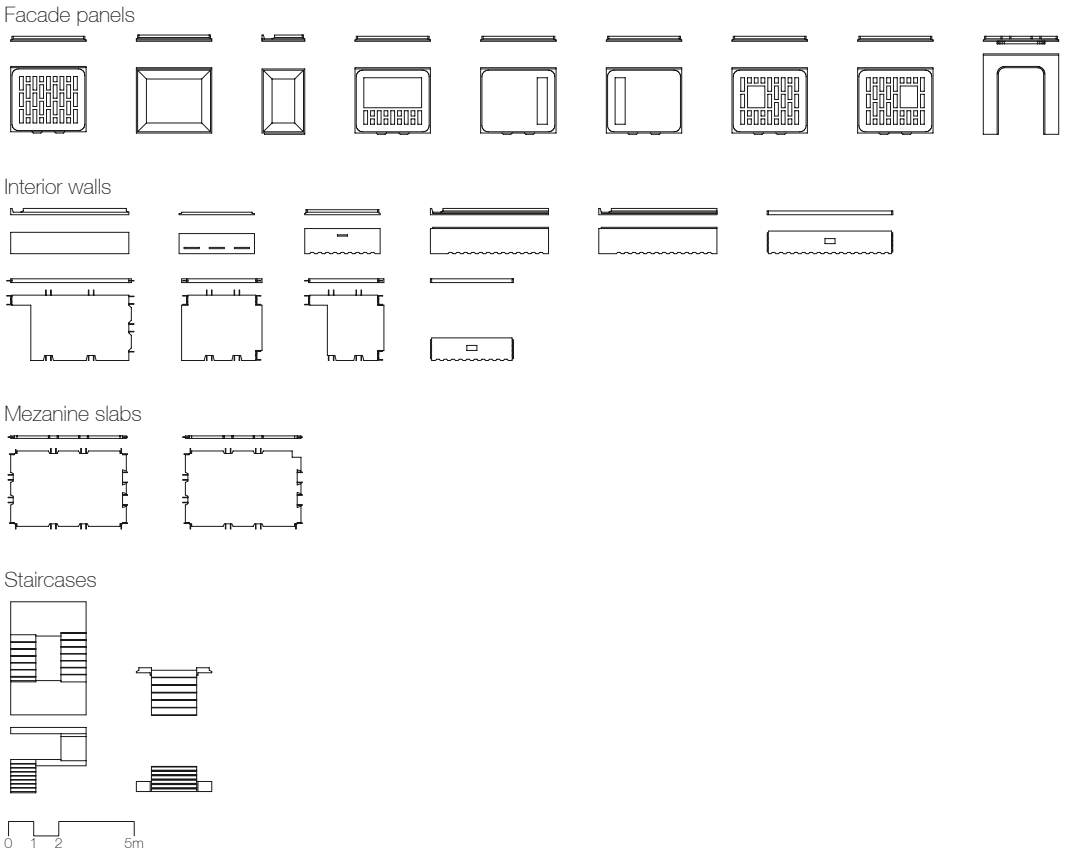
This structural wall system of was an adaptation to the Cuban context from the 1-464 Soviet prefabrication series. The joints of the precast elements were designed with exposed metal reinforcements, which were concreted in the cavities left for the panels to stiffen the knots. The appropriation of the original Soviet concept and its adaptation to the Cuban context was the responsibility of local Architect Hugo D'Acosta, who generated a housing typology of buildings with an average height of five stories, with local languages that used environmental principles to control the passage of the natural light and allow the passage of air, which improved bioclimatic conditions (González, 2009, pp. 69-92). This modification achieved significant savings in the use of concrete and created a less-monotonous impression regarding the elements used in the architecture of collective housing in the former Soviet Union (Alonso & Palmarola, 2014, pp. 204-205).

The large-panel prefabrication plant donated by the Soviet Union to the Cuban Government caused several changes in the traditional construction of housing. From that time it was necessary to massively construct standardized buildings with similar appearances to be inhabited by diverse family groups. The first experience of applying these systems was in the *José Martí* Microdistrict in Santiago de Cuba, where the molds for the wall elements were adapted to Cuban conditions, both climatic as well as economic.[35]

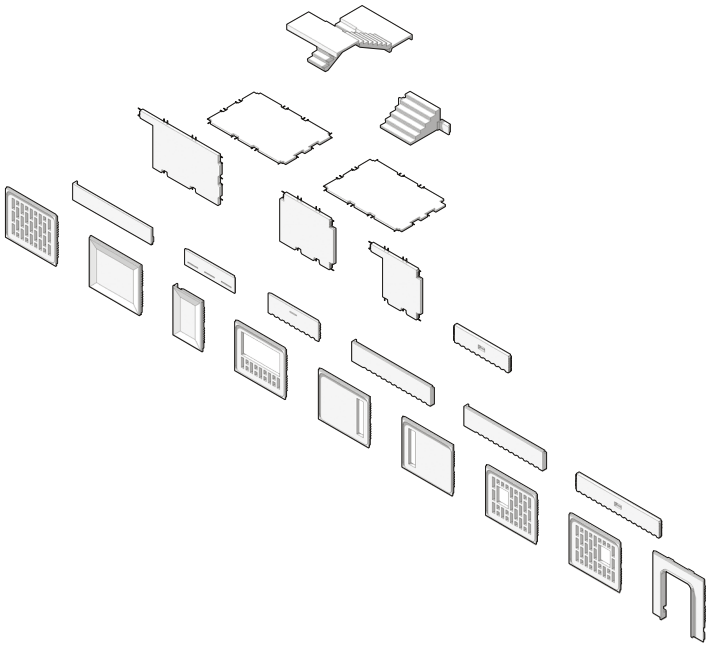
The buildings constructed with this series of prefabrication remain valid and inhabited in Cuba, where their production was massified from the appropriation of this technology, originally developed in the former Soviet Union. The floor slabs, flat, solid and 9cm high, were installed simply leaning on the load-bearing panels that had 10 cm sections. The solution of the foundations was made with footings or beams. For the construction of the footings, *in-situ* cast concrete was used; prefabricated elements were used for the foundation beams. According to the load-bearing capacity of the terrain and the height of the building, the depth of the foundation could vary. With this technology, 1,700 homes were built annually in Cuba. Subsequent developments led the Large Soviet Panel technology to consider the possibility of giving way to open prefabrication, in search of a greater variety in the expression of the buildings and increase the height from four or five to nine stories.[36]

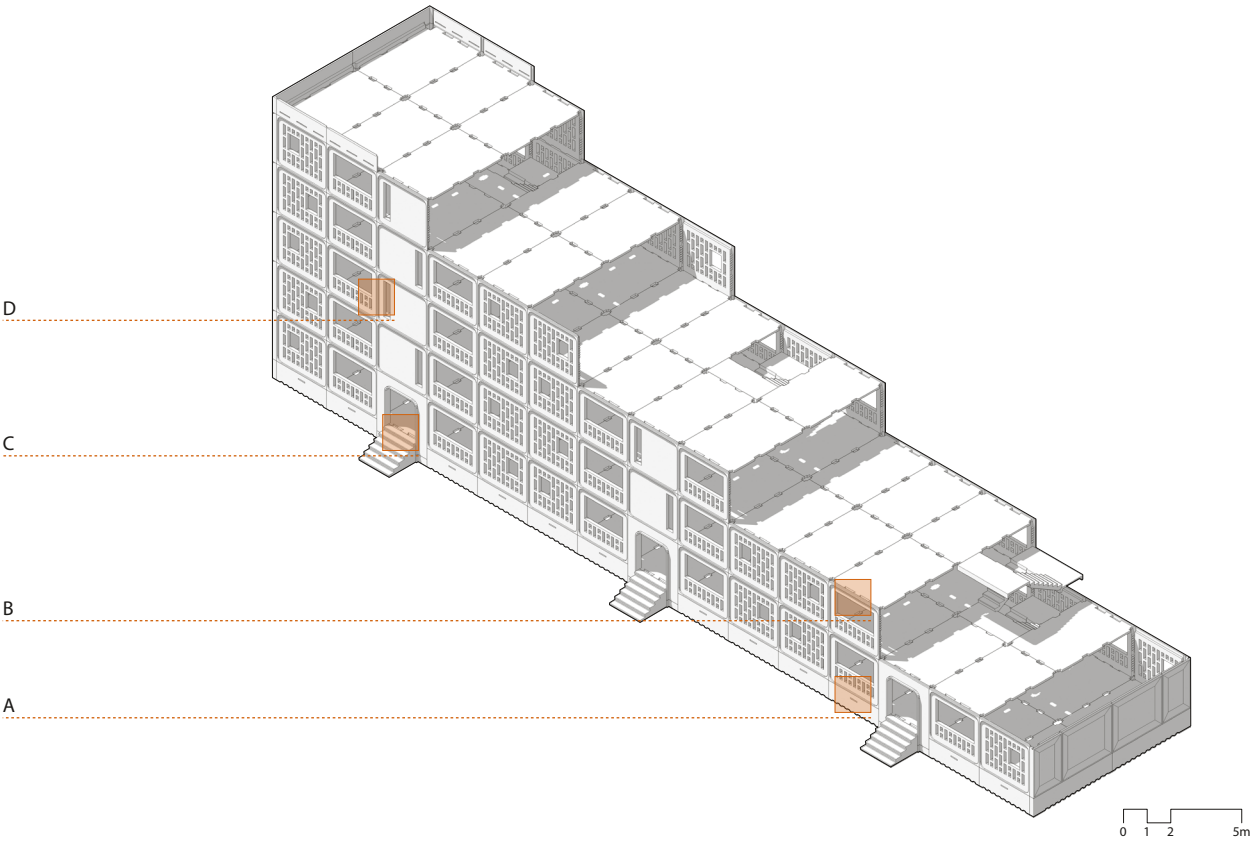
35 González Couret, Dania. *Revista Invi,* No. 67/November 2009/ Volume No. 24. Havana, Cuba, pp. 69-92.

36 *Centro Técnico de la Construcción y los Materiales. Consejo Superior de Investigaciones Científicas. Revista Informes de la Construcción.* Madrid. pp. 13, 14. Accessed June 2, 2017; available at http://informesdelaconstruccion.revistas.csic.es.



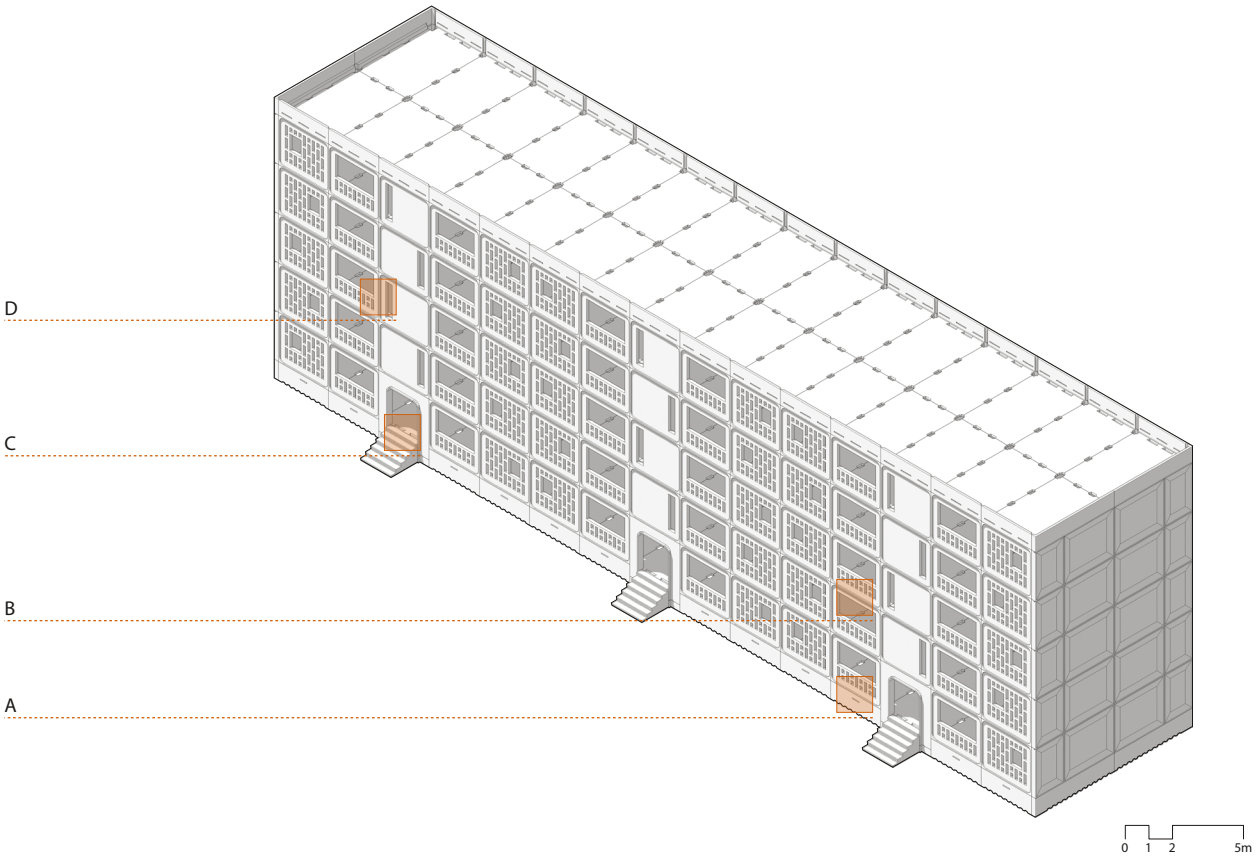
Graphic 117
Components: floor plans and façade





Graphic 118
Components: axonometry

Graphic 119
Construction process



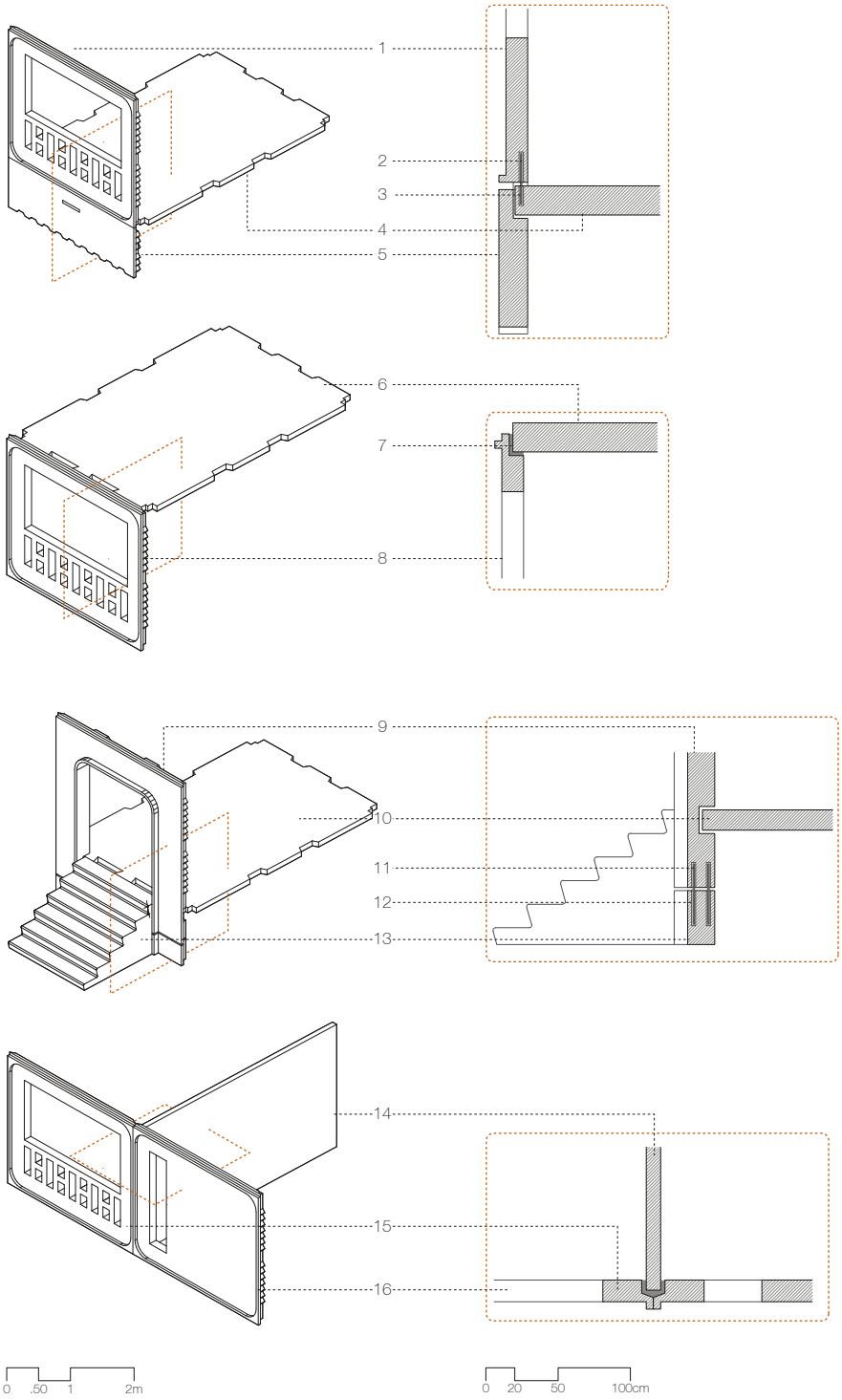
Graphic 120
The technical system and the architectural language

Advantages

- The façade panels and the interior load-bearing walls standardized their measurements, which were associated with the proportions of the floor slabs, the stairs and other components of the building.
- Due to the geometry of its components, the number of pieces and the characteristics of its assemblies, the system could be replicated in several cities, with similar conditions in different contexts.
- The size of the elements permitted their transport from the production plants to the work sites, or mobile plants were enabled for the production of the precast elements.
- Soviet technology was adapted to Cuban social and climatic conditions for the production of more-open, lightweight panels, which allowed cross ventilation and the control of lighting in the interior space. The construction system was replicated in different contexts, a desirable situation in the industrialization of housing. Panel thickness was reduced from 30cm to 10cm and the surfaces of some of these panels were perforated.
- The first floors of the buildings could be accessed from the urban space. The interior spaces of the dwellings permitted displacement and accessibility.
- The joints among the structural elements (exposed cast-concrete steel rods) allowed the system to be replicated in different contexts. In some cases, the slabs were fixed by simple support on the structural panels. The simplicity of the fixation process among the structural elements allowed the massification of the system, controlling costs and execution time.
- The original conformation of the panels in terms of massiveness and solidity was modified by lighter, thinner and perforated elements to allow cross ventilation and improve the bioclimatic conditions of the interior space.

Disadvantages

- The presence of non-structural elements in the interior space permitted different architectural designs, without substantial modifications among them. The geometry of the panels and their volume of concrete adapted to Cuban climatic characteristics, without generating aesthetic differences between them.
- The repetitiveness of the language of the building generated monotonous, monochromatic buildings that were isolated from Cuban social and cultural traditions.
- The interior spaces and the language of the dwellings were not transformed after families occupied them, due to the presence of structural elements in the façades and the interior space. The absence of transformation and appropriation of the interior space meant that families did not fully develop their ideas or their dreams in occupying these houses.



1. Precast concrete facade wall
2. Metal bars
3. In-situ cast concrete
4. Precast concrete slab
5. Precast concrete facade wall
6. Precast concrete slab
7. In-situ cast concrete
8. Precast concrete facade wall
9. Precast concrete facade wall
10. Precast concrete slab
11. Metal bars
12. In-situ cast concrete
13. Precast concrete stairs
14. Precast concrete interior wall
15. Precast concrete facade wall
16. Precast concrete facade wall

Graphic 121
Constructive details

5.2.4. Skarne S66, Sweden, 1966



Graphic 122
Exterior view

Skarne 66. Sweden, 1966	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	Ohlsson & Skarne
Average areas per home (in square meters)	42, 60, 78
Number of housing units (on average, per building)	16
Average height of the buildings (in number of stories)	4
Number of types of precast elements	24
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	13
Interior walls	5
Mezzanine slabs	2
Types of structural elements or slabs for rooves	3
Special elements (ducts, joints, common areas, awnings)	0
Stairs	1
Structural spatial cells	0
Types of joints	Metal bars, welding and cast concrete

Information taken from: Alonso and Palmarola, 2014. pp. 232-233, 265, 326-327.

Table 25
Skarne S66, Sweden, 1966.

System and building

This series, developed by the company Ohisson & Skarne in Sweden in the 1960s, was mainly used for the construction of residential buildings. It is a system of structural walls on the façade that reduced the number of interior walls and increased the flexibility in interior spaces. As a consequence, this condition resulted in the offering of different typologies of housing in the same areas constructed in four- and five-story buildings.

The unions between the precast elements were made with metallic bars welded together and with *in-situ* concrete castings on the knots. With other series –such as the Skarne Heavy System (with load-bearing walls)– developed by the same company, buildings with an average height of four stories were constructed; buildings with the Skarne Light System (which combined load-bearing walls and columns), and buildings up to fifteen stories tall were constructed (Alonso & Palmarola, 2014, pp. 232-233).

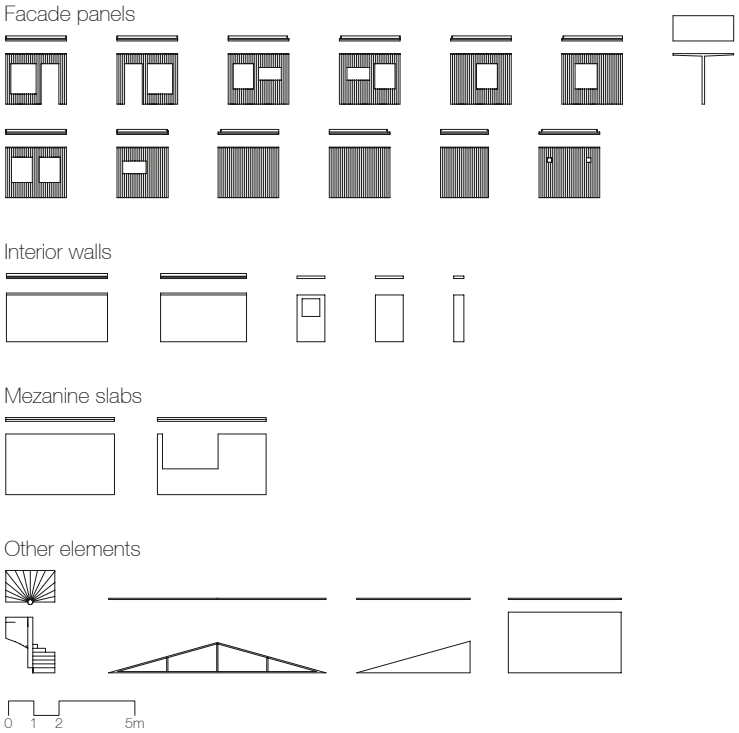
This variant combined precast façade panels and interior walls (structural and non-structural, produced in temporary factories at the construction site) with prefabricated or *in-situ* cast concrete slabs. The standardized module of slabs and façade structural panels was 2.7m, and in some projects, they were combined with a framework of columns in the interior space. The hydrosanitary and electrical installations were grouped in a technical duct so that the interior space had different possibilities of use.

The buildings constructed with this system were supported on *in-situ* cast-concrete foundations. Beams and pedestals located on the foundations were designed to support the concrete slabs of the access floor. Thus, a technical floor was built to house all the facilities, which were easily accessible. Each one of the floors contained precast-concrete slabs that did not contain any kind of technical installations. The castings of each element, its transport and installation were done vertically.

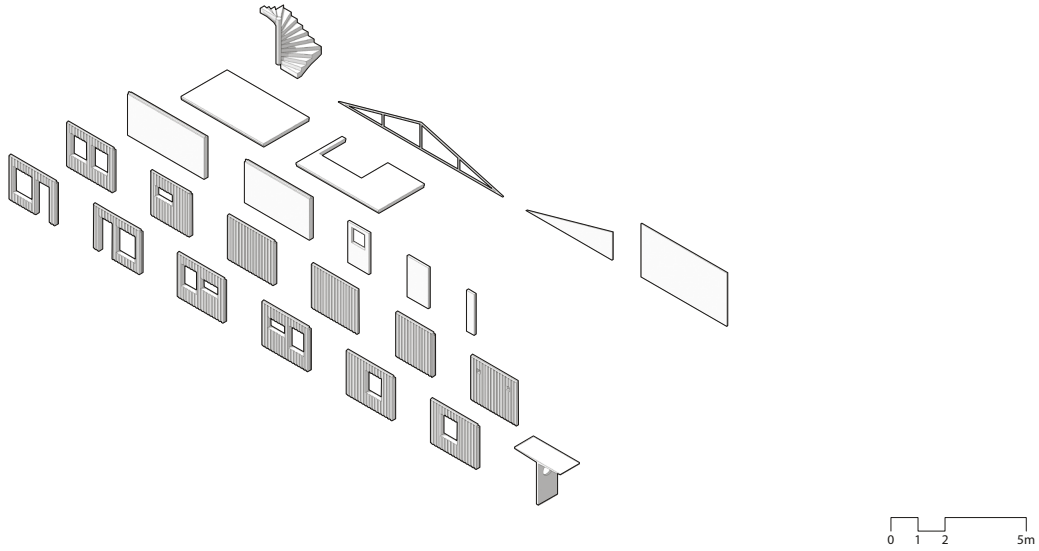
Given the climatic conditions, the façade panels had two exterior layers in precast concrete and interior insulation. Windows and doors, completely painted and ready, were installed between the panels in the prefabrication process. The company was later renamed Skarne Group and its primary mission has been the continuous improvement of the system and projecting itself in the international market.[37] This firm became one of the leading housing-construction companies in Sweden and in Europe beginning in the 70s and was part of the "Million Program Era" group of structural systems.[38]

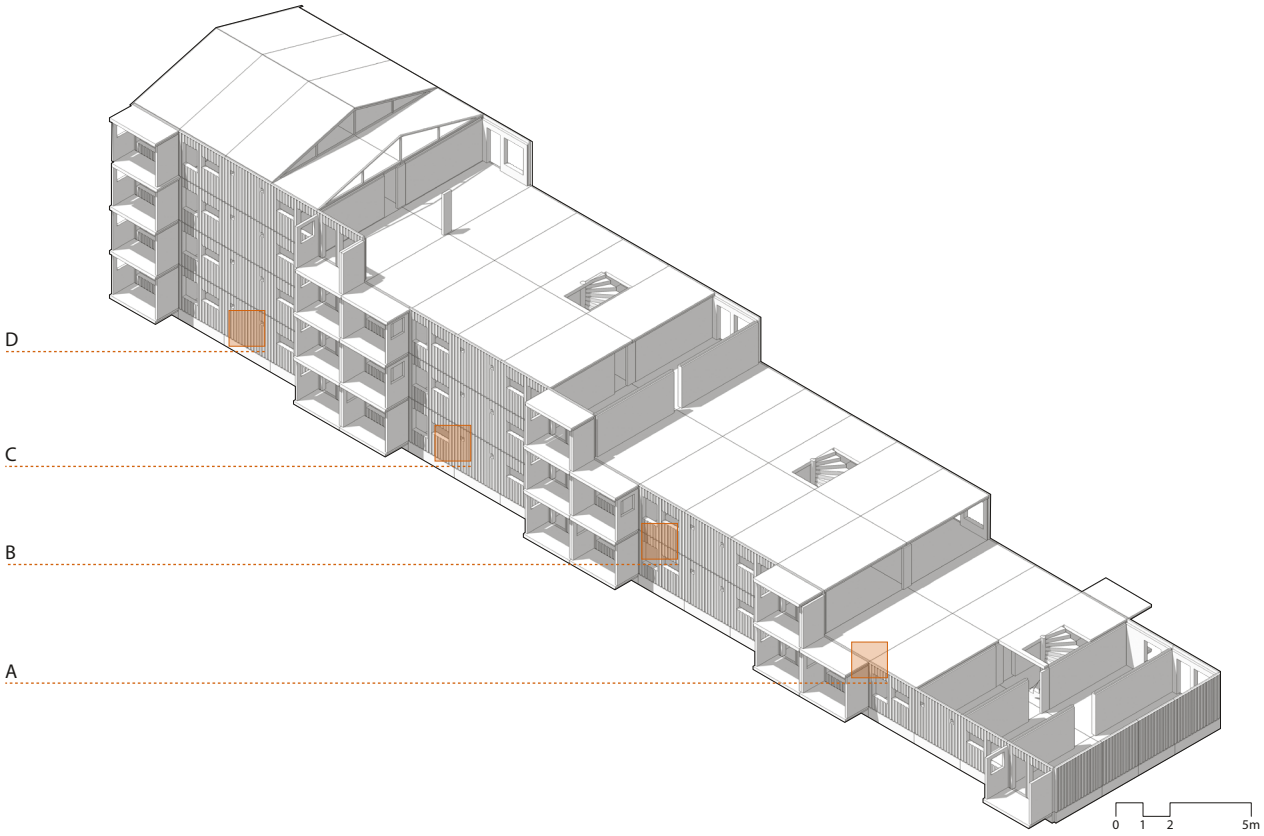
37 Stenberg, Erik (Editor). Structural Systems of the Million Program Era. KTH School of Architecture, 2013. Printed by Elanders. pp. 31-33. Accessed on June 4, 2017; available at: https://issuu.com/kth-arkitekturskolan/docs/structuralsystems

38 Stenberg, Erik (Editor). Structural Systems of the Million Program Era. KTH School of Architecture, 2013. Printed by Elanders. pp. 14, 15. Accessed on June 4, 2017; available at: https://issuu.com/kth-arkitekturskolan/docs/structuralsystems



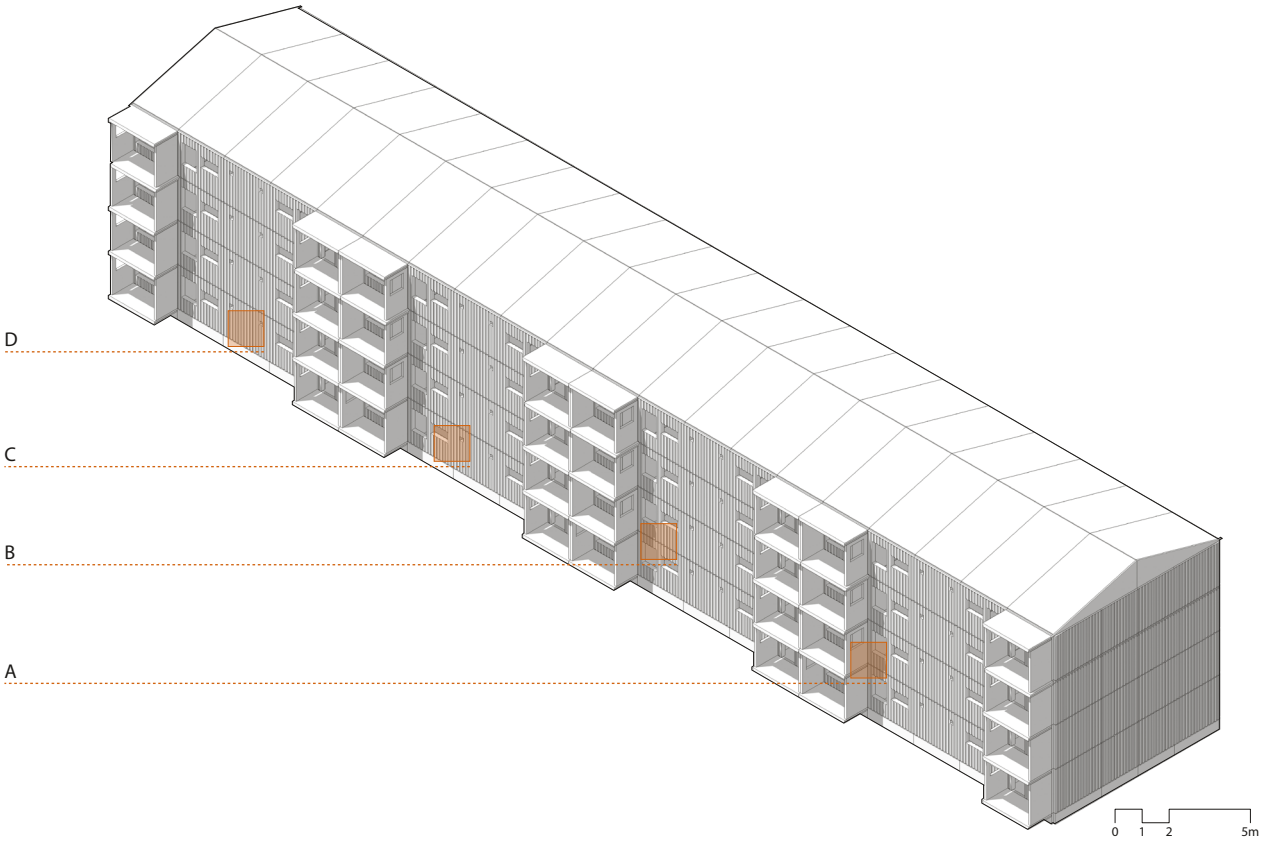
Graphic 123
Components: floor plans and façade





Graphic 124
Components: axonometry

Graphic 125
Construction process



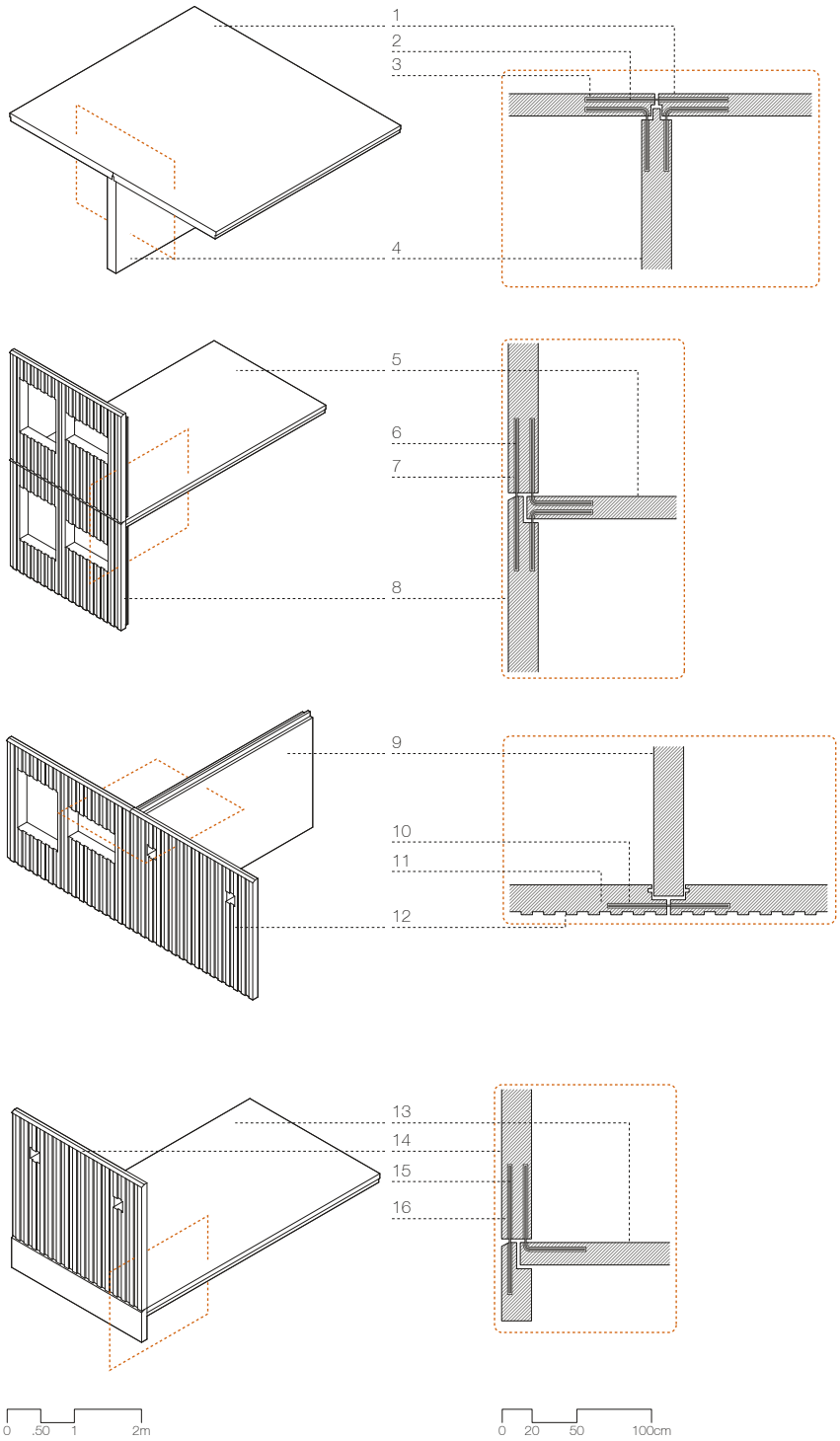
Graphic 126
The technical system and the architectural language

Advantages

- From a fixed, 2.70m dimensional module, floor slabs, structural façade panels, interior walls and columns, a structural framework is defined on which the living spaces were located.
- The geometry of the elements, the construction of the façade panels or interior walls with finished windows and doors, the fixations among structural elements with metallic rods and precast concrete and the modularity of the system allows its construction in different geographic, climatic and cultural contexts.
- The dimensions of the pieces allow transporting and installing them vertically. In some projects, the precast panels are produced at the construction site to reduce transport costs.
- In different geographic contexts, buildings are constructed with this system that, through the dimensions and modular coordination among its panels, are adapted to various topographic profiles.
- The dimensions of the structural modules allow configuring different spaces with the system. The thermal insulation of the precast façade panels is adapted to European climatic conditions. In the local context, thermal insulation is not necessary as long as conditions of cross ventilation and a control of solar incursion accompany the designs of the buildings.
- The location of a duct that groups the technical installations allows the interior space to be transformed according to the needs of the users.

Disadvantages

- Metallic and welded joints stiffened with concrete castings are a standardized, typical solution to fix the elements that make up the system. The number of elements and the separate production among slabs, façades, walls and columns increase the number of joints and processes in the work.
- The location of the load-bearing walls in the façades causes these to have few variations in the same project. In the interior, the reduction of structural elements permits the configuration of more-flexible living spaces and houses with different typologies.
- With this system, the beauty of the buildings is limited to the characteristics of the façade panels and the variants that are proposed from the architectural designs of the building. Different types of façade panels, with different proportions of windows, balconies and open spaces, should be considered in order to increase aesthetic possibilities and respond to each context.



1. Precast concrete slab
2. Steel bars
3. In situ cast concrete
4. Precast concrete interior wall
5. Precast concrete slab
6. Steel bars
7. In situ cast concrete
8. Precast concrete facade wall
9. Precast concrete interior wall
10. Steel bars
11. In situ cast concrete
12. Precast concrete facade wall
13. Precast concrete slab
14. Precast concrete facade wall
15. Steel bars
16. In situ cast concrete

Graphic 127
Constructive details

5.2.5. Habitat 67. Montreal, Canada, 1967



Graphic 128
Exterior view

Habitat 67. Montreal, Canada, 1967	
Type of structure	Spatial cells
Type of prefabrication	Open
Architect, inventor or designer	Moshe Safdie
Average areas per home (in square meters)	From 60 to 460
Number of housing units (on average, per building)	354 modules, 146 homes
Average height of the buildings (in number of stories)	12
Number of types of precast elements	15
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	0
Interior walls	0
Mezzanine slabs	3
Types of structural elements or slabs for rooves	2
Special elements (ducts, joints, common areas, awnings)	2
Stairs	3
Structural spatial cells	5
Types of joints	Metal bars and *in situ* cast concrete

Information taken from: Bergdoll and Christensen, 2008. pp. 124-127. Also taken from: Staib, Dörrhöfer and Rosenthal, n. d., p. 163.

Table 26
Habitat 67 - Montreal, Canada, 1967.

System and building

This building was conceived as a modular housing complex through the structural system of spatial cells, made up of walls and slabs integrated since the production process, which reduced the number of joints in the work and were made through metallic connectors, concreted joints and simple supports (Staib, et al., 2008b, p. 163). The project was commissioned for the International and Universal Exposition *Expo 67*. It proposed construction through principles of industrialization and the combining of modules to generate different types of housing in dense contexts. This project was originally a master's thesis, developed in 1961 in McGill University's Faculty of Architecture, in Canada, by Moshe Safdie, who, from some principles of the Metabolist movement, proposed a sum of modules with a structural installation pattern for the grouping of this residential building (Bergdoll & Christensen, 2008, pp. 124-127).

The project was designed to integrate the benefits of suburban housing (such as gardens, fresh air, privacy and terraces) with the economic factors and the density of an apartment building. This building included 354 precast concrete modules with dimensions of 11.80m x 5.30m x 3.50m, which were located on 12 stories through a spatial and structural order. The union of these modules generated 146 housing units with different sizes and configurations, ranging from a single typical precast module up to eight modules to compose 15 housing types with areas from 60 to 460 m² (Habitat 67, n. d.). Each unit was connected to at least one private terrace that ranged in size from 20 m² to 90 m², located on the rooves of the lower modules. In the group of elements that were part of the load-bearing walls, there was the nucleus of stairways and elevators. The modules were not covered, since the floor of the upper module functioned as the roof of the lower module. The upper modules had narrower wall sections to reduce the weight of the structure, which was shaped with the presence of vertical circulation cores (Fox, 1997, p. J1).

Due to its architectural characteristics, the technical processes by which it was executed and the validity of the principles in the course of its occupation, Habitat 67 is considered an architectural milestone. The project was designed to integrate the benefits of suburban homes and proposed a system of gardens, fresh air and privacy in height, with the economic benefits and the density of a modern urban apartment building.[39] The housing complex was conceived as a reference for the new lifestyle of people in increasingly populated cities around the world. The cost of the housing units was higher than originally thought. Habitat 67 is considered as an experiment that redefined some conditions of urban life. However, the construction of economic housing or the start of a wave of prefabricated modular projects, as Safdie has imagined, was not achieved. This project allowed him and other architects to reimagine high-density housing through industrialization and improve social integration through architecture.[40]

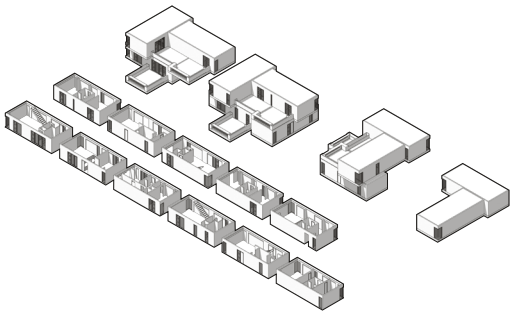
39 Fox, Matthew (January 4, 1997). «At home in Habitat». Toronto Star. p. J1.

40 Rémillard, Francois. Montreal architecture: A Guide to Styles and Buildings. Montreal: Meridian Press, 1990.

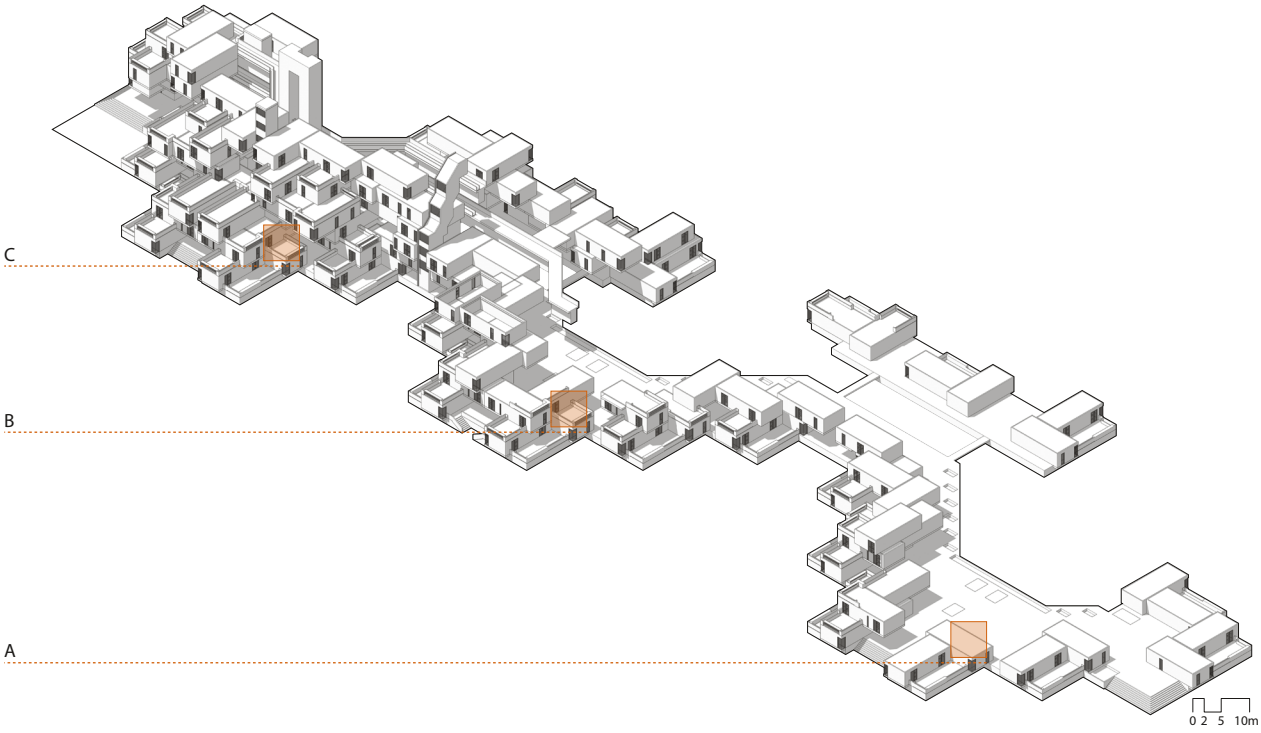
Spatial cells



Graphic 129
Components: floor plans and façade

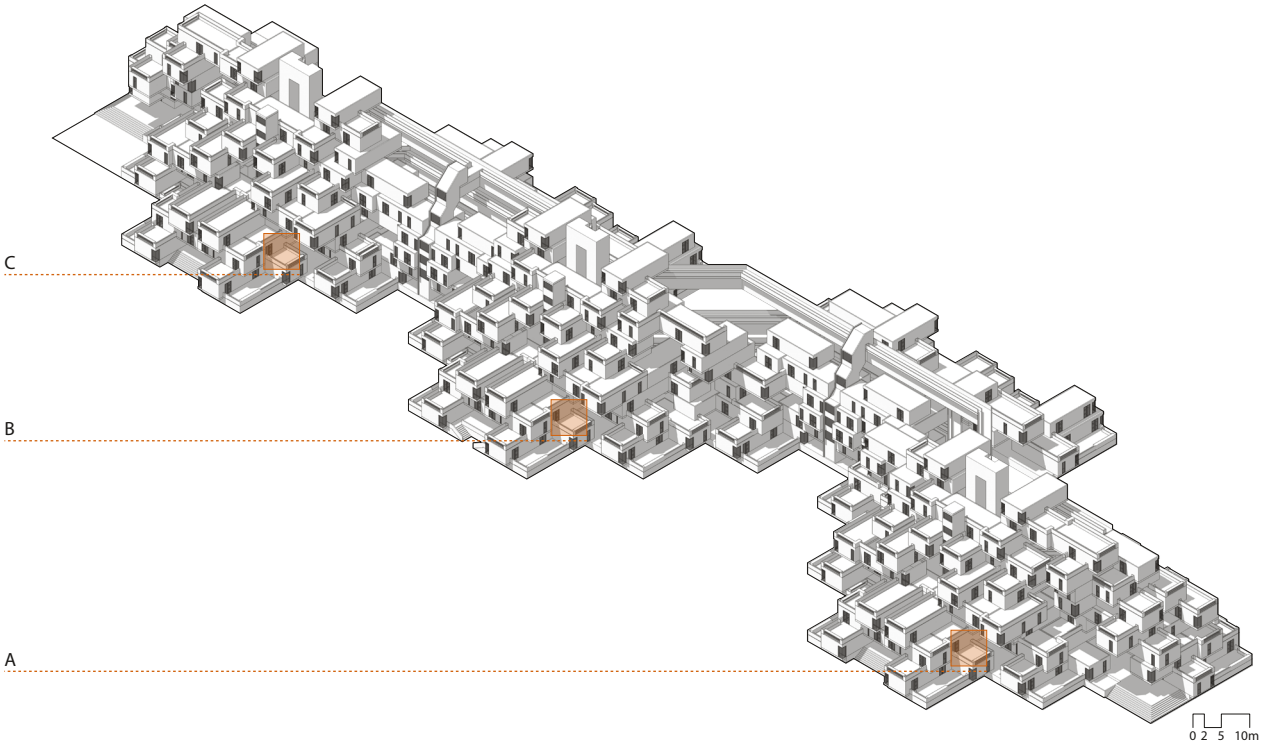


0 2 5 10m



Graphic 130
Components: axonometry

Graphic 131
Construction process



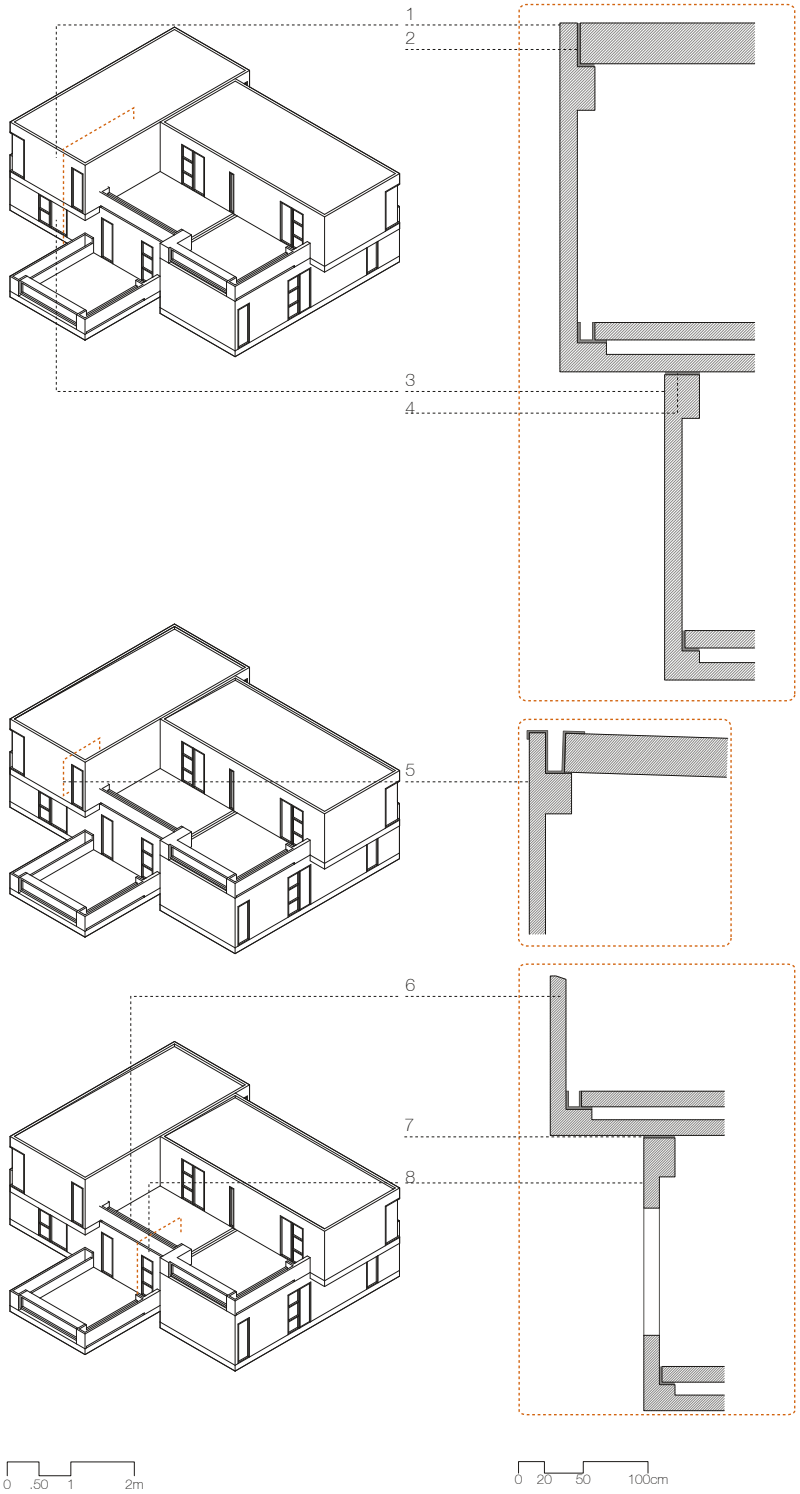
Graphic 132
The technical system and the architectural language

Advantages

- A group of precast, standardized modules, with the same characteristics and some variations in the location of windows or doors, allows the massive construction of houses that can adapt their areas to different typologies.
- A modular system of self-supporting structural cells allows individual or group adaptation to different topographies and types of soil. Floor slabs distribute the loads to the ground per unit area, causing foundations to have a reduced depth.
- By solving the fixations among the slabs and load-bearing walls in the prefabrication plants, the reduction in the number of joints on site reduces assembly time. In some cases, the joint between spatial cells can be made by simple support or with a number of fixations smaller than those required to fix walls and slabs individually. The geometric configuration and the superficial distribution of the loads to the ground reduce the depth of the foundations of the system.
- The layout of the modules allows controlling solar incursion, generates cross ventilation and configures exterior spaces such as terraces or gardens in height, evoking the life of a house in a housing cluster.
- By reducing the number of structural elements in the interior, the living space can be adapted to the needs of use of its occupants.

Disadvantages

- The arrangement of the modules in the building causes some of them to duplicate the structural dividing walls or the floor slabs between the dwellings, thereby increasing costs and construction time.
- The dimensions of the complete housing modules mean that the transport and installation process requires large vehicles and cranes, which makes the system inaccessible to different contexts or geographic settings.
- The prefabrication of the façades of the habitable modules causes them to reduce the number of variants in the same project. Although it permits the participation of other materials and construction systems, this prefabrication system reduces the possibility of generating other languages in the façades, from the use of local construction techniques or the wishes of the community.
- The aesthetics of the system is related to the layout of the modules in the building and with the different languages of the designs of the façades of the precast-concrete cells. Despite the versatility of the system, this condition does not allow other materials, local construction techniques or the workforce of the community to actively participate in the construction of the project. The language, defined by the prefabrication system, reduces the community participation in the architectural design or occupation process.



1. Spatial cell
2. In situ cast concrete
3. Spatial cell
4. In situ cast concrete

5. Spatial cell
6. Spatial cell
7. In situ cast concrete
8. In situ cast concrete

Graphic 133
Constructive details

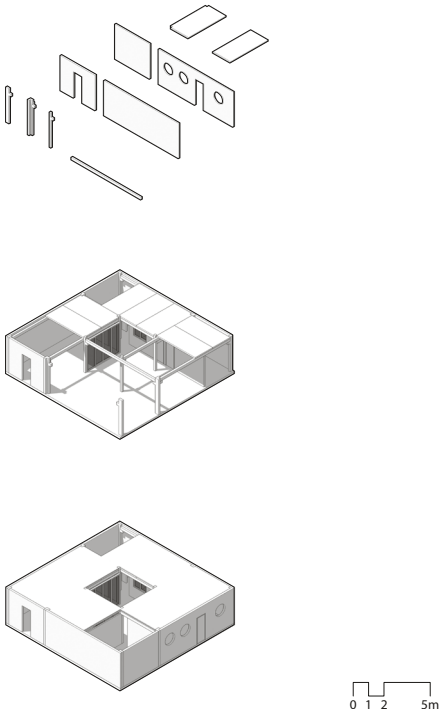
5.2.6. Other projects

5.2.6.1. PREVI Experimental Housing Project. Lima, Peru, 1966

Invited by the Peruvian Government, the Housing Bank of Peru and the United Nations (UN), in the beginning of the 1960s, British architect Peter Land began his work as a consultant in future social housing programs in this country (Land, 2008, pp. 10-11). In its initial form, the PREVI consisted of four pilot projects. The first (PP1) proposed a new neighborhood of low-cost houses with new design and construction methods, based on the results of an international competition. Altogether, four of the 26 types of housing used precast concrete structural systems.

5.2.6.1.1. Precast houses designed by James Stirling. Lima, Peru, 1966

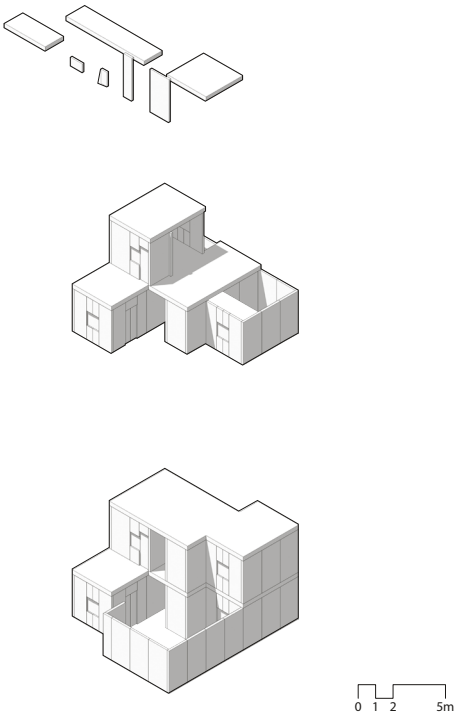
James Stirling designed these homes with a mixed system composed of structural walls on the façades and four columns in the interior space. The connections among the precast structural elements were made with metallic bars welded together. On the knots, *in-situ* cast concrete was used to increase the rigidity and to ensure the stability of the set (García-Huidobro, Torres & Tugas, 2008). The architectural designs originally proposed that the living room and bedrooms would be placed around the central courtyard. The kitchen, bathroom and laundry area would be distributed around a second courtyard, which was smaller than the central courtyard. These conditions permitted transformations of the original architecture to develop spaces destined to the neighborhood trade and enlargements of the house in free areas of the access floor, or through the construction of a second story (Lucas, Salas & Barrionuevo, 2012, pp. 56-59).



Graphic 134
Precast houses designed by James Stirling. Lima, Peru, 1966. Construction process

5.2.6.1.2. Precast houses designed by Llanos and Mazzarri

These houses were designed and built with modular precast-concrete structural walls that were joined to the slabs by metallic connectors stiffened through *in-situ* cast concrete. For each home, a backyard patio for services and a main-access patio were made. The center of the house contained the kitchen, the bathroom and the stairs. Through the patios, different degrees of privacy between the living room, dining room and the bedrooms were resolved. In these two-story homes, the stiffness of the precast façades conditioned future interventions because all of them were structural. Hence, the homes had to be enlarged in the patio areas located on the sides. These were not fully occupied to maintain the entrance of air and natural light to the interior spaces (García-Huidobro et al., 2008, pp. 110-113).



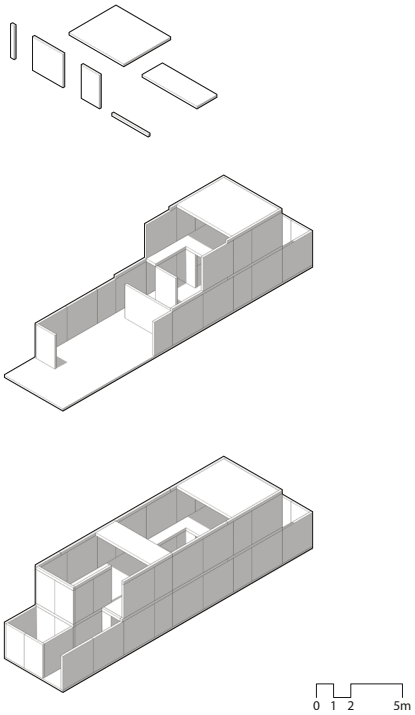
Graphic 135
Precast houses designed by Llanos and Mazzarri. Construction process

5.2.6.1.3. Precast houses designed by ATELIER 5

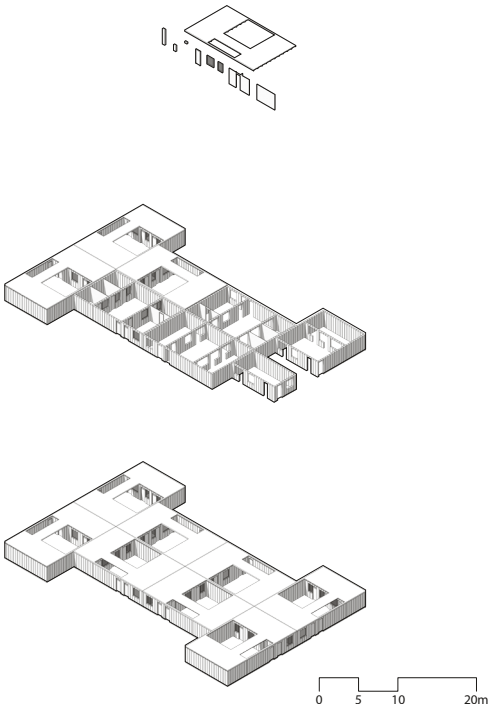
The houses were designed with a mixed system of structural walls and elements belonging to the skeletal system, such as columns and beams in precast concrete. In the construction of the project, a system of walls and precast slabs, similar to formworks, was used. The precast slabs were joined to the beams and columns by welding the structural reinforcement and then casting concrete on their knots. In these two-story homes, access was solved through a courtyard built at a mid-height level. The access, halfway up, was obtained by reusing the land from the excavation process to build the foundations. The original house proposed the program on two levels: the ground floor had the bedrooms; the upper floor had the living room, the kitchen, the bathroom and the terraces. The enlargement process began by building on top of the original terraces, taking advantage of the interior walls to build the roof. Courtyards were designed to illuminate the interior spaces, and the reform processes of the houses have not removed them, according to the need to incorporate air and natural light into the interior space. (García-Huidobro et al., 2008, pp. 78-85).

5.2.6.1.4. Precast houses designed by Montagne and Morales

In these houses, the reinforced precast concrete structural walls functioned as the lost formwork. The houses, originally conceived as having one story and projected so that their growth reached two stories, were structured around an interior courtyard measuring 4.40m on each side. In this way, the homes were joined laterally through structural dividing walls and toward the back with a wall that separated the interior courtyards. The precast elements were joined by metallic connectors welded together, with an *in-situ* concrete casting on the knots. All the spaces of the houses were designed to be illuminated and ventilated toward the main façades and toward the interior courtyard, separated by precast structural panels. On one side were the social spaces, such as the living room, the dining room and the kitchen. On the other sides were the bedrooms and a bathroom. The houses were grouped in sets of 10 units, generating urban courtyards to illuminate and naturally ventilate the main façades (García-Huidobro et al., 2008, pp. 114-116).



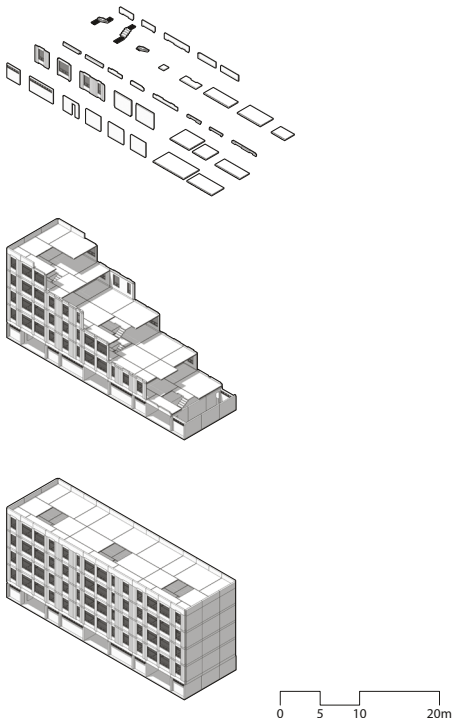
Graphic 136
Precast houses designed by ATELIER 5. Construction process



Graphic 137
Precast houses designed by Montagne and Morales. Construction process

5.2.6.2. Larsen & Nielsen, Denmark, 1960

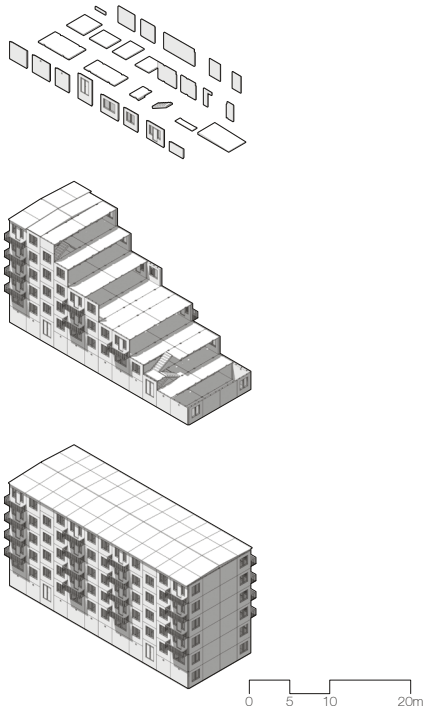
This structural wall system, designed and developed in Denmark in 1960, was widely spread in Africa, Asia and America. The degree of detail reached in the designs and the versatility of the pieces and their proportions reduced the construction time on site. With this series, buildings up to 12 stories tall were constructed. The joints were resolved through assemblies, metallic bars and *in-situ* concrete castings. In order to make the projects feasible, the architectural designs were rationalized in the production plants to improve standardization in the production and process' efficiency. The Larsen & Nielsen prefabrication technology was adapted to different architectural designs, allowing each project to have a set of structural components with different ranges of measurements. The construction details with which the precast elements were designed and produced extended the possibilities of use and allowed their adaptation to several contexts (Alonso & Palmarola, 2014, pp. 224-225).



Graphic 138
Larsen & Nielsen, Denmark, 1960. Construction process

5.2.6.3. 1-464, Former Soviet Union, 1960

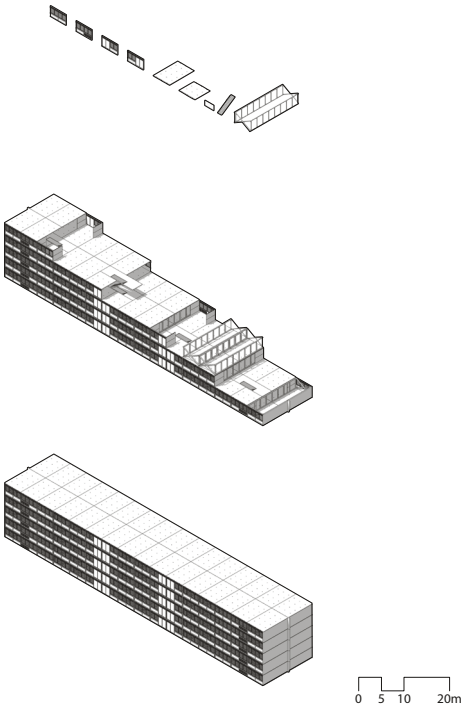
The 1-464 prefabrication series was inspired in the Camus structural system for its technical developments. Comprised of structural walls, it was designed to achieve the largest construction area with the lowest consumption of concrete; it was the second cheapest housing in the former USSR and one of the most widely constructed in Eastern Europe between 1960 and 1980. With these prefabricated elements, residential buildings up to five stories tall were built. The free interior heights of the houses reached up to 2.55m and the apartments had one or two bedrooms. The mezzanine slabs were produced with a partial prefabrication and the finishes were installed on site. The joints were designed with steel bars between the precast panels; they were stiffened with an *in-situ* concrete casting. The level of comfort in these houses was widely questioned, as the living areas were narrow, the acoustic insulation of the walls and slabs did not function adequately and the buildings lacked elevators. The houses of the 1-464 series were produced until the mid-1990s (Alonso & Palmarola, 2014, pp. 200-201).



Graphic 139
1-464, Former Soviet Union, 1960. Construction process

5.2.6.4. Jugomont 61, Former Yugoslavia, 1961

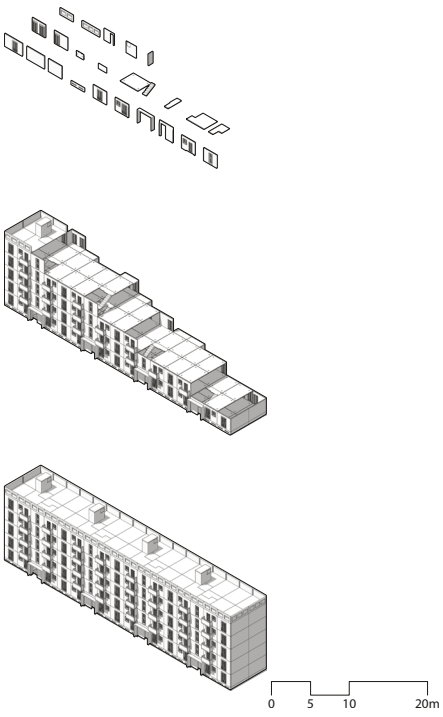
This system, based on structural walls, was used in the construction of housing projects in former Yugoslavia in the 1960s and 1970s. Other lightweight, removable precast elements – such as aluminum and wood panels, generally specified for the façades – were added to the reinforced precast concrete panels. This condition allowed the replacement of obsolete or weathered components and the renovation of the buildings. In *Neues Bauen in der Welt* (1965), Udo Kulterman wrote that this precast series was the one that most approached the concept of "machines for living", proposed by modern architecture (Kulterman, 1965). The structure was located inside the buildings, in the living spaces, leaving the façades free to be resolved with non-structural precast elements. The unions between its components were made with metallic connectors and concrete joints. With this series, approximately 30,000 housing units were built, with an average height of six stories, over a period of 20 years. It had 10 types of precast elements and attained a wide possibility of constructive combinations with different technical and aesthetic responses (Alonso & Palmarola, 2014, pp. 222-223).



Graphic 140
Jugomont 61, Former Yugoslavia, 1961. Construction process

5.2.6.5. Ital-Camus, Italy, 1960

This system, based on structural walls, was the Italian adaptation of the Camus French prefabrication patent, which began in 1960. For this new development, some modifications were made in technical, functional and aesthetic terms. The interior perimeter of the homes was made up of structural panels. The façade walls reached up to 24cm per section and were specified with interior and exterior layers of precast concrete, separated by mineral wool that served as thermal and acoustic insulation. The fundamental difference with the French version was the reduction of the set of joints and assemblies with metallic bars and elements between the panels, which simplified the process compared to the original system. The largest production of houses with the Ital-Camus series occurred between 1960 and 1975, mainly in five-story buildings (Alonso & Palmarola, 2014, pp. 230-231).



Graphic 141
Ital-Camus, Italy, 1960. Construction process

5.3. 1970s

5.3.1. Large Panel 70 (Gran Panel 70). Cuba, 1970



Graphic 142
Exterior view

Large Panel 70 (Gran Panel 70). Cuba, 1970	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	Osmundo Machado, Grupo Nacional de Viviendas
Average areas per home (in square meters)	60
Number of housing units (on average, per building)	20
Average height of the buildings (in number of stories)	5
Number of types of precast elements	16
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	5
Interior walls	6
Mezzanine slabs	4
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	0
Stairs	1
Structural spatial cells	0
Types of joints	Metal bars and *in situ* cast concrete

Information taken from: Alonso and Palmarola, 2014, pp. 208-209, 253, 298-299.

Table 27
Large Panel 70 (Gran Panel 70). Cuba, 1970.

System and building

After the experiences in Cuba with the Large Soviet Panel and with the Large Panel IV, Architect Osmundo Machado and the National Housing Group Directorate proposed two fundamental objectives to develop new residential units with higher quality, shorter time and lower costs. The first was to consolidate the technological base necessary for the prefabrication of housing; the second, to consolidate an open general prefabrication system based on a technical regulation and a range of dimensions to standardize the precast elements produced in Cuba. The Large Panel 70 was the first step in this search, due to its versatility in the plant and in the façade, which permitted the use of elements belonging to other construction systems.

This series, based in structural walls, was conceived and developed following the Dutch Larsen & Nielsen model to provide a more open prefabrication model, allowing the use of other industrialized components and other materials, increasing their adaptability to different contexts. The joints between the pieces were made with metallic bars and in-situ cast concrete on the knots. Residential buildings were constructed with an average height of five stories. The economic crisis of the 1990s, after the fall of the Berlin Wall, reduced trade between Cuba and the countries in Eastern Europe, leading to the abandonment of heavy industrialization while seeking other types of solutions to social housing (Alonso & Palmarola, 2014, pp. 208-209).

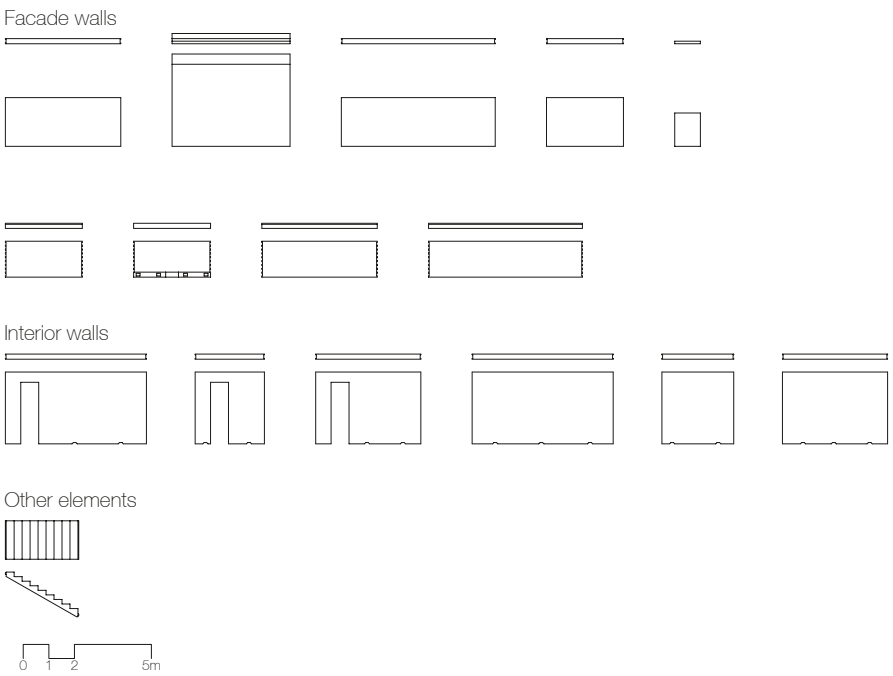
This system permitted the development of new variants of prefabrication of housing in Cuba. It used metallic sliding molds for the prefabrication of structural elements, with which a 17-story residential building was constructed in Havana in the mid-70s. It also permitted the insertion of a prefabricated bathroom and kitchen module, produced in an industrial plant and inserted into the free space of the cell.[41] These technical solutions, derived from the improvement of the system, allowed increasing the efficiency and productivity in the construction of social housing with respect to systems, such as the Sandino method, previously considered and the improvement of the functional, productive and design standards.[42]

An evolution of the system was the design and production of the *Spiroll* lightened slab, which reduced building components and reached distances between 8m and 12m. The living units that used the precast structural panels and this type of slab were conceived in terms of a single space subdivided by light panels and furniture, made the system more flexible, permitted the variation in height of the blocks and integrated services into the living space.[43]

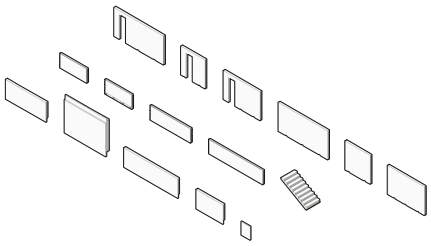
41 Construction systems for social housing and buildings in the Cuban Revolution. Ministry of Construction. Havana, 1981, p. 45; Salvador Gomila, Experiences in the Technological Development of Housing. Construction Information Center, Havana, 1981, p. 24.

42 Estévez, Reynaldo. Popular Powers and the Housing Plan: Ways to extend resources to increase the construction of homes. In: VII Seminar of Housing and Urban Planning. Volume 2. Desa, Ceditec. Havana, 1977, p. 69.

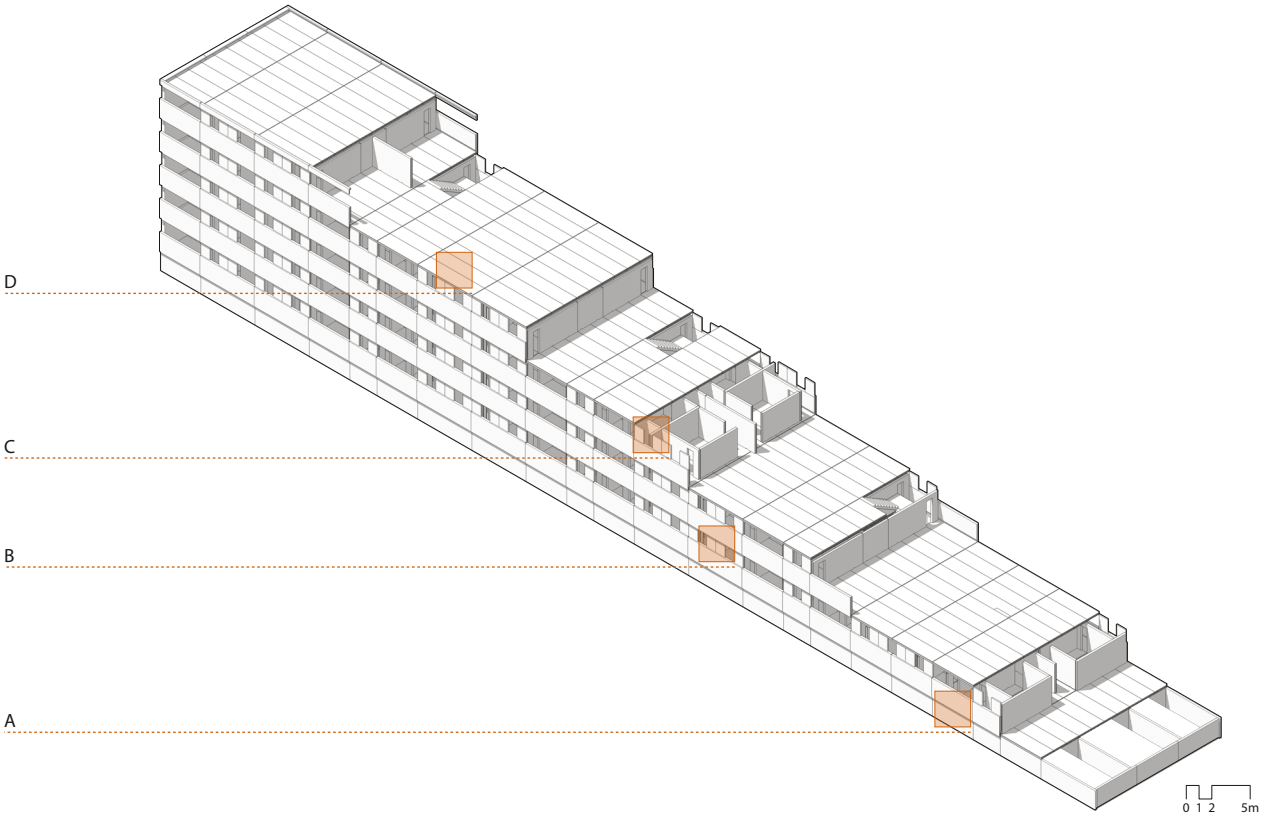
43 Segre, Roberto. Three decades of reflections of the Latin American habitat. National University of Colombia, 2005, 171 p.



Graphic 143
Components: floor plans and façade

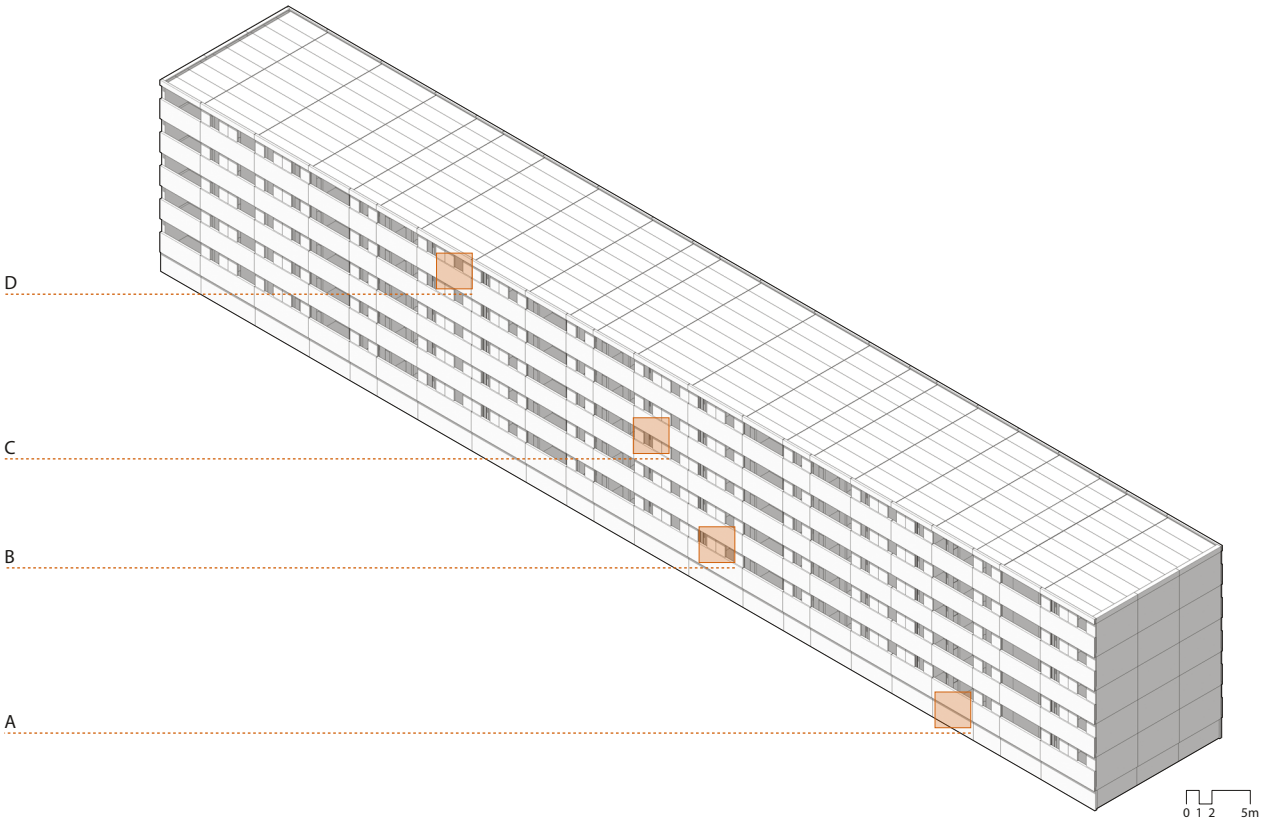


0 1 2 5m



Graphic 144
Components: axonometry

Graphic 145
Construction process



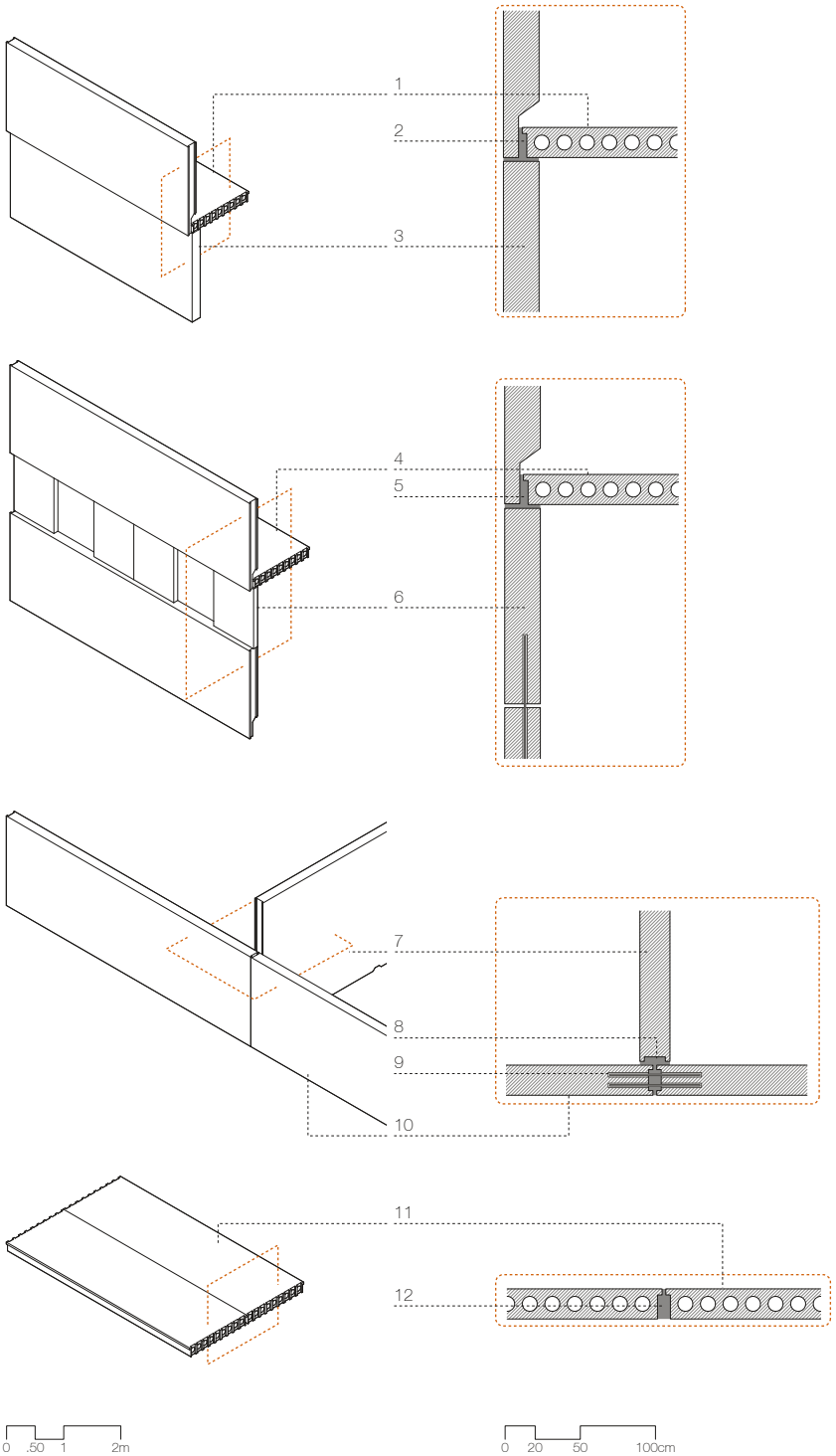
Graphic 146
The technical system and the architectural language

Advantages

- In addition to standardizing a range of dimensions for the production of prefabricated elements, the system permits the inclusion of other materials and elements dimensionally coordinated among each other, to expand the possibilities of industrialization.
- With different configurations in the plan or volume, due to the proportions of the elements and the designs of their metallic joints stiffened in concrete, this series can be repeated in different geographic contexts from the combination between its prefabricated elements and other materials or systems. This open-prefabrication system permits the use of other materials related to the context and the presence of local labor in construction processes.
- The dimensions of the precast panels allows their transport and access to different urban or rural contexts, or the production of the elements that make it up at the project site.
- This series permits the adaptation of other materials and industrialized or local construction systems, which permits extending the technical, aesthetic and construction possibilities in different contexts.
- The combination with other elements or construction systems from the same dimensional module allows this series to have different languages, interior spaces, housing typologies and uses by the communities.
- The presence of other materials and systems permit establishing principles of cross ventilation, control of solar incursion and well being in the design of the interior space.
- The combination with other systems and materials expands the possibilities of the language of the system, according to the materials used in the local contexts and with the traditions.
- Non-structural elements inside the living space allow the modification of the dwellings by the families that occupy them, according to their needs or desires.

Disadvantages

- Each element of the slab, façade and wall must be assembled individually in the work process. Although the designs of the joints (in metallic bars stiffened with concrete castings) permit standardizing the hoisting process and the joints among the pieces, the number of assemblies on site reduces the efficiency of the process.



1. Precast concrete slab
2. In situ cast concrete
3. Precast concrete facade wall
4. Precast concrete slab
5. In situ cast concrete
6. Precast concrete facade wall
7. Precast concrete interior wall
8. In situ cast concrete
9. Steel bars
10. Precast concrete facade wall
11. Precast concrete slab
12. In situ cast concrete

Graphic 147
Constructive details

5.3.2. WBS 70 (Wohnhungsbauserie 70). Former German Democratic Republic, 1970



Graphic 148
Exterior view

WBS 70 (Wohnhungsbauserie 70), Former German Democratic Republic, 1970	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	Deutschen Bauakademie, TU Dresden
Average areas per home (in square meters)	32, 45, 67, 78, 90
Number of housing units (on average, per building)	28
Average height of the buildings (in number of stories)	7
Number of types of precast elements	68
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	6
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	24
Interior walls	8
Mezzanine slabs	16
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	12
Stairs	2
Structural spatial cells	0
Types of joints	Metal bars, welding and cast concrete

Information taken from: Alonso and Palmarola, 2014, pp. 202-203, 250, 290-291.

Table 28
WBS 70 (Wohnhungsbauserie 70). Former German Democratic Republic, 1970.

System and building

This structural wall system was developed by the German Academy of Construction (*Deutsche Bauakademie*) and by the Technical University of Dresden (*Technische Universität Dresden*) since 1970. From the beginning of the German Democratic Republic's Radical Democratic Party principle of "a dwelling for each person", the conception and development of five types of housing, with an area of between 32 and 90 m², which used concrete structural panels, began. The joining process was done with metallic bars and weldings, with *in-situ* concrete castings that stiffened the knots. This series was developed to be adapted to different topographic conditions by varying the proportions of its elements. Collective circulations were reduced so that the private areas of the homes were larger. Variability in the sizes of the apartments, the occupancy density and the height of the buildings (generally between five and seven stories) were defined from the proportions of the precast modules with which they were designed (Wikiwand, n. d.). Detailed design work and textures –including stone finishes, ceramic veneers or paints– were incorporated into the panel surfaces in order to diversify their language and generate other aesthetic conditions (Alonso & Palmarola, 2014, pp. 202-203).

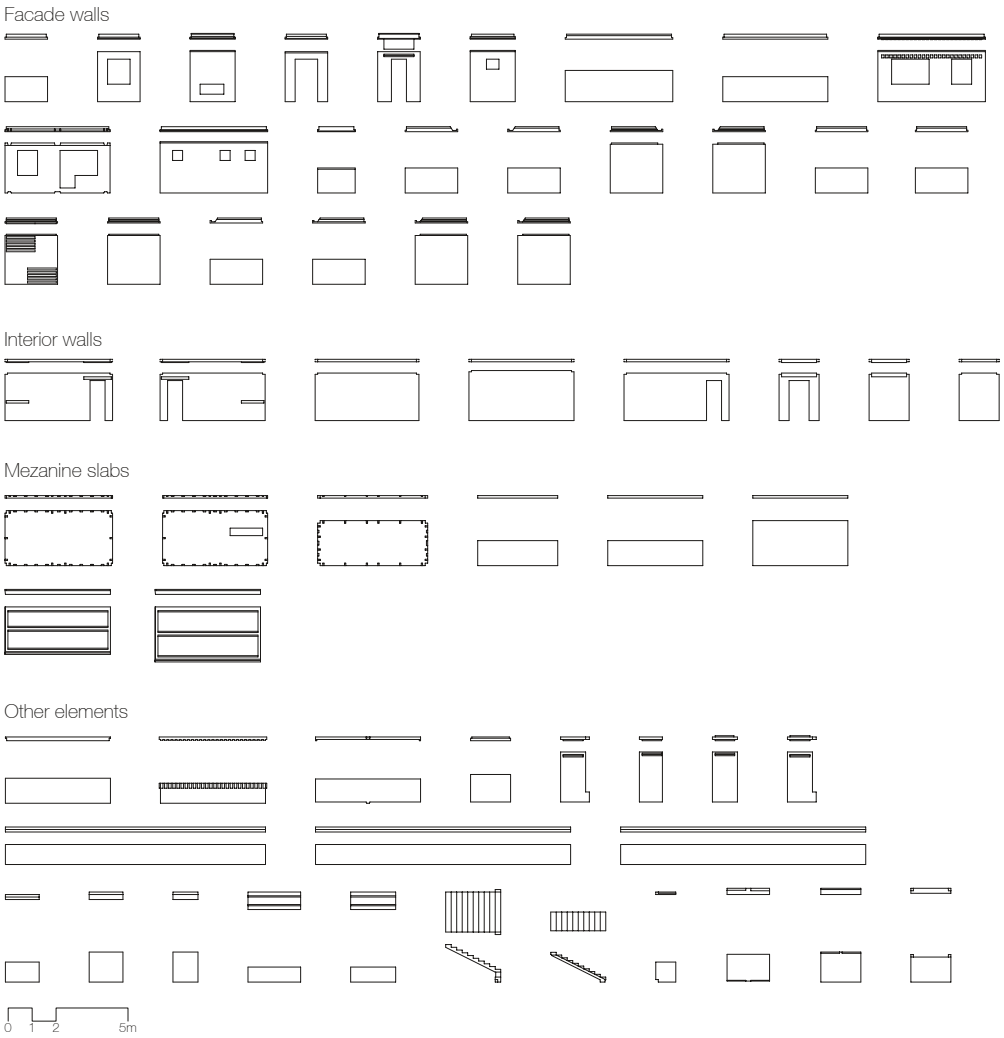
For the development of this system, a reduced number of structural elements was implemented, which permitted different combinations in the design and construction processes of the dwellings. The production of the first elements of this series began in October 1972; in April 1973, the assembly began on the first five-story apartment building in the western part of the city of Neubrandenburg, Germany. Of the 1.5 million homes built in the *Plattenbau* (Structural Panels) between 1973 until 1991, 644,900 belong to this system, nearly 42% of the total amount.

This series was mainly used because the flexibility that allowed the design of the house was greater than that of other systems used.[44] The load-bearing walls were located at a distance of 6m. The design concept of the interior space was proposed with a service unit that associated the kitchen and the bathroom (the latter without natural lighting or ventilation) to leave the social area and rooms as free spaces. This system was developed with wall modules measuring 6.00m x 2.80m; the ceiling slabs measured 6.00m x 3.00m when produced in prestressed concrete and 3.60m x 3.00m in reinforced concrete.[45] Its architectural conception reduced the circulation areas to the maximum so that the living areas were greater.[46]

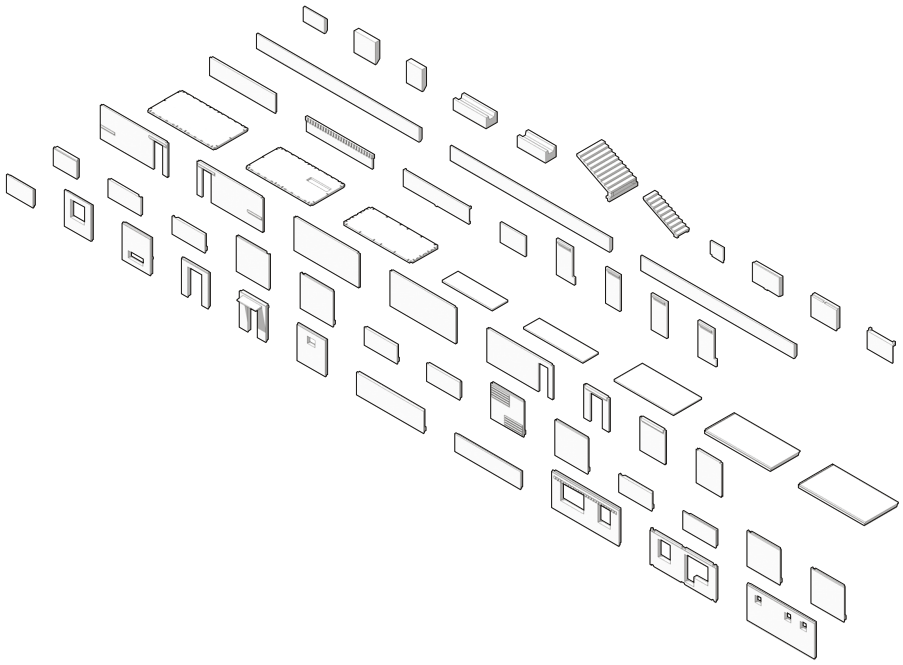
44 WBS 70, *die Einheistplatte*. In: Jeder m2 Du: *das Plattenportal*. Accessed June 4, 2017; available at: https://www.jeder-qm-du.de/ueber-die-platte/detail/wbs-70/.

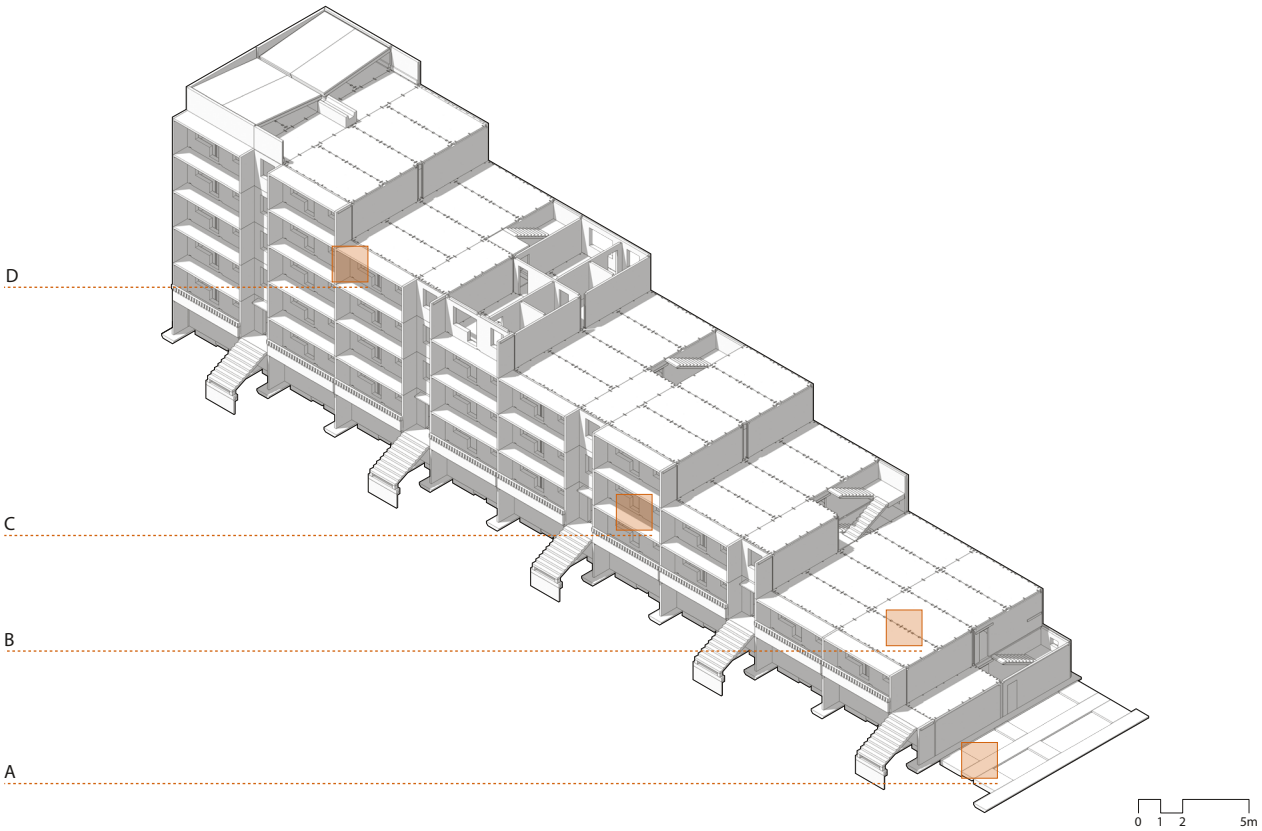
45 Bauakademie der DDR: *Wohnungsbauserie* 70. *Ersteinführung im VEB* (B) *Wohnungsbaukombinat Neubrandenburg,* 1. Ausgabe 1974.

46 WBS 70, *die Einheistplatte*. In: Jeder m2 Du: *das Plattenportal*. Accessed June 4, 2017; available at: https://www.jeder-qm-du.de/ueber-die-platte/detail/wbs-70/.



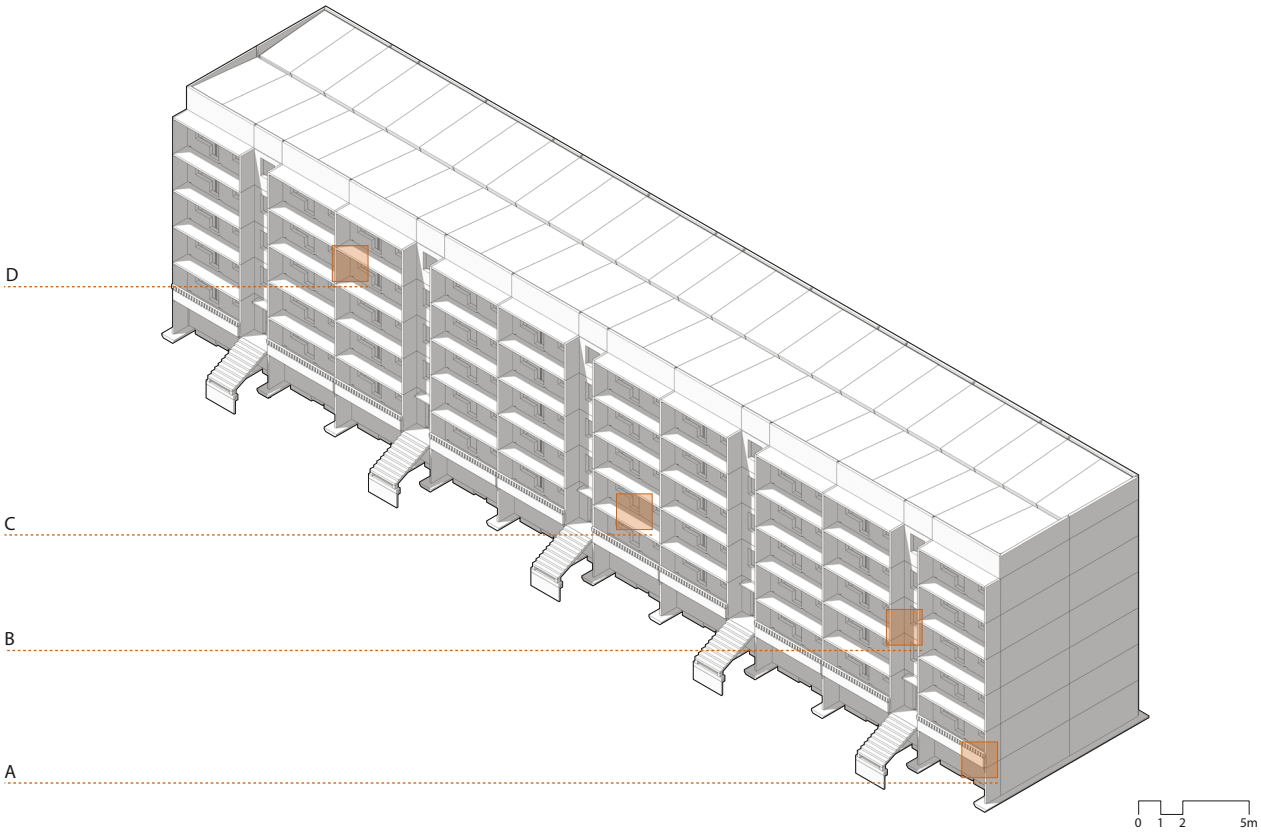
Graphic 149
Components: floor plans and façade





Graphic 150
Components: axonometry

Graphic 151
Construction process



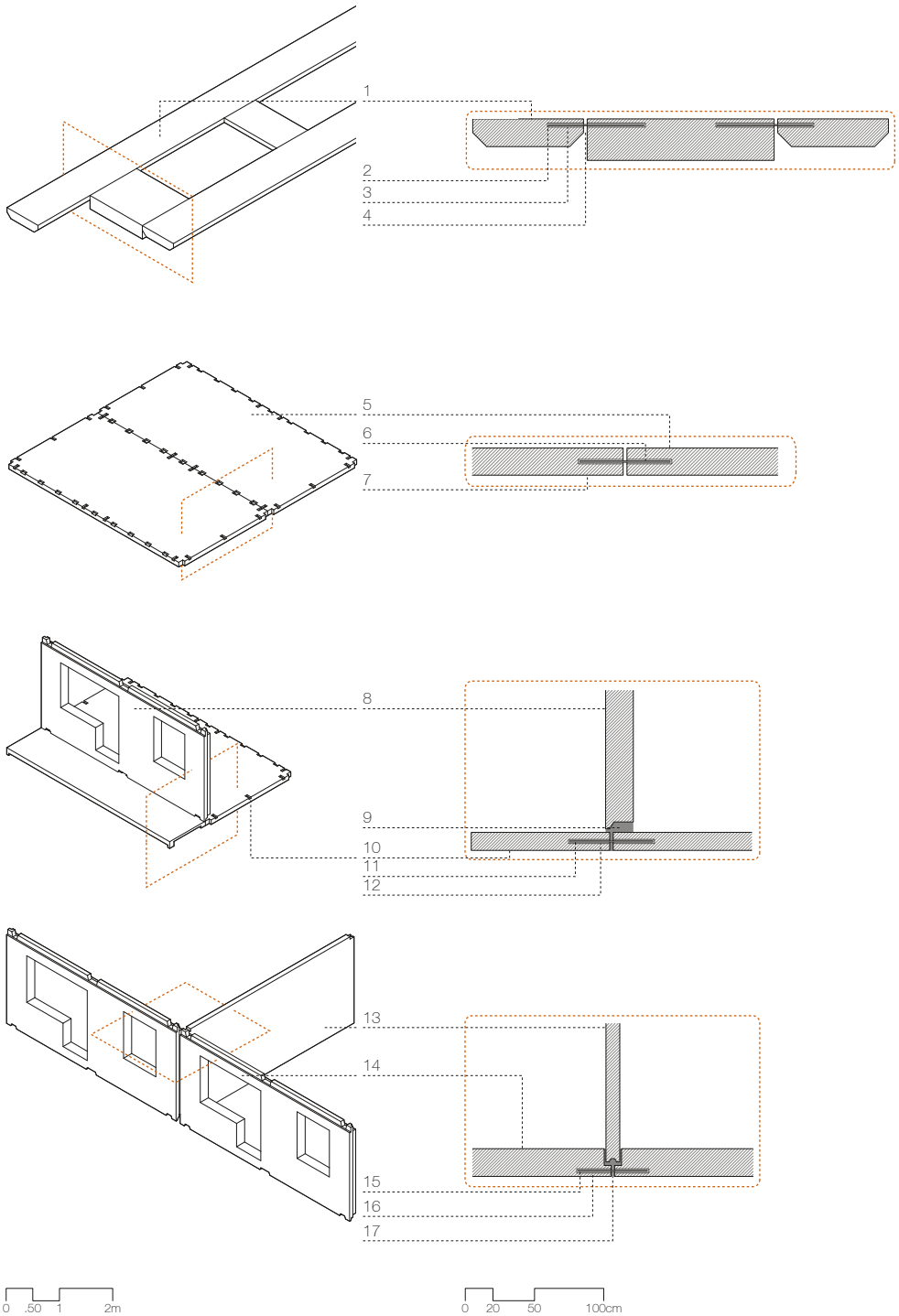
Graphic 152
The technical system and the architectural language

Advantages

- The series is designed from modular coordination among the slabs, façades and interior walls. All the elements are defined from a base modulation of 1.20m x 1.20m, which allow other materials or components to be part of the designs from these proportions.
- The layout of the panels to form the support structure, the designs of the joints and the versatility of the system allowed the construction of 644,900 housing units from 1973 to 1991, an average of 33,942 homes per year.
- The dimensions of the panels (even those 6.00m long, which were the longest in the system) allow the transport of the precast elements from the industrial plants to the construction sites. The concrete volumes of these elements also allow them to be produced in temporary plants located on site.
- The flexibility of the system and the modularity of these pieces allows designing houses with different areas using the same structural elements, which generates the possibility of considering a wider market with different types of families and in different geographic contexts.
- The location of structural elements at a distance of 6.00m allows the variability of sizes of apartments with different typologies from the sum of the modules, ranging from 32.31 m^2 (with one bedroom) to 102.48 m^2 (with five bedrooms).
- To respond to bioclimatic conditions, the exterior walls are formed by three layers with a central core for thermal insulation. In the local context, a single wall, without thermal insulation and with a thickness corresponding to the structural designs, is sufficient to be part of the system.
- The location of structural walls every 6m allows intervening in the inhabited space according to the conditions that each family requires in the process of inhabiting the housing. According to the versatility in the designs and the management of areas, the occupation of the interior space could modify non-structural elements according to the needs of the families.

Disadvantages

- When conceived as individual elements, the joints of the façade panels, slabs and interior walls in the assembly process increases the number of fixations and, therefore, time in the construction process.
- Textures on the surfaces of the façade panels and different sizes of windows or doors define the language of the project. The construction of façades with structural elements reduces the design possibilities of the project language and, therefore, reduces the possibility of establishing participatory designs with the communities or modifying the appearance of the project in the occupation process.



1. Precast concrete foundation
2. Steel bars
3. In situ cast concrete
4. Welding
5. Precast concrete slab
6. Steel bars
7. In situ cast concrete
8. Precast concrete facade wall
9. Welding
10. Precast concrete slab
11. Steel bars
12. In situ cast concrete
13. Precast concrete interior wall
14. Precast concrete facade wall
15. Steel bars
16. In situ cast concrete
17. Welding

Graphic 153
Constructive details

5.3.3. *Genter Straße* Residential Complex. Munich (Phase 1), Germany, 1972



Graphic 154
Exterior view

***Genter Straße* Residential Complex,** Munich (Phase 1), Germany, 1972	
Type of structure	Skeletal
Type of prefabrication	Open
Architect, inventor or designer	O. Steidle, R. Thut, D. Thut
Average areas per home (in square meters)	56, 97, 106
Number of housing units (on average, per building)	7
Average height of the buildings (in number of stories)	7
Number of types of precast elements	6
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	2
Beams	2
Facade panels	0
Interior walls	0
Mezzanine slabs	2
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	0
Stairs	0
Structural spatial cells	0
Types of joints	Metal bars and fixings

Information taken from: Pawlitschko, 2011.

Table 29
Genter Straße Residential Complex. Munich (Phase 1), Germany, 1972.

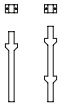
System and building

The three phases of this housing complex, designed by Otto Steidle, Raph Thut and Doris Thut in 1972, are made up of four sets of buildings between the Genter, Peter-Paul Althaus and Osterwald Streets. The project was conceived through a skeletal structural system, consisting of regularly spaced columns with corbels at half-story intervals, longitudinal and crossbeams, and floor slabs. Metallic connectors, such as bars and bolts, ensured the stability necessary (Fernández, 2009). The architectural intention was to create a neutral framework in precast concrete, which would permit the installation of housing modules with flexible interior spaces adapted to the needs of its residents (Pawlitschko, 2011). The configuration of the building was made through three-story-high split levels, which had a central staircase in each house to integrate its different uses until arriving at a terrace at the top.

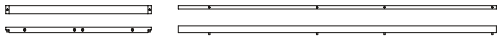
The arrangement of the structural elements in the project allowed future enlargements of the houses. The non-structural elements such as metal profiles, plasterboard panels and aluminum coating, were also produced industrially with other materials, giving way to the open precast system (Musso, 2016, p.103). Steidle described his approach as "unfinished prefabrication", whereby "it is possible to have different design qualities and choose different price levels through identical primary structures. Expensive perfectioning-simple functionality" (Steidle, 1974, as cited in Musso, 2016, p. 104). In this project, the primary structure in precast reinforced concrete generated an order. Theoretically, users could enlarge their homes in the future and use them according to the size of the family or according to their economy. In this project, the rationality of the structural system was combined with the flexibility of the non-structural elements. Partial prefabrication helped to achieve diversity in the language from a predetermined structure with a specific order (Krippner, 2001, pp. 606-607).

The prefabricated elements in this building transmit a clear distinction between the skeletal support structure and its complementary systems. The use of industrialized systems was complemented with the materials that ended up configuring the project and its surrounding environment. To the residential vocation of the building, some of its areas were also used as offices. The massification of a structural system with a limited number of elements that make it up and that permit different typologies of housing centered Steidle's reflection in the consideration of the inhabitants of the project and not only in its standardization. After its construction, this residential complex maintained its appearance and original functions. In addition to permitting flexibility in the division of the houses and their areas, the structural frames created by the precast-concrete columns and beams generated diversity in terms of size and occupancy of the dwellings.

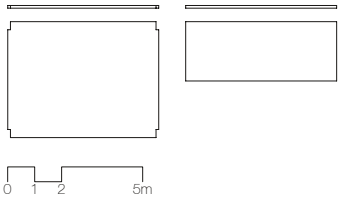
Columns



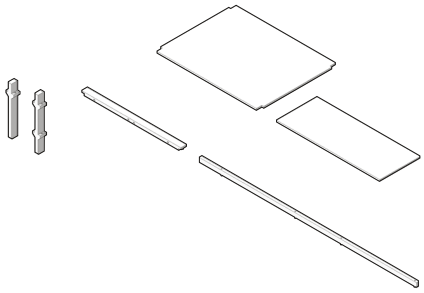
Beams

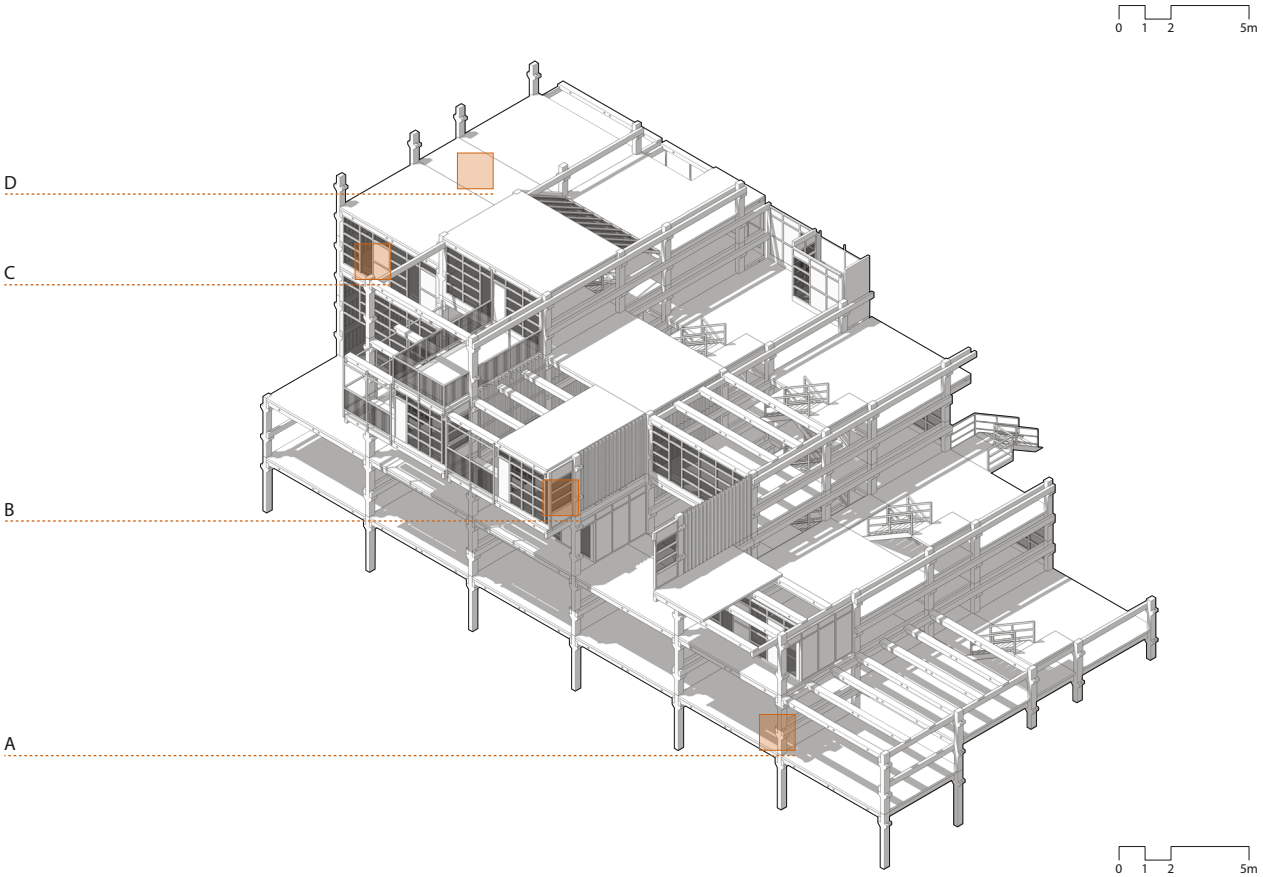


Mezzanine slabs



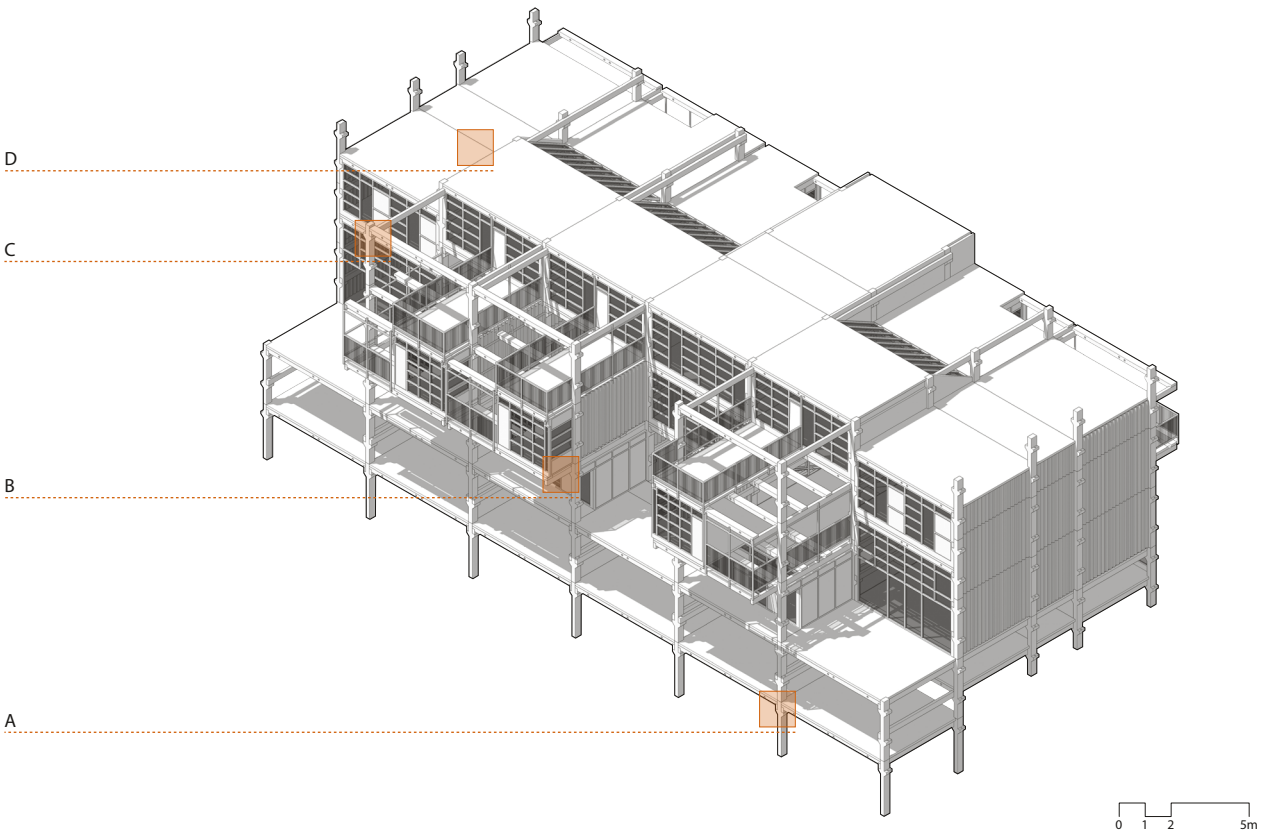
Graphic 155
Components: floor plans and façade





Graphic 156
Components: axonometry

Graphic 157
Construction process



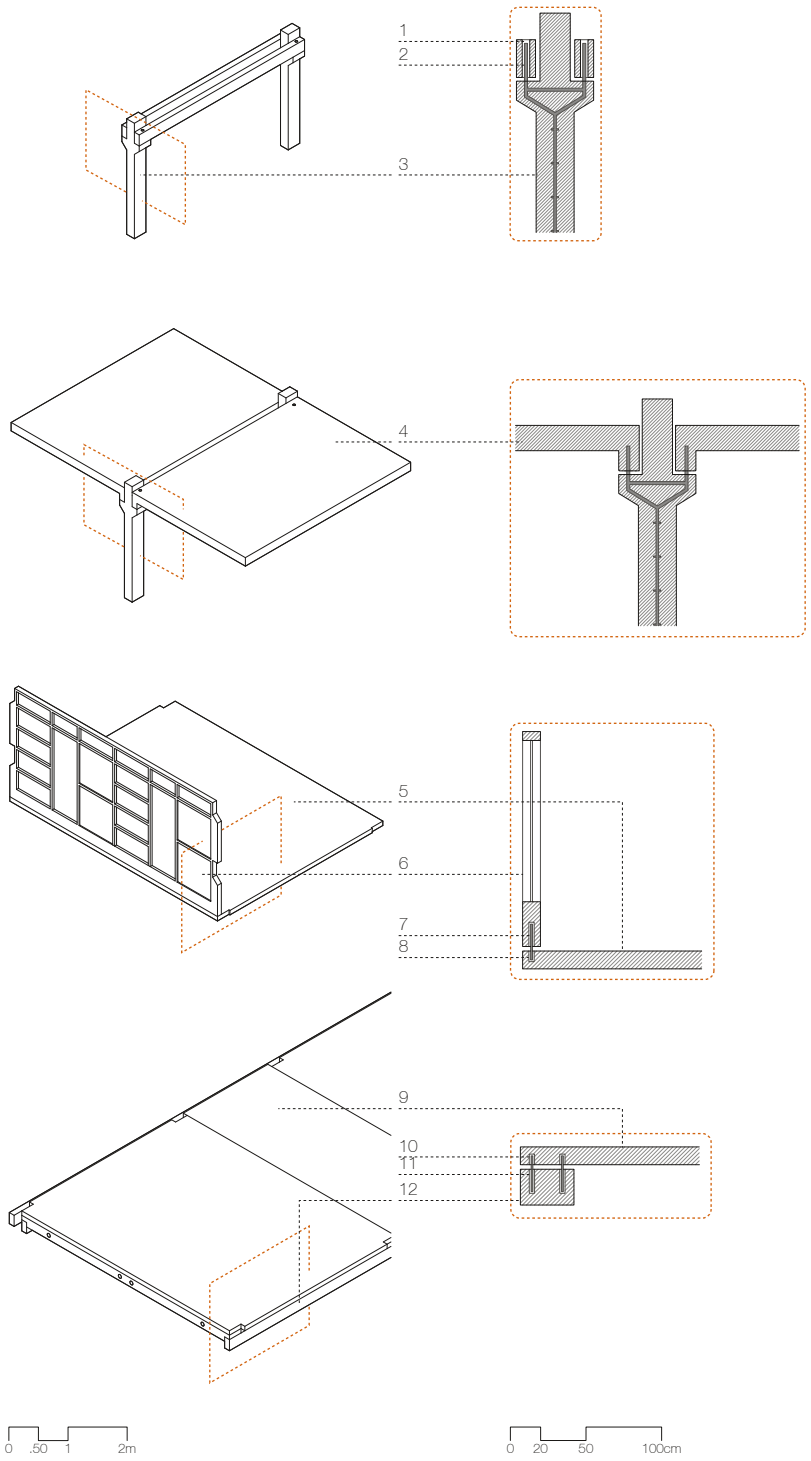
Graphic 158
The technical system and the architectural language

Advantages

- A reduced number of variants in the typologies of the structural elements are dimensionally coordinated with other elements or construction systems that can be part of the project.
- A girder system of precast-concrete beams, columns and floor slabs allows using these elements in different architectural designs. This open, partial prefabrication resolves what the communities could not do for themselves: the support structure and the bathroom and kitchen units (prefabricated in other systems) and permits local materials, other industrialized systems and local labor being used in other contexts for the construction of non-structural elements, such as the façades and interior walls.
- The volume and dimensions of the structural elements allow transport to be made in vehicles with different capacities, which increases the number of transported units.
- The elements permit adapting its geometry and that of its designs to the characteristics of the site, to the conditions of the topography and to the dimensions of the buildings.
- The configuration of the building from the skeletal structural elements permits enabling housing in the access levels and activities complementary to residential use. The distances between columns allow accessibility systems, such as ramps or elevators, can be implemented in the designs of the dwellings. The non-structural elements can define circulation widths and spaces so that they are accessible.
- The mounting of the support structure is made by simple supports between beams and columns or by welded joints between these elements. The beams are supported on brackets previously arranged in the columns, which streamlines the installation process of the project structure.
- The arrangement of the beams and columns permits locating the dwellings in different positions in the structure with different areas.
- Freedom in the design of the façades without structural elements permits bioclimatically designing the interior space in different contexts.
- The flexibility of the system allows contrasting the rationality of the support structure with the façade designs where other industrialization systems. The structural systems do not condition the aesthetic conditions or the language of the building.

Disadvantages

- The system of foundations for skeletal structural elements (beams and columns) requires depths according to the load-bearing capacity of the terrain, the loads of the building and the seismic area. In the local context, the territories available for the construction of social housing are generally on hillsides, in intermediate- or high-seismic areas and with low load-bearing capacities, which makes the cost of the foundations as high as those used in conventional construction systems.



1. Fixing
2. Steel bars
3. Precast concrete column
4. Precast concrete slab
5. Precast concrete slab
6. Precast concrete facade element
7. Steel bars
8. Fixing
9. Precast concrete slab
10. Steel bars
11. Fixing
12. Precast concrete beam

Graphic 159
Constructive details

5.3.4. Soviet KPD System (Krupnopanelnoye Domostroyenie). Chile, 1972



Graphic 160
Exterior view

Soviet KPD System (Krupnopanelnoye Domostroyenie), Chile, 1972	
Type of structure	Structural walls
Type of prefabrication	Closed
Architect, inventor or designer	Vitaly Lagutenko
Average areas per home (in square meters)	60
Number of housing units (on average, per building)	20
Average height of the buildings (in number of stories)	4 to 5
Number of types of precast elements	27
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	5
Facade panels	11
Interior walls	5
Mezzanine slabs	3
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	2
Stairs	1
Structural spatial cells	0
Types of joints	Metal bars and *in situ* cast concrete

Information taken from: Alonso and Palmarola, 2014, pp. 186-187, 242, 270-271.

Table 30
Soviet KPD System (Krupnopanelnoye Domostroyenie). Chile, 1972.

System and building

The name Krupnopanelnoye Domostroyenie is where the Russian acronym KPD (КПД) comes from, and means "construction in large panels". The development of this series corresponds to successive adaptations of the Camus system (patented in 1948), transformed in the USSR to the 1-464 series (developed since 1956) and subsequently in Cuba, using the Large Soviet Panel in 1965. KPD shared structural walls with these systems and the same technical principles. After the *Los Vilos* earthquake in Chile on July 8, 1971, with a magnitude of 7.75 on the Richter scale, the Chilean Government received the donation of a plant to produce precast concrete panels from the USSR. This plant was located in El Belloto industrial area in the town of Quilpué, northwest of Santiago (Alonso & Palmarola, 2014, pp. 186-187).

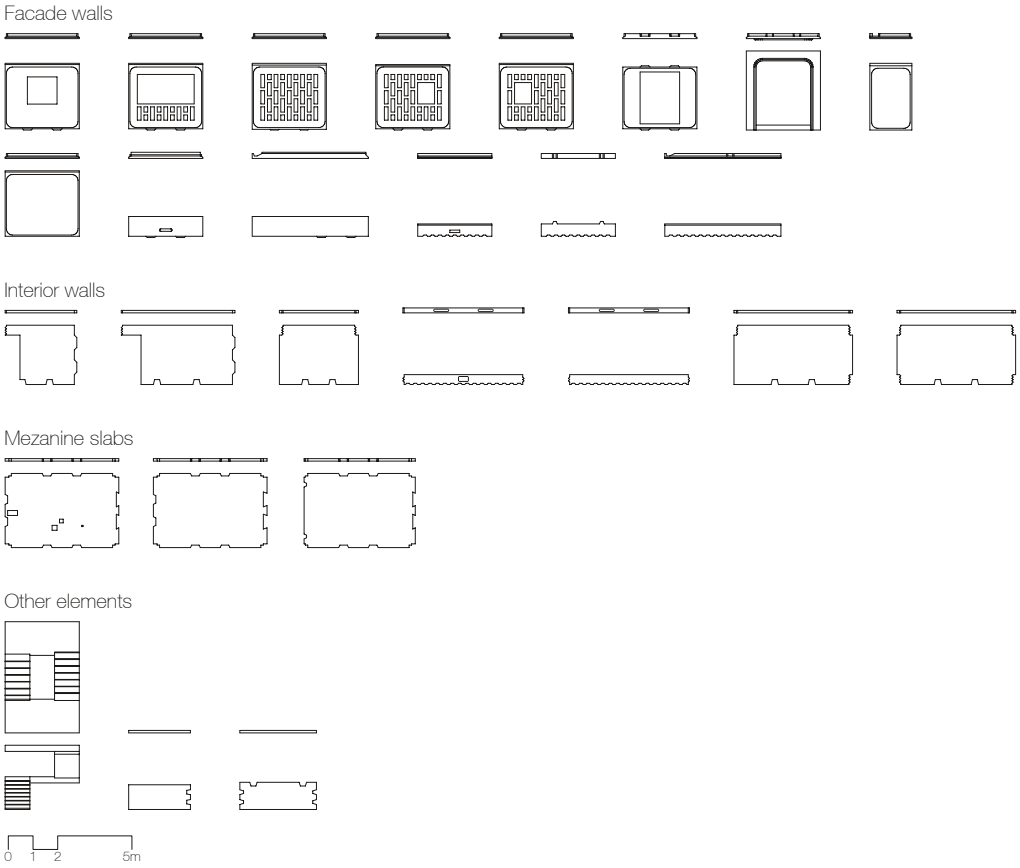
In July 1973, the first 48 apartments were constructed in Quilpué, and were four stories tall. The Chilean KPD plant generated precast concrete elements for the construction of 140,000 m² to be divided among 1,600 apartments per year, located in 153 housing blocks in the cities of Quilpué, Valparaíso, Viña del Mar and Santiago. Each block had 16 apartments with two different conceptions: the first with six apartments, each having three bedrooms and an area of 84 m²; the second with ten apartments, each having two bedrooms and an area of 67 m². The joints between the structural elements were designed with steel bars and *in-situ* cast concrete between the joints (Alonso & Palmarola, 2014, pp. 186-187). A political condition of precast concrete was presented as a "unified effort" between Chile and the former Soviet Union, which would permit the construction of "taller buildings with healthy, clean and affordable apartments" (Alonso & Palmarola, 2012, pp. 305-306) The slogan "From the shovel to the button" was used to show the technological advances offered by prefabricated construction (Alonso & Palmarola, 2012, pp. 305-306). Even after the 1973 military coup and the overthrow of Salvador Allende's government, the plant remained open with the Soviet machinery and production techniques, but had an unstable operation. In 1979, the plant closed its production and in the early 1980s it was dismantled (Alonso & Palmarola, 2012, pp. 306-307).

In addition to this extinct factory, there are 153 buildings and more than 3,500 housing units in Chile that were built from the technical principles proposed by this structural system. Of the 153 buildings, only 30 were built under the Chilean-Soviet administration. The rest were built with the KPD factory, transformed since the military coup of 1973, under the name of Prefabricated Economic Housing *(Vivienda Económica Prefabricada,* VEP). From that moment, the Russian advisors were expelled from Chile and some of the plant workers were detained. This experience in the construction of social housing had a great impact due to its technical conditions and its coverage. The plant was designed to product 1,600 housing units annually, each with 84 m² of area. These buildings have withstood all the earthquakes that have occurred in Chile since 1973.[47]

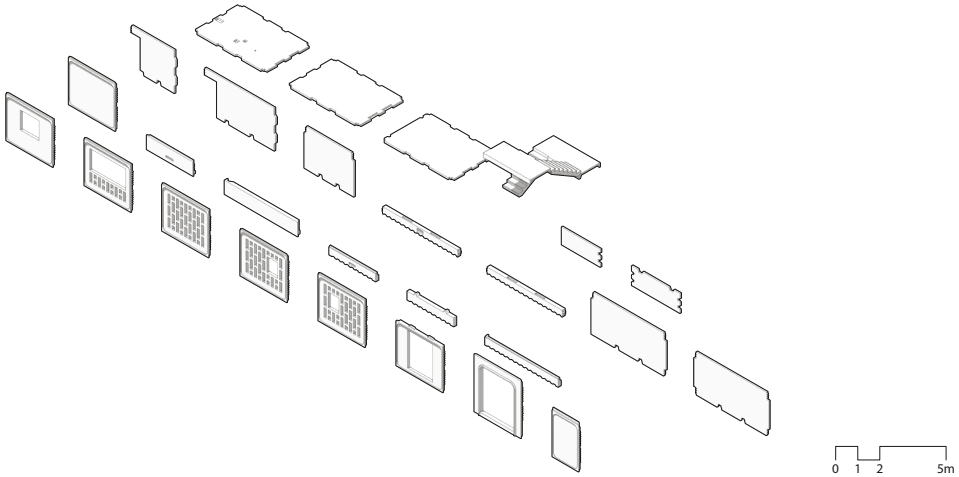
To date, no other industrialization system has surpassed Chile's production volume, cost and time efficiency and constructed areas for the dwellings of the KPD system.[48]

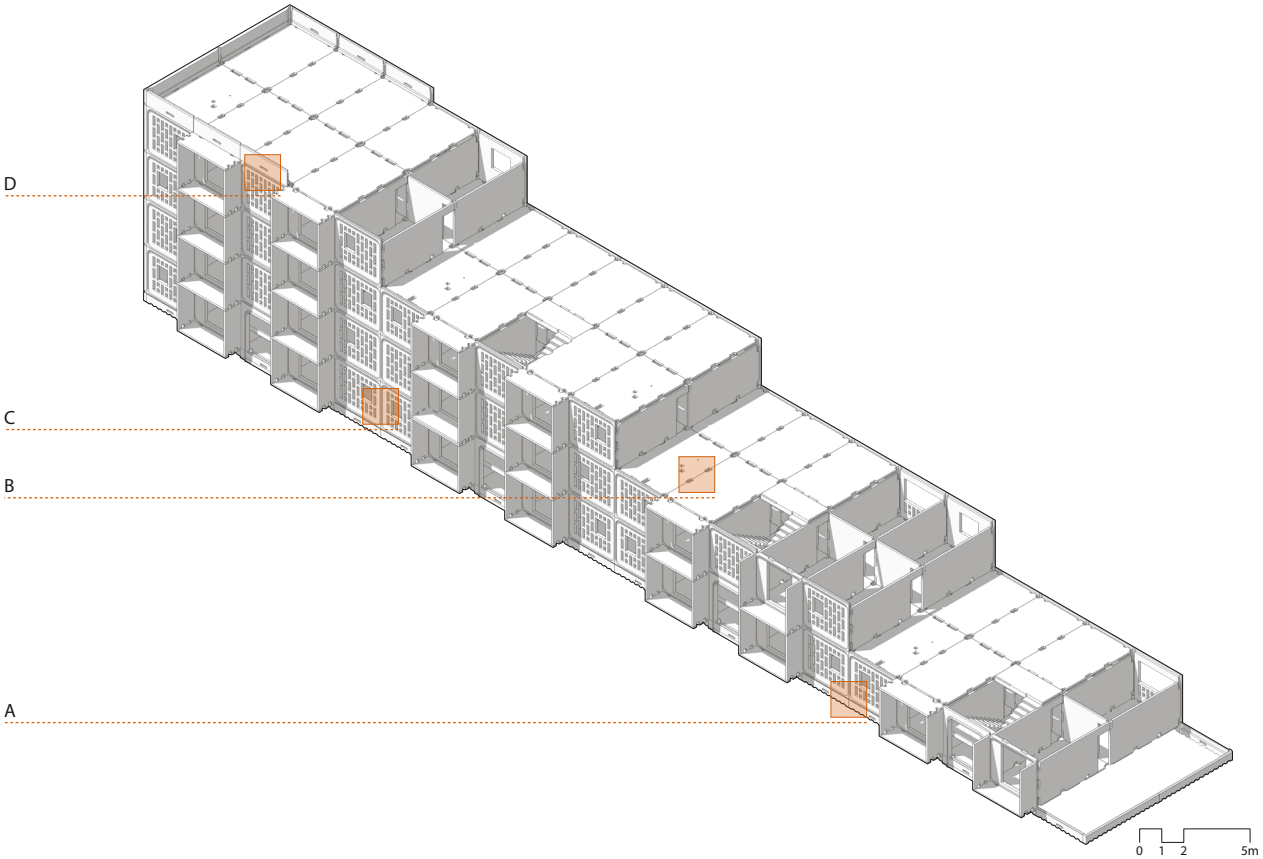
47 Pérez, María Elizabeth. The forgotten social housing that the USSR left in Chile. In: *La Tercera*. November 11, 2012. Section País, p. 34.

48 Brignardello Valdivia, Andrés. KPD, the dream of decent housing of Salvador Allende. September 11, 2015. In: *La Región Hoy,* Chile. Accessed April 2, 2017; available at: http://www.laregion-hoy.cl/2015/09/11/kpd-el-sueno-de-la-vivienda-digna-de-salvador-allende/.



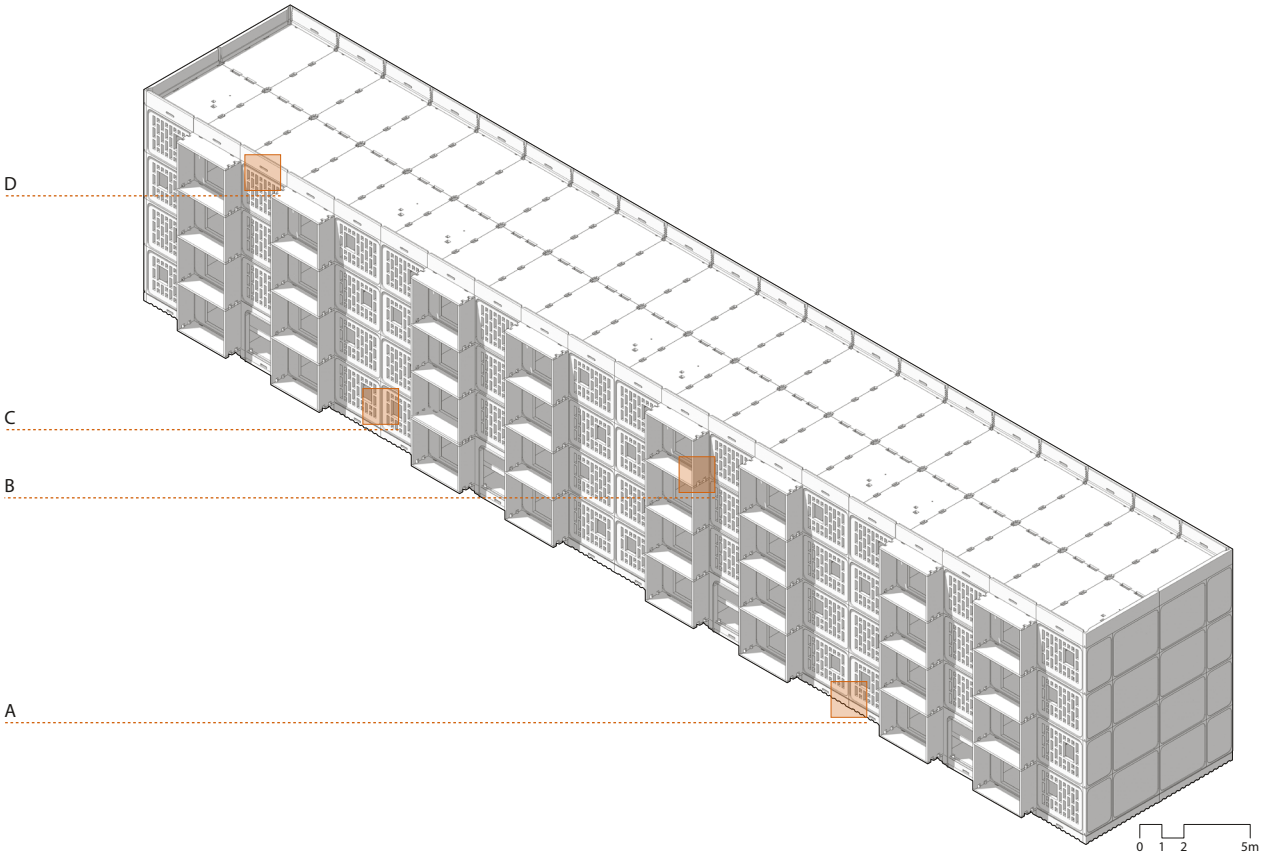
Graphic 161
Components: floor plans and façade





Graphic 162
Components: axonometry

Graphic 163
Construction process



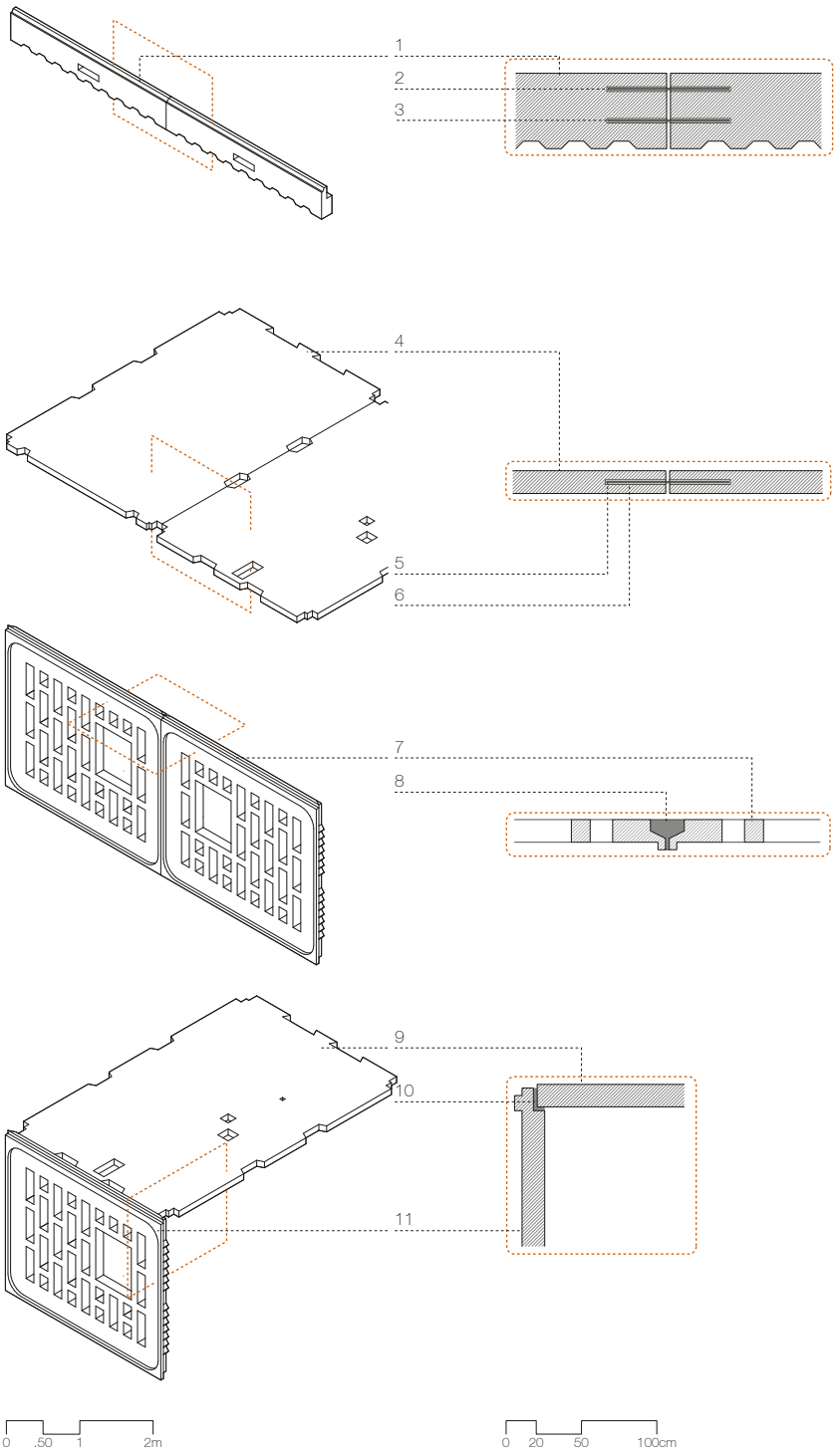
Graphic 164
The technical system and the architectural language

Advantages

- The precast façade panels, the interior walls and the floor slabs correspond to the same module, which allows coordinating the designs from the dimensions of the elements that make up the system.
- A reduced number of variants in the typologies of the precast elements, their seismic resistance, the designs of their joints and the modularity of the system allow it to be replicated in different geographic contexts and on topographic profiles.
- The proportions and weight of the panels allow them to be transported to the work site in cargo vehicles that can access different lots and install them with conventional cranes for elements up to 10 tons.
- The dimensions of the panels and the structural configuration allow the system to be adapted to different topographic profiles. The designs of the façades, conceived as structural elements, allow solar incursion and ventilation in the interior space to be controlled through their openings.
- With this type of panels, housing related to the level of access can be designed. For the upper floors, the architectural configuration through the structural panels restricts the installation of elevators and ramps.
- The joint between the panels is made through metallic elements stiffened with weldings or concrete castings. The system defines individual elements, which must be joined together in the assembly process, which delays time and increases the activities on site.

Disadvantages

- The closed prefabrication system does not allow the adaptation of other architectural designs to the previously conceived living spaces. Façade walls and interior structural walls define the occupation and the language of the project.
- With this system, the dimensions of the interior spaces respond to the proportions of the panels. The well being of the living space must be generated through the disposition of the façade elements and their openings, to respond to solar radiation and ventilation conditions in each context.
- The language of the building must be composed of the existing panels and the openings that are produced in them from the industrialization process, which closes possibilities for flexibility in the façades, to participatory design processes and to the use of local materials in non-structural elements.
- The presence of structural elements in the interior space and in the façade does not allow their transformation during the occupation process. Therefore, the variation in the composition of the families or in the uses of the dwelling presents limitations in the space, in the language and in the habitation process.



1. Precast concrete facade panel
2. Steel bars
3. In situ cast concrete
4. Precast concrete slab
5. Steel bars
6. In situ cast concrete
7. Precast concrete facade wall
8. In situ cast concrete
9. Precast concrete slab
10. In situ cast concrete
11. Precast concrete facade wall

Graphic 165
Constructive details

5.3.5. *Martinsviertel*. Cologne, Germany, 1977



Graphic 166
Exterior view

Martinsviertel. Cologne, Germany, 1977	
Type of structure	Mixed: skeletal and structural walls
Type of prefabrication	Open
Architect, inventor or designer	Schürmann Architekten - Köln
Average areas per home (in square meters)	45, 65, 90, 105
Number of housing units (on average, per building)	90
Average height of the buildings (in number of stories)	7
Number of types of precast elements	30
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	4
Beams	5
Facade panels	6
Interior walls	4
Mezzanine slabs	2
Types of structural elements or slabs for rooves	2
Special elements (ducts, joints, common areas, awnings)	5
Stairs	2
Structural spatial cells	0
Types of joints	Metal bars and *in situ* cast concrete

Information taken from: Martinsviertel, 1969-1977.

Table 31
Martinsviertel. Cologne, Germany, 1977.

System and building

This neighborhood in Cologne, Germany was destroyed during World War II. Through an architectural competition, organized by the city in 1969, the office of Architect Joachim Schürmann was selected to design urban spaces, squares, office buildings, commercial spaces and residential buildings that made up this development. These buildings were constructed using a skeletal structure of columns and beams combined with structural walls resolved with precast concrete panels. The joints were specified with metallic reinforcements stiffened with *in-situ* cast concrete (*Martinsviertel,* n. d.). The buildings were designed with a height of seven stories. The first floors were conceived for commercial spaces and complementary services. The upper floors were designed for residences with similar areas and programs, differentiated by the number of rooms and by the typology that the upper floors occupied, which had three inhabitable levels and a terrace (J. Schürmann, personal communication, July 4, 2014).

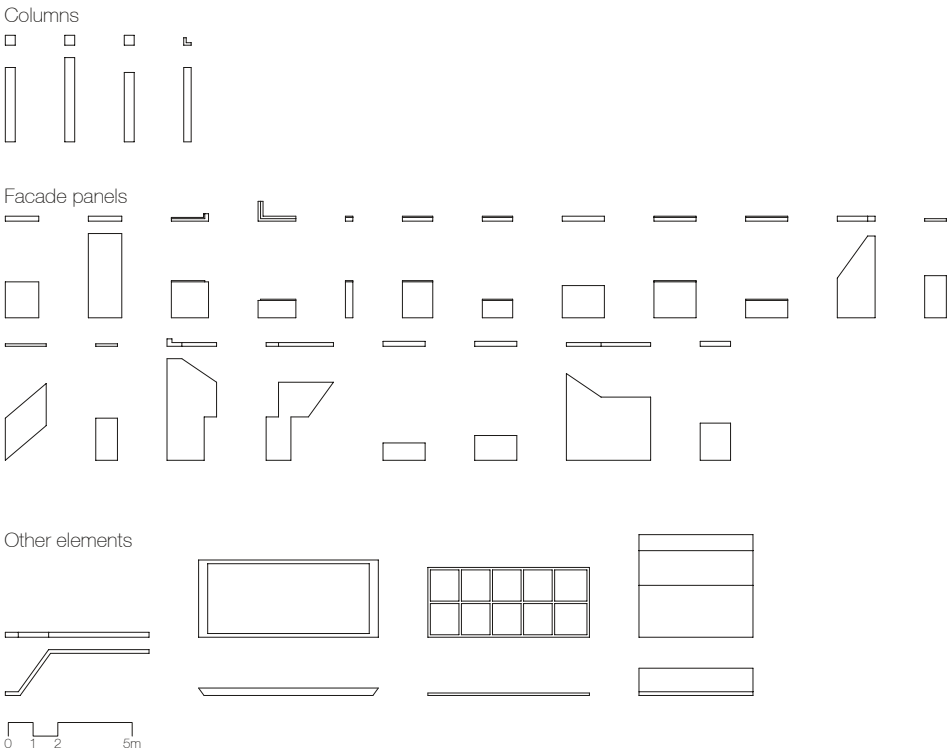
These proportions intended to adapt the profile of the buildings to the scale of the environment and were groups in urban courtyards where access to public uses and the apartments were located. The set of houses did not need the usual spaces reserved for children's play, as this activity was permitted anywhere. [49]

The inclined rooves of the housing complex assume the geometry of the historic setting that surrounds it, generating an urban profile that shows the union between a modern set of dwellings and the traditional architecture of the city. The project proposes a neighborhood life in the geographic and historic center of Cologne around a courtyard, a space where 14 buildings, grouped in a U shape, stand out to the side of the *Groß Saint Martin* Church.

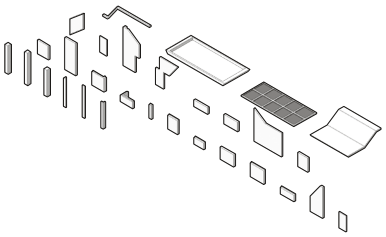
These houses are formed in their structure and façades by precast-concrete elements, dimensionally coordinated with the proportions of the windows and the doors toward the balconies. The colors of the church determine the tones of the precast-concrete façades in the set of houses, defined by white and yellow mineral colors. The materiality of the project is a response to the functional aspects of a residential building that connects with the church and with the complementary public spaces made up of pedestrian paths, places for neighborhood to meet, sidewalks protected by the shade offered by buildings and the wooded courtyards.[50]

49 Technical information found in the architectural and constructive plans of the *Martinsviertel* Project, provided by the *Schürmann Architekten* office to conduct this research. Cologne, Germany. October 16, 2013.

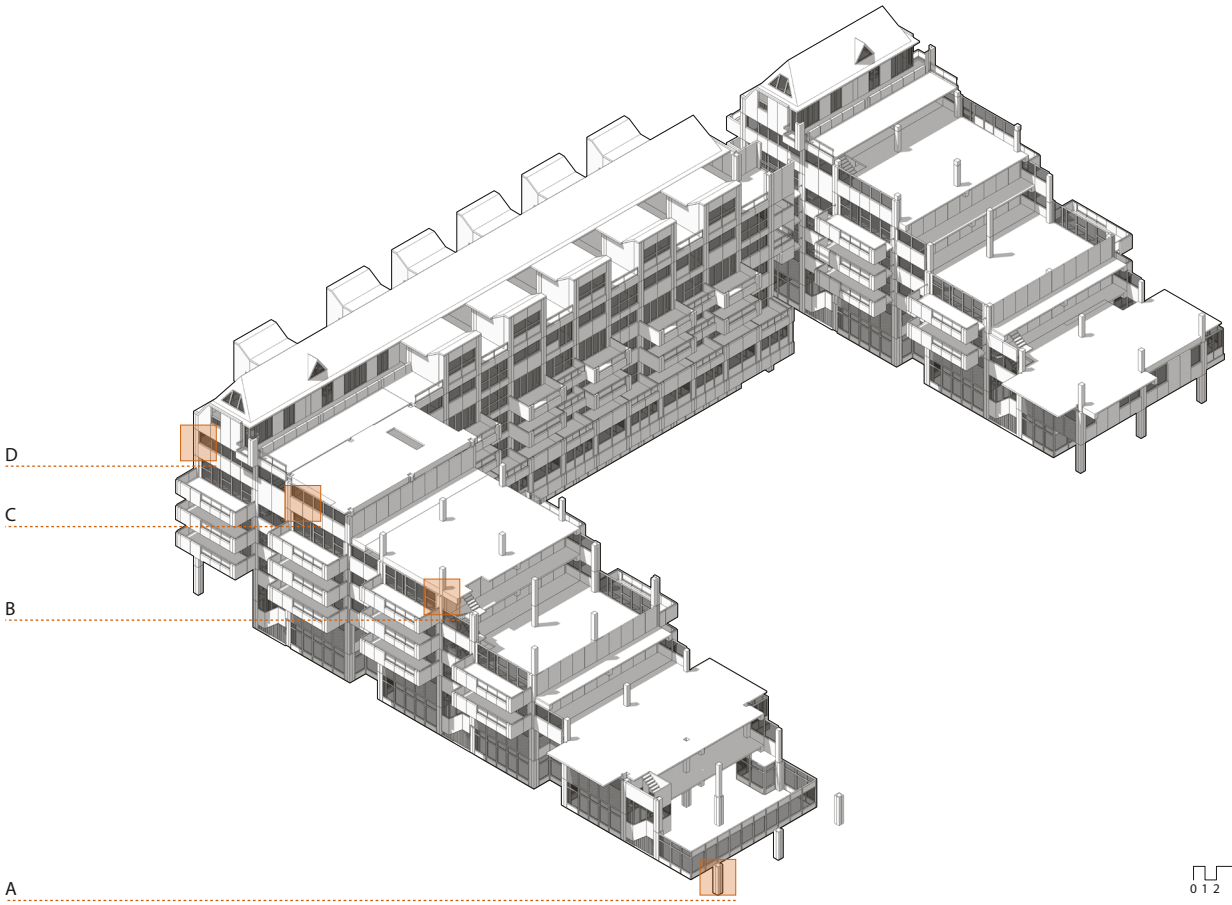
50 Schürmann, Joachim. Ed: Ingeborg Flagge. Schürmann: Entwürfe und Bauten. Ernst Wasmuth Verlag, Tubingen – Berlin. 1997, pp. 80, 81.



Graphic 167
Components: floor plans and façade



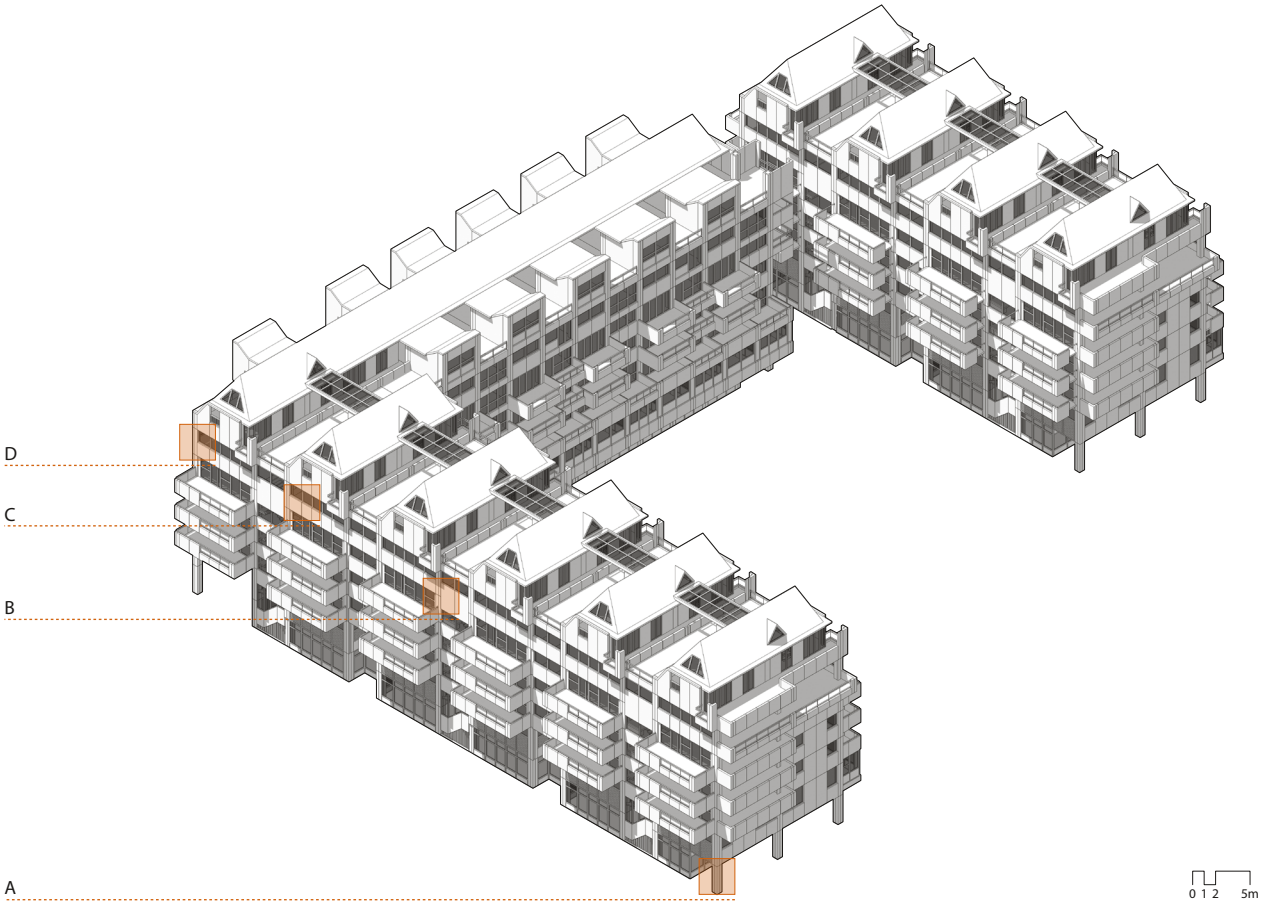
0 1 2 5m



0 1 2 5m

Graphic 168
Components: axonometry

Graphic 169
Construction process



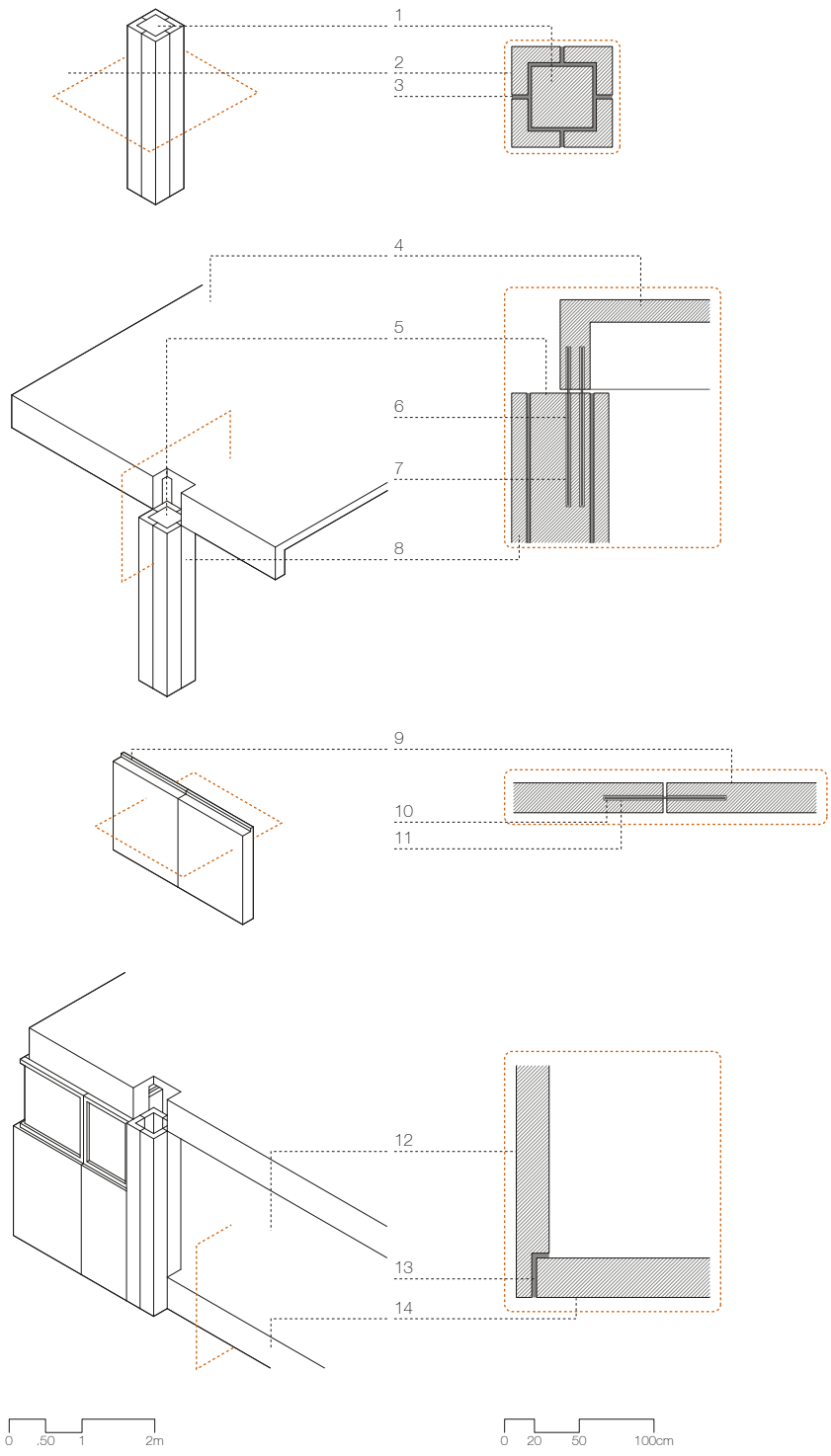
Graphic 170
The technical system and the architectural language

Advantages

- The open prefabrication system allows the composition of the language and interior spaces with other materials or systems.
- The replicability of the system generated a greater number of housing units with different urban configurations, according to the context and the characteristics of the site.
- The size of the precast elements allows its transport and installation in spaces where the passage of a cargo vehicle or crane is restricted. The configuration of this project allows hoisting the elements to an approximate height of 20m.
- The geometry of the building adapts to the conditions of the terrain and to the existing constructions, forming an urban space around the church.
- The structural system of columns and panels allows perimetral circulation covered by the access floor. The configuration of the building, with a skeletal support system to the interior, allows the installation of elevators from the first to the last floor. The presence of columns in the interior space makes it possible for the dimensions of corridors and spaces to be defined from the architectural design and not from the constraints of the structural elements.
- The columns in the interior space allow the living space to be modified, generate other possibilities of occupation and the housing units have different proportions. The façades, composed of non-structural panels, can be designed from the required architectural, urban, environmental or social conditions.
- By the precast-concrete façades not having a structural commitment, bioclimatic conditions can be adapted to different settings, according to the openings or solar controls and ventilations desired.
- The façades can be a composition made from architectural designs; they can respond to different environmental or cultural conditions or the result of participatory designs with the community. The non-intervention of the structure in the façade makes the language of the project be flexible and allows it to resolve the visual and environmental relationship with the setting in different ways.
- The non-structural façades and the interior space with a skeletal support system can be adapted to the requirements of communities, the environmental characteristics of the different settings or to the needs of families in their occupation process.

Disadvantages

- A system of independently produced columns, beams and interior structural panels increase the number and types of connections among the elements, which make the their installation process on site more complex. Column foundation systems generally require depths that increase with the load-bearing capacity of the terrain and with the height of the building.



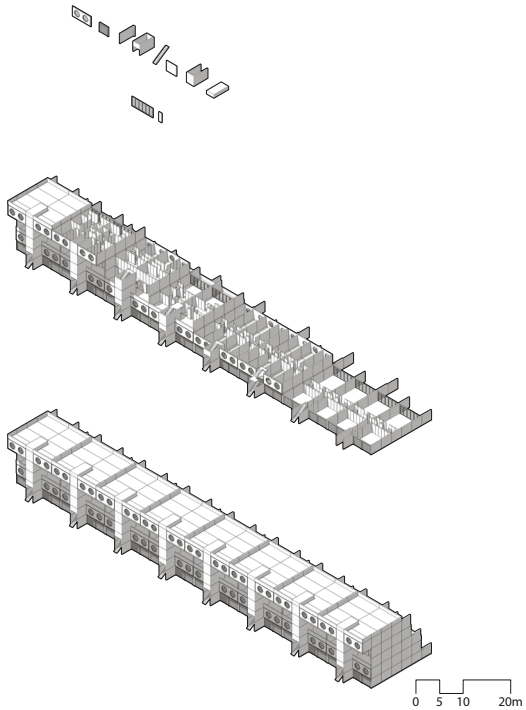
1. Precast concrete column
2. Precast concrete facade panel
3. In situ cast concrete
4. Precast concrete slab
5. Precast concrete column
6. Steel bars
7. In situ cast concrete
8. Precast concrete facade panel
9. Precast concrete facade wall
10. Steel bars
11. In situ cast concrete
12. Precast concrete facade wall
13. Precast concrete slab
14. In situ cast concrete

Graphic 171
Constructive details

5.3.6. Other projects

5.3.6.1. Southgate Estate Residential Complex, England 1977

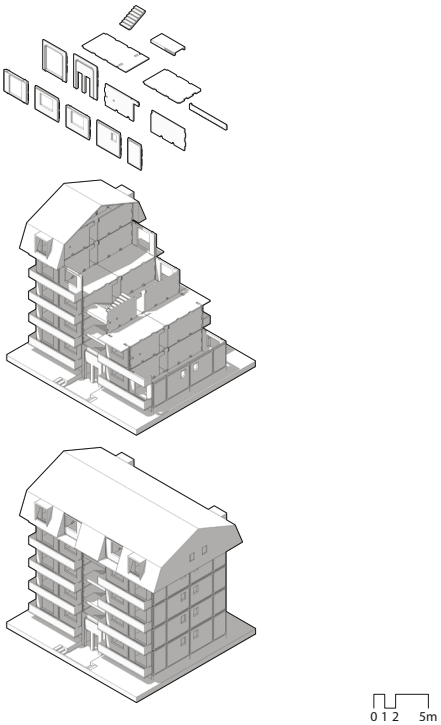
Southgate Estate was a project consisting of 1,500 public houses, inhabited by nearly 6,000 people. It was designed by James Stirling with a system of structural walls. In this complex, with buildings up to five stories in height, the houses were arranged around landscaped patios, which were connected to each other through a network of elevated walkways. The façades were resolved with different materials through open prefabrication: glass-reinforced polystyrene panels, corrugated plastic and glass surfaces (Araújo, 1997, pp. 6-7). The blocks were formed of three types of residences: at the ground and first-floor levels, the blocks were formed of 3 to 5 bedroom duplex family homes; at the second and third-floor levels, smaller duplex family homes were located off the raised pedestrian access decks; and at fourth-floor level, single story penthouse flats. The fronts of the blocks included car-parking garages along with a series of stairwell towers providing access to the upper floors. The joints between its components were specified with metallic bars and *in-situ* cast concrete. The operation of the project was particularly troublesome. The conditions of access and the repetitive use of stair towers (which were dark and hardly used), led to criminal activity. The occupants complained about insecurity, heating costs, accesses by bridges, the inability to personalize the exterior of their homes, the absence of garden spaces, the remoteness of public transport and environmental pollution. Many families abandoned the project, leaving their homes vacant. The space deteriorated throughout the 1980s and was demolished in 1992 (Morton, 1994).



Graphic 172
Southgate Estate Residential Complex, England 1977. Construction process

5.3.6.2. Precast Affordable Housing (Viviendas Económicas Prefabricadas, VEP). Chile, 1975

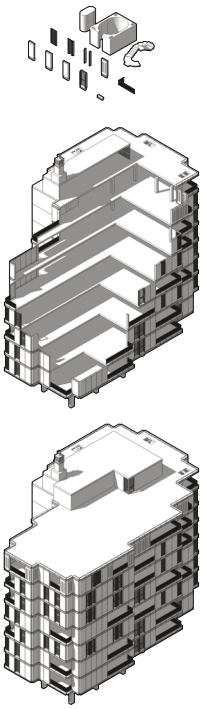
The VEP prefabrication series, derived from the KPD Large Soviet Panels in Chile, was proposed as a system of structural walls that was combined with traditional carpentry and masonry. This condition generated a hybrid process that combined large-scale prefabrication with construction work that employed conventional labor. It was developed in Chile after the overthrow of Salvador Allende's government. This series was conceived and developed to be adapted to the new neoliberal economic model that was implemented with the arrival of Augusto Pinochet's military government. The joints were specified with steel bars and concrete castings between the panels, which had edged and irregular geometries to improve the rigidity of the assembly. It differed from the KPD series in the length of the residence block: while with the KPD, six five-story housing units could be built, with the VEP two residences per floor could be built in the same five-story height. It was a conscious replacement of the typology of the massive block of houses for buildings with a larger balcony space, with gutters and a less-dense in-plant configuration (Alonso & Palmarola, 2014, pp. 188-189).The joints were specified with steel bars and concrete castings between the panels, which had edged and irregular geometries to improve the rigidity of the assembly.



Graphic 173
Precast Affordable Housing (Viviendas Económicas Prefabricadas, VEP). Chile, 1975. Construction process

5.3.6.3. Residential Building. Monza, Italy, 1972

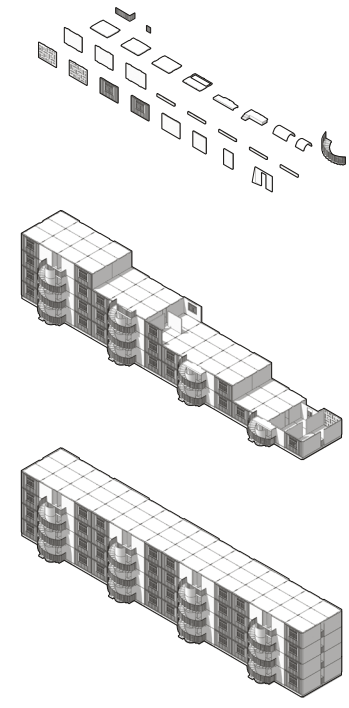
This residential building was designed with precast concrete non-structural façade panels and with a skeletal structure of columns and *in-situ* cast beams for economic reasons. The building was designed with a height of eight stories and with an access through a semi-buried basement. The project was conceived through a 32cm modular grid in the structural elements and in the living spaces. The location of the columns made the interior space of the houses flexible in terms of the distribution of rooms and social areas. The concept used in these developments was based on the combination of economic forms of construction with a high degree of flexibility in use. The precast concrete elements in the façade (walls, slabs and slab edges) were designed so they could be modified and meet the requirements of the users in the future. These were joined to the mezzanine slabs through metallic bars and concrete castings. Surfaces were textured with a granular fine stone finish extracted in the city of Vicenza. With a reticular structure as support of the building, it was possible to achieve a set of precast façades articulated with the interior space (Herzog, 1998, pp. 67-69).



Graphic 174
Residential Building. Monza, Italy, 1972. Construction process

5.3.6.4. Brecast, United Kingdom, 1970

This structural wall system was conceived and developed by the British Building Research Establishment (BRE) agency, under the direction of Nares Craig. The joints were made through assemblies or metallic bars rigidized with concrete castings. These elements and the prefabrication series were mostly exported to developing countries, where buildings were constructed with an average height of five stories. It was designed to increase the flexibility in housing typologies, with an internal distribution according to the preferences of the users. Brecast had vertical molds to produce prefabricated panels in the industrial plants or on site, without the need for specialized equipment and with the same structural and surface quality offered by other industrial developments (Alonso & Palmarola, 2014, pp. 226-227).It was designed to increase the flexibility in housing typologies, with an internal distribution according to the preferences of the users. Brecast had vertical molds to produce prefabricated panels in the industrial plants or on site, without the need for specialized equipment and with the same structural and surface quality offered by other industrial developments (Alonso & Palmarola, 2014, pp. 226-227).



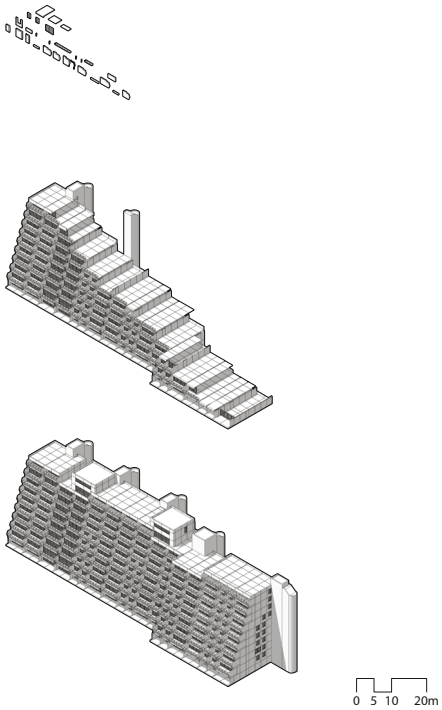
Graphic 175
Brecast, United Kingdom, 1970. Construction process

5.3.6.5. Residences in the Olympic Village. Munich, Germany, 1971

This housing project was designed and built between 1968 and 1971 to receive 12,000 people, including athletes and the staff of the participating teams of the 1972 Olympic Games. For case studies, two types of precast concrete buildings were selected: the men's residences (terraced buildings with staggered heights of between 7 to 14 stories) and the women's residences (precast concrete two-story bungalows).

In order to carry out the urban planning and architectural concepts, the planners decided to apply the "optimation process", a method frequently used in engineering to find the best possible solution of a given task. The final concept stood up to the criticism of the expert advisors in regard to living quality, room layout, daylight, hygiene, and sound conditioning, as well as in relation to sociological conditions, building codes, ecology, green zones, traffic patterns, urban planning and general considerations of landscaping. One of the difficulties in allocating the various apartments was the diversity in the size of the various competing teams.

Three tracts of terraced houses with seven to fourteen stories each (for male athletes) extend out of this center on an east-west axis toward the south. In front of these are terraced houses three- to five-stories high; and in front there are one- to three-story semi-detached houses. In the south this village ends in rows of two-story bungalows (ground floor with a set-back on the upper level) for the female athletes. Pedestrian and vehicular traffic is separated on two levels. The green zones stretch from Olympic Park through the free area between the three tracts all the way to the center. (Amateur Athletic Foundation of Los Angeles, 2003, pp. 100).



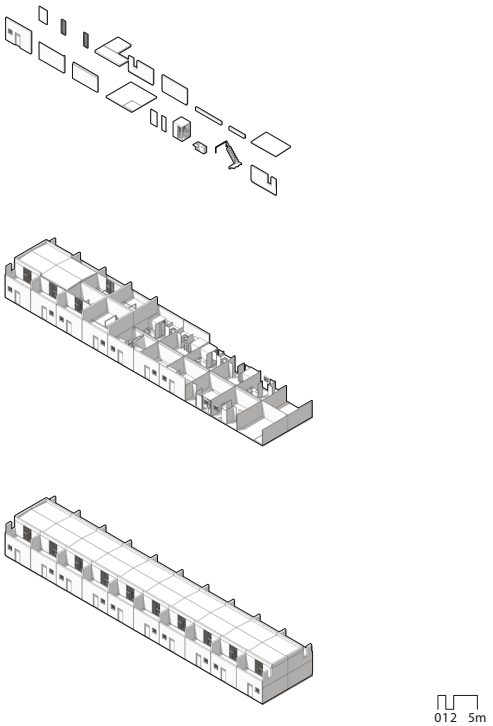
Graphic 176
Construction process

5.3.6.5.1. Men's residences

Three stretches with terraced houses, with heights between seven and 14 stories, served as the Men's Olympic Village. These buildings were conceived with a structural wall system.

The east and west façades were conceived with the "Stacked Wall" principle, connected with walls and precast concrete beams that extended from the northern façade to the southern façade. The staggering of the façades through precast elements generated a language of balconies and load-bearing walls with social areas facing public spaces. The kitchen areas and bathrooms were located adjacent to collective circulations. The precast balcony with flower boxes specified for each apartment was assembled with the structural walls located between the houses. The joints of these structural panels with the floor slabs were done by welding the protruding reinforcements and *in-situ* cast concrete in the knots to ensure their structural continuity (Amateur Athletic Foundation of Los Angeles, 2003, pp. 102-103).

The building was constructed to be used after the Olympics and, therefore, the houses had different areas: apartments from 24 m2 with one bedroom to apartments measuring 240 m2 with six bedrooms. For interior spaces, non-structural precast walls, which could be modified or eliminated in the reform processes, were used; this facilitated the conception of new typologies of housing after the Olympic Games (Amateur Athletic Foundation of Los Angeles, 2003, pp. 102-103).



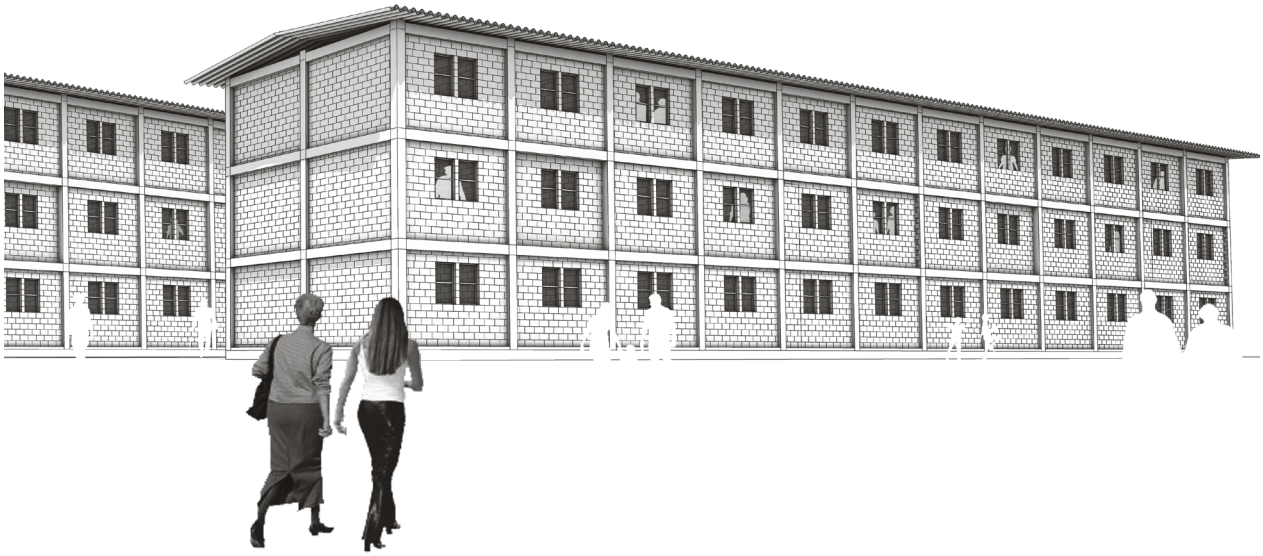
Graphic 177
Construction process

5.3.6.5.2. Women's residences

These 800 precast two-story houses (known in the Olympic Village as "bungalows") were designed with a system of structural walls. Each house had an area of 24 m2 distributed on two covered floors and an uncovered balcony. These units were projected with a frontage of 3.2m and a depth of 4.40m. The bathroom units were produced in factories and connected to the houses in the construction process. The joints between the structural walls with the floor slabs were made by welding between the metal reinforcements that were left exposed. In-situ cast concrete was added to this welding to stiffen the knots and ensure the structural continuity of the houses. The wall that was supported on the mezzanine slab was also joined to it using the same system. The roof elements were supported on the precast walls and were joined to them with metallic bars and a precast concrete perimeter beam. The precast slabs for the rooves were covered with gravel (Amateur Athletic Foundation of Los Angeles, 2003, pp. 102-110).

5.4. 1980s, 1990s and 2000s

5.4.1. *Ciudad Bachué III*. Bogotá, Colombia, 1980



Graphic 178
Exterior view

Bachué City III (*Ciudad Bachué III*). Bogotá, Colombia, 1980	
Type of structure	Skeletal (masonry enclosures)
Type of prefabrication	Open
Architect, inventor or designer	P. Samper, L. Tapias, C. Moreno and G. Marín
Average areas per home (in square meters)	45, 60
Number of housing units (on average, per building)	1480
Average height of the buildings (in number of stories)	2 to 5
Number of types of precast elements	18
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	2
Beams	2
Facade panels	0
Interior walls	4
Mezzanine slabs	2
Types of structural elements or slabs for rooves	2
Special elements (ducts, joints, common areas, awnings)	4
Stairs	2
Structural spatial cells	0
Types of joints	Metal bars, welding and cast concrete

Information taken from: Aguilera, n. d., pp. 25-26.

Table 32
Bachué City III (*Ciudad Bachué III*). Colombia, 1980.

System and building

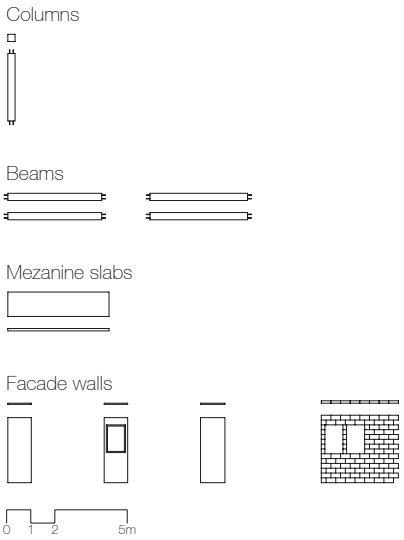
Located in western Bogotá, this project contemplated the construction of more than 15,000 homes for low-income families in three stages. This program was developed in the "Cities within the City" Policy with the following design characteristics: vertical developments on terraces and covered by regulated expansions, flexible designs and different sized in single and multi-family schemes.

To construct this project, three different prefabrication systems were used through open tenders that linked private enterprise with official urban developments: structural walls, skeletal structures with precast concrete panel enclosures, and skeletal structures with masonry enclosures. The works were assigned to the least expensive proposals. The contracts awarded at that time were signed by sums of money lower than the cost of traditional construction systems, such as the reinforced *in-situ* cast concrete structures and brick masonry. Since 1977, the ICT modified the concept of massive construction of homes through the realization of urban developments (Aguilera, n. d. pp. 23-26).

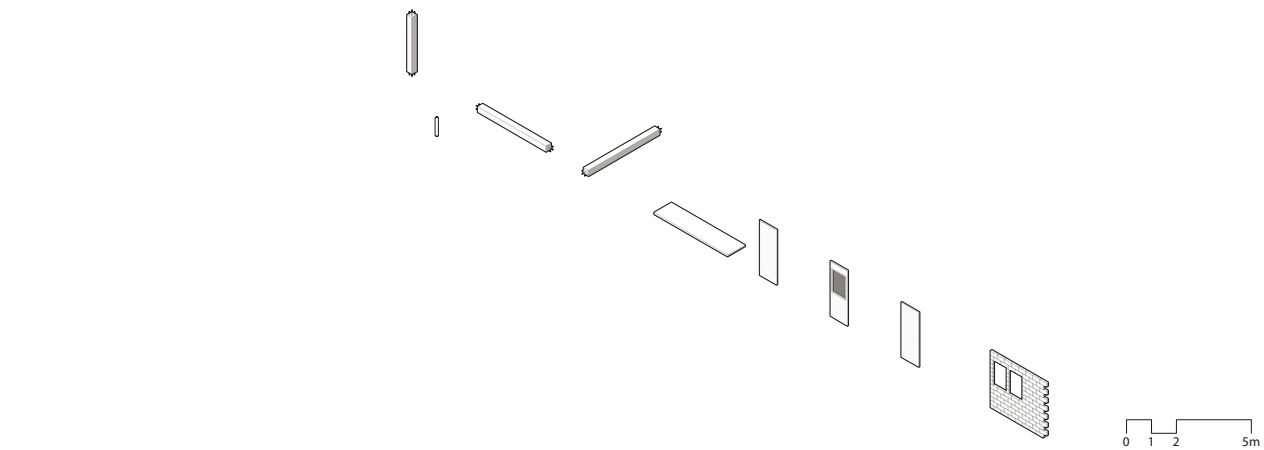
In this stage of the project, the support structure was also constructed with the skeletal system of precast concrete beams and columns. The façades and interior walls were specified in brick and were installed conventionally on the precast concrete structure. The group of architects of this stage was also led by Patricio Samper, who designed 1,480 housing units with an average area of approximately 45 m² to 60 m² in buildings two to five stories tall. For cost reasons, the homes were delivered without finishes, which was left to the criterion of each user. The system was the result of investigating new methods in view of the lack of skilled labor and the huge volume of construction that was offered. In this construction method, there was the idea of combining an industrialized system (a support structure with precast beams, columns and slabs) with a traditional system (façade walls built in brick masonry). This strategy brought the advantages of speed of execution and higher yields to the project, due to an efficient organization. The contractors at the time considered that the organization of the activities represented 60% of the system performance for them (Aguilera, n. d., p. 25). The combination of these two systems allowed the simultaneous and programmed work on two fronts: the prefabrication in the support structure and the installation of non-structural masonry elements. Beams and columns were joined by welding their reinforcements with concrete on their knots to increase the rigidity of the connections. Precast concrete slabs were installed on these elements, joined to the beams with metallic bars and *in-situ* cast concrete. The brick façades and interior walls were installed with mortar paste, which allowed the organization of different, sequential activities in the construction of the project (Aguilera, n. d., p. 26).

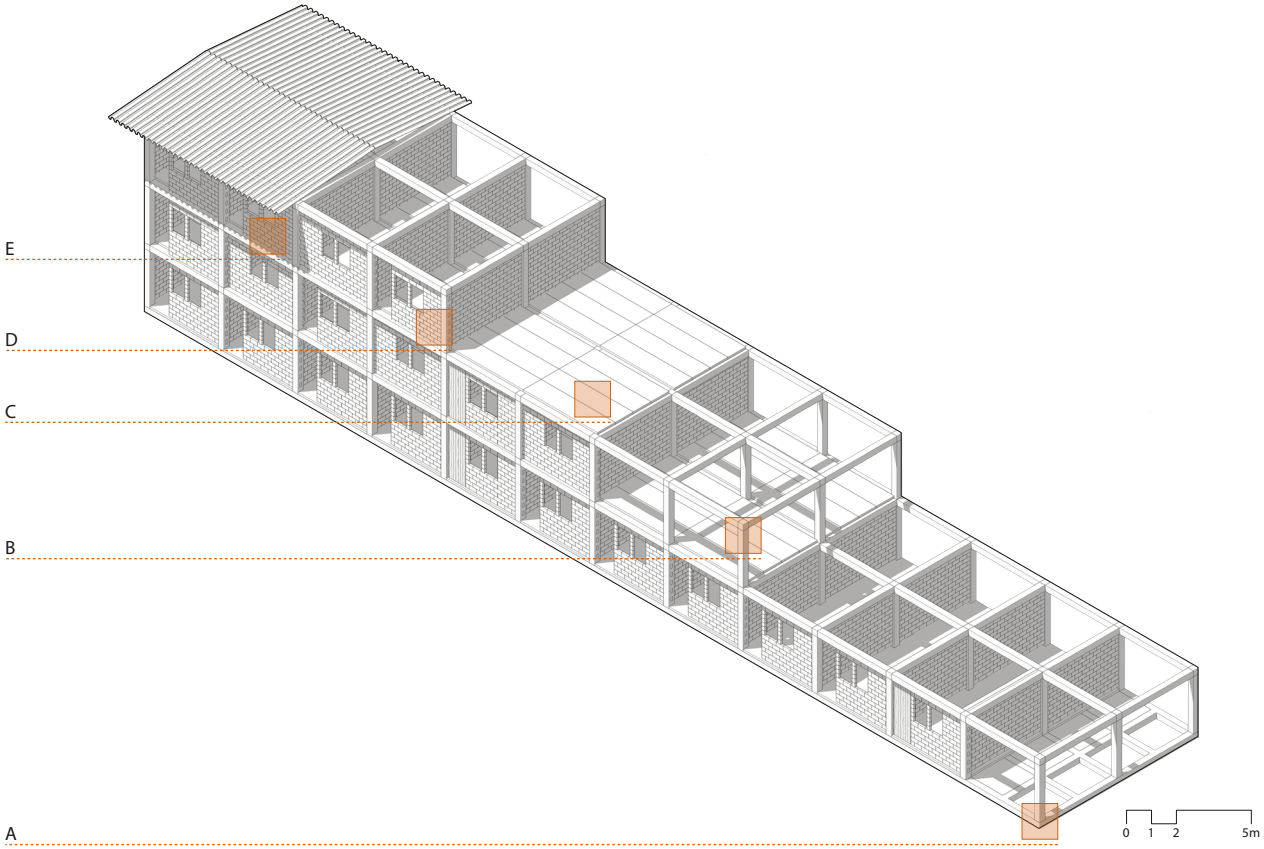
This housing program, planned by the Colombian Institute for Territorial Credit (*Instituto de Crédito Territorial,* ICT) since 1978 considered the possibility of having subsequent growth on its terraces, an activity carried out by users after having occupied the project. The houses were built and regulated to expand their original area through self-construction processes. In this project, originally proposed for 15,000 homes, three contracts were awarded, each with different construction systems. The first one was specified with structural façade structural panels and precast-concrete interior walls.

The second stage was constructed with a system of precast-concrete structural girders (beams and columns) and non-structural panels also in precast concrete. *Ciudad Bachué III* was built with a precast-concrete skeletal system (beams and columns), with façades and interior walls in systems of non-structural masonry. Once the third stage was completed, the contractors of the construction project proposed that there could be other innovations in the production processes and in the connections of the structural elements, since most of them were solved on site with procedures that did not completely control the quality of the components. Once of the technical and social processes that had the best results was working with users, who cooperated in the installation of non-structural elements in the construction process and who modified or expanded their dwellings once they were occupied. (Aguilera, n. d., p. 26).



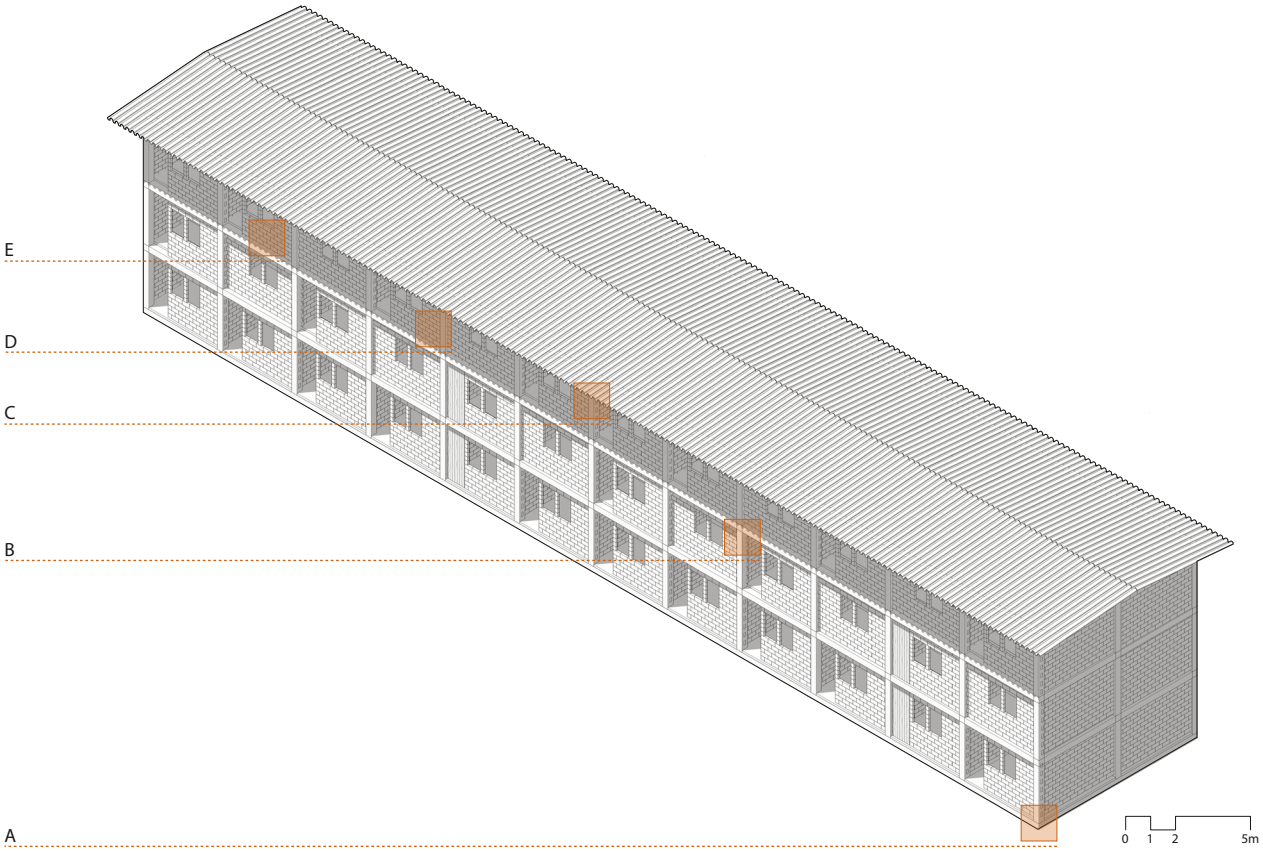
Graphic 179
Components: floor plans and façade





Graphic 180
Components: axonometry

Graphic 181
Construction process



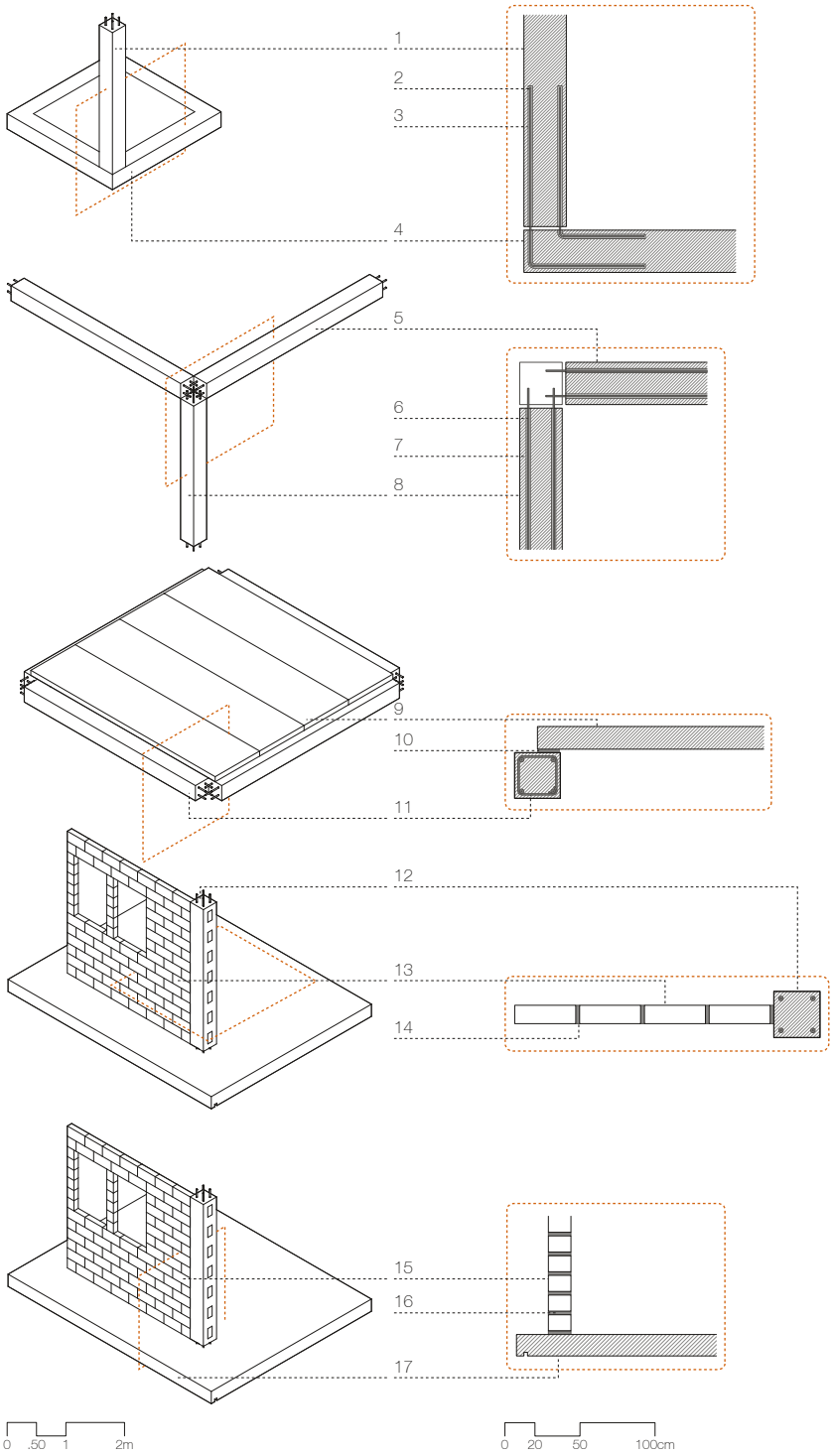
Graphic 182
The technical system and the architectural language

Advantages

- The project was designed through a structural module measuring 3.20 x 3.20, which allowed an open, partial prefabrication system with precast-concrete structural frames, dimensionally coordinated with façade walls and non-structural masonry interiors.
- The industrialization of the support structure, with simple joint mechanisms among the structural elements and their combination with traditional construction systems allowed the intervention of traditional labor and the use of local materials.
- The volume and the weight of the constructive elements permit their transport to different contexts. The production of the construction elements can also be done at the project site.
- The system of frames allows the adaptation of the system to different topographies. The partial prefabrication of the support structure and the use of local materials in the non-structural elements are adapted to different social, economic and technical contexts.
- The combination of the structural frames with non-structural masonry elements allows the interior spaces and common areas of the building to be dimensioned for accessibility and for movement through their spaces.
- The number of variants in the typologies of the precast elements, the designs of the connections, the weight and the volume of each of them facilitate the constructive processes.
- The precast structural elements of the girder system allow the dividing walls and façade walls to be built in a system of non-structural masonry. The designs of the façades and the interior space can be adjusted to different areas, housing typologies and the needs of families.
- The non-structural masonry elements that make up the façades allow designs according to the bioclimatic context and according to the environmental conditions desired. In the interior, the proportions of the spaces can be determined by the inhabitants themselves.
- Through different materials or non-structural constructive systems, the language of the building can respond to the social context, to the cultural traditions or to different criteria of architectural composition.
- The construction system of the project allows the area of the housing to be expanded through the non-structural elements, which are modified over time and have different languages.

Disadvantages

- Each column and beam must be joined individually in the site, which increases the number of connections in the construction process and, therefore, the on-site activities, costs and construction time.
- The frame structure, which proposes structural terraces on the houses, allows its growth in height, but does not control the number of floors that can be built, generating a structural risk in the buildings.



1. Precast concrete column
2. Steel bars
3. In situ cast concrete
4. Precast concrete beam
5. Precast concrete beam
6. Steel bars
7. In situ cast concrete
8. Precast concrete column
9. Precast concrete slab
10. In situ cast concrete
11. Precast concrete beam
12. Precast concrete column
13. Precast concrete facade wall
14. In situ cast concrete
15. Precast concrete facade wall
16. In situ cast concrete
9. Precast concrete slab

Graphic 183
Constructive details

5.4.2. Niza Residential Complex (*Urbanización Niza*). Pereira, Colombia, 1980



Graphic 184
Exterior view

Niza Residential Complex (*Urbanización Niza*). Pereira, Colombia, 1980	
Type of structure	Structural walls (Cortina system)
Type of prefabrication	Closed
Architect, inventor or designer	Pablo Cortina
Average areas per home (in square meters)	93
Number of housing units (on average, per building)	450
Average height of the buildings (in number of stories)	5
Number of types of precast elements	15
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	5
Interior walls	3
Mezzanine slabs	2
Types of structural elements or slabs for rooves	2
Special elements (ducts, joints, common areas, awnings)	3
Stairs	2
Structural spatial cells	0
Types of joints	Metal connectors and *in situ* cast concrete

Information taken from: Aguilera, n. d., pp. 27-28.

Table 33
Niza Residential Complex (*Urbanización Niza*). Pereira, Colombia, 1980.

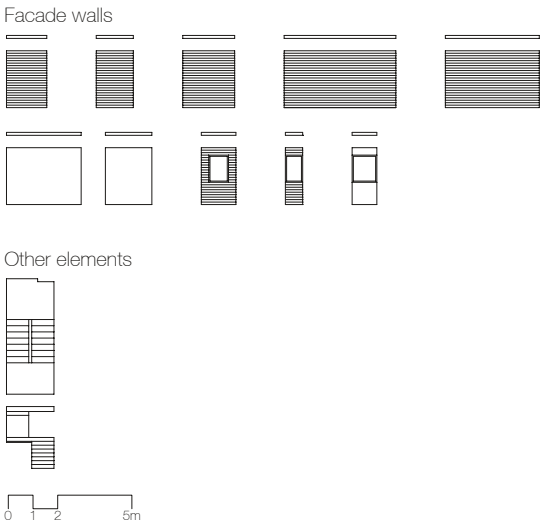
System and building

Since the 1970s, this structural wall system, patented by Mexican Engineer Pablo Cortina, was used for the construction of housing in Colombia. It is a system of stacked structural walls and slabs joined by hinges or metal pins, which –when deployed by gravity– make up the building (Aguilera, n. d., p. 27). The foundation of the building was a solid 60cm -thick plate in reinforced concrete and *in-situ* cast. Another solid in-situ cast concrete plate was built for the installation of the equipment that would lift the precast elements. The lifting equipment was hydraulic-mechanical jacks. The union of these elements to the previously hoisted structures was made through welded metallic connectors, stiffened with concrete. Once the set of walls and slabs was installed on each floor, the jacks were raised to the next floor and the operation was repeated.

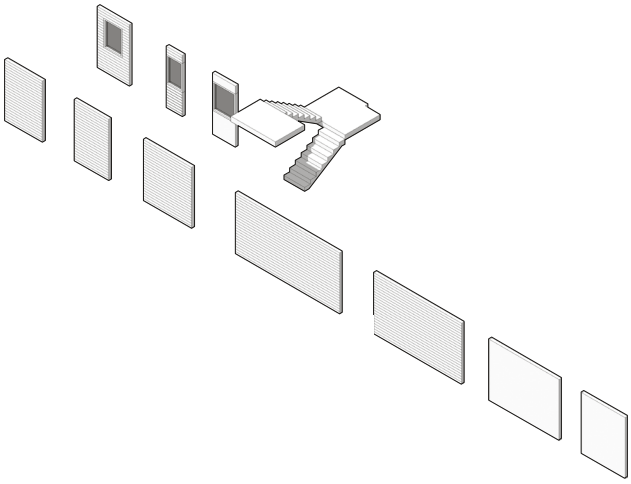
The system was designed to construct buildings up to 10 stories in height. When the walls and slabs were cast in the molds, a release agent was used between them to keep them separated and to prevent them from striking when lifted. This housing complex had 450 apartments and was built in three stages. Each stage consisted of 15 blocks with 10 apartments, distributed in five stories on a steep terrain, with no possibility for enlargement. The area of each apartment was 93 m^2, larger than the average area of other social housing units, since there are more-affluent solutions than those contracted by the ICT. The hoisting time of the structure of each building with 10 apartments was three weeks (Aguilera, n. d., pp. 27-28).

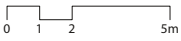
This system achieved equal costs but reduced one-third of the time, compared to traditional construction systems. The prefabrication of slabs and structural walls was done on site, in the same place in which these elements were then hoisted until locating them in their final position in the building. The walls were designed with a thickness of 12cm and dimensions from 6.10m x 2.50m to 0.70m x 2.30m. The slabs, with a thickness of 20cm, could be lightened or solid and included their finishes in the casting process, which reduced the amount of activities on site. The walls were designed to be hinged to the plates to fall by gravity at the time of the hoisting to the exact point of their location in the project.

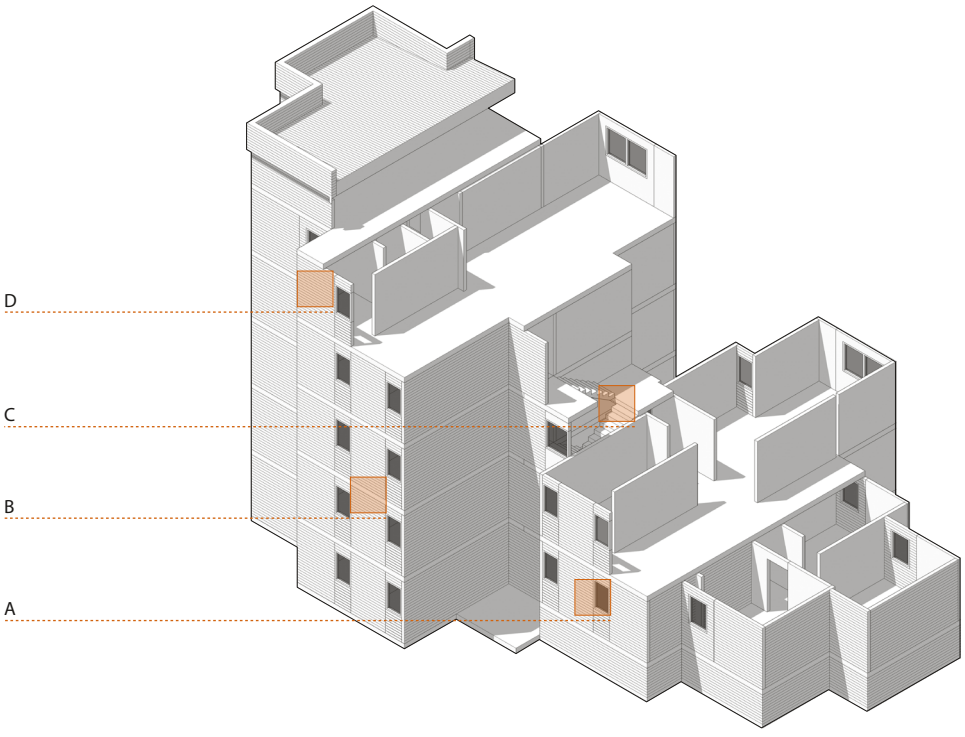
Prior to the prefabrication of each element, all necessary accessories, electrical and hydrosanitary pipes, reinforcements and lightenings, including the hinging of walls and plates, had to be installed. The *Cortina* System required extremely strict, detailed planning and control in the hoisting process, since there were several elements that had to be installed simultaneously to build each of the levels of the building. In this system, there could be as many work fronts as there is hoisting equipment available (Aguilera, n. d., p. 28).

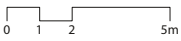


Graphic 185
Components: floor plans and façade



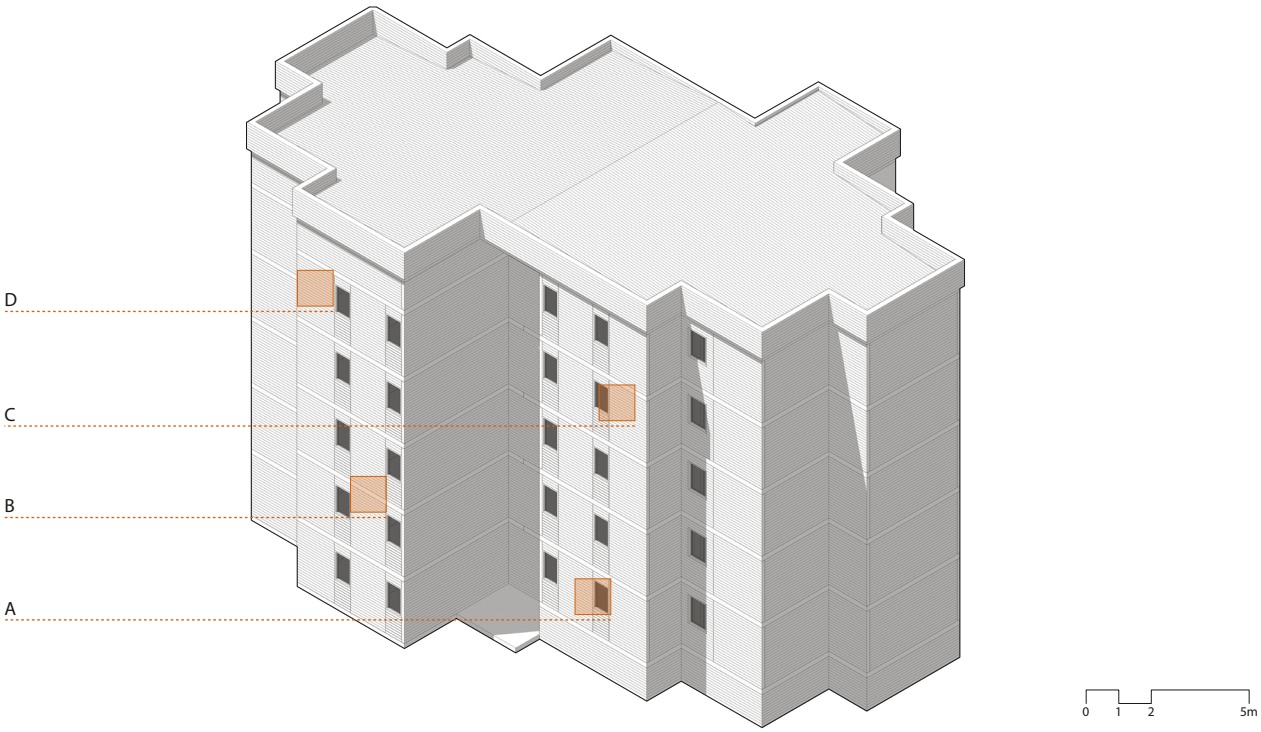






Graphic 186
Components: axonometry

Graphic 187
Construction process



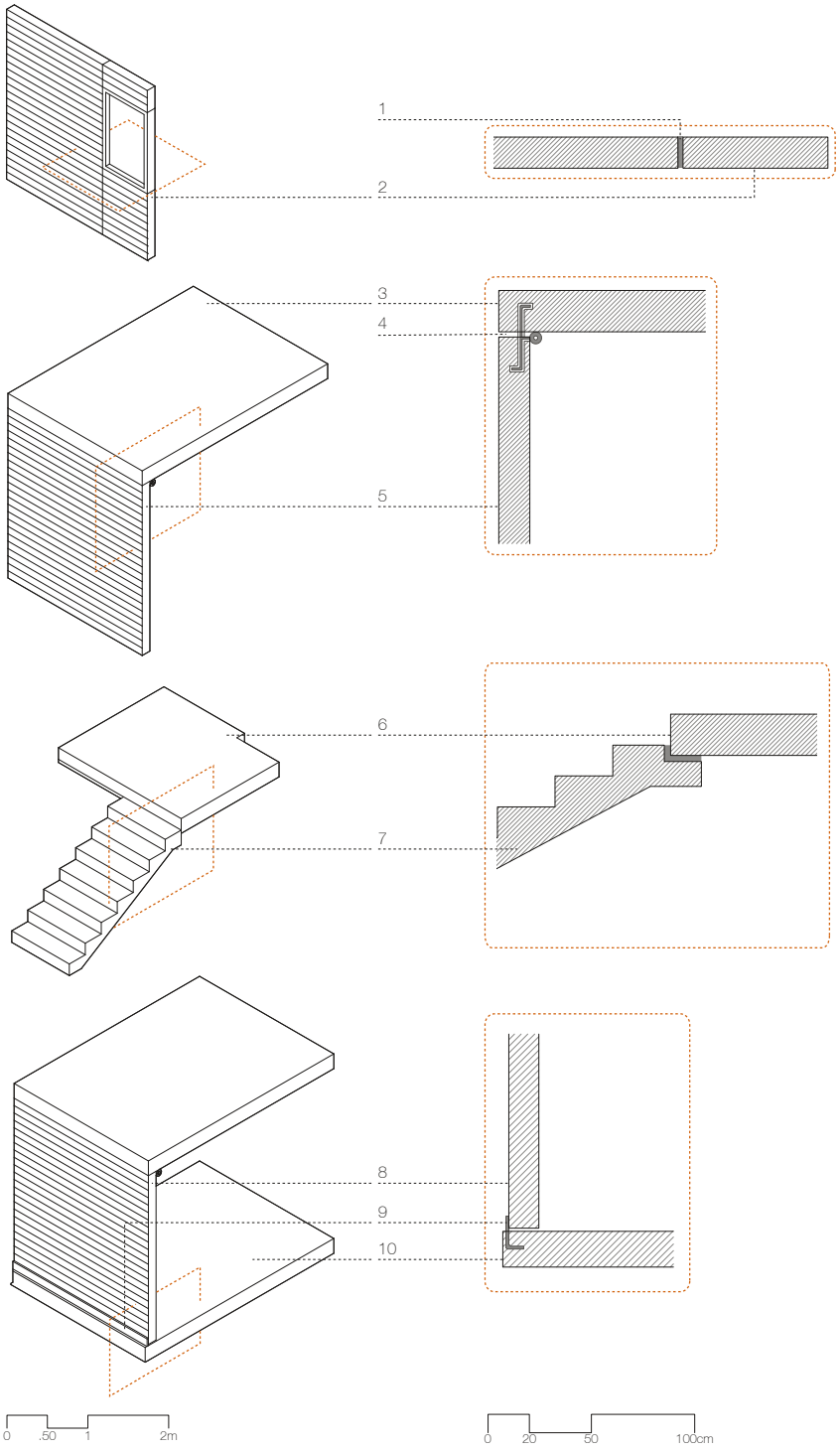
Graphic 188
The technical system and the architectural language

Advantages

- The walls and slabs of the system are designed as an integrated module, which is installed together from the dimensions of the dwellings and can be dimensionally coordinated with the proportions of its finishes, which can be incorporated to these elements from the casting process.
- With the same structural and architectural principles, the system can be replicated in locations that permit using hoisting cranes. The castings of each structural element are done on the ground, in the same place where the cranes raise them to each level of the building. The speed achieved in the prefabrication and installation process reduces assembly time by up to one-third compared to traditional construction systems and allow the construction of a greater number of housing units.
- The precast elements are produced in the same site of the project, which allows reaching territories with different types of access. The hoisting cranes, which are made up of columns and metal trusses are assembled in sections, which facilitates their transport to the work site.
- The hoisting equipment can be adjusted to the existing topographies in different contexts, according to the configuration of the building. Other materials used as floor finishes and wall can be merged from the prefabrication process, adapting the production techniques to the dimensions of the materials that complement the system.

Disadvantages

- While the system reduces construction time and integrated the precast elements, the construction process uses complex hoisting equipment and requires a strict modular planning and coordination to simultaneously install the slabs and walls that, when hinged to the plates, fall by gravity until they rest on the lower plate.
- Each plate and wall of the system are part of its support structure; therefore, the dwellings have no possibility of modifying their typology, eliminating some interior walls or expanding over time according to the needs of the users.
- The interior proportions, the orientation of the dwellings, the cross-air circulations and the control of solar incursion are conditioned by the dimensions and locations of the walls and structural slabs of the dwellings.
- The language of the building constructed with this system respond to the designs of the prefabricated façade walls, which do not allow modifications over time and reduce the possibilities of individualizing or personalizing the houses.
- The interior and exterior walls, which have structural specifications, do not allow the transformation of the dwellings over time, nor their growth, nor their adaptation to the needs of their inhabitants.



1. In situ cast concrete
2. Precast concrete facade wall
3. Precast concrete slab
4. In situ cast concrete
5. Precast concrete facade wall
6. Precast concrete slab
7. Precast concrete stairs
8. Precast concrete facade wall
9. Metal angle
10. Precast concrete slab

Graphic 189
Constructive details

5.4.3. *Viviendas de Protección Oficial*. Alcobendas, España, 1995



Graphic 190
Exterior view

Viviendas de Protección Oficial. Alcobendas, España, 1995	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	Manuel de las Casas
Average areas per home (in square meters)	43, 65, 92
Number of housing units (on average, per building)	198
Average height of the buildings (in number of stories)	5
Number of types of precast elements	23
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	6
Interior walls	4
Mezzanine slabs	4
Types of structural elements or slabs for rooves	3
Special elements (ducts, joints, common areas, awnings)	4
Stairs	2
Structural spatial cells	0
Types of joints	Anchors, welding and *in situ* cast concrete

Information taken from: Bravo, 1997, p. 28.

Table 34
Official Protected Housing (*Viviendas de Protección Oficial*). Alcobendas, Spain, 1995.

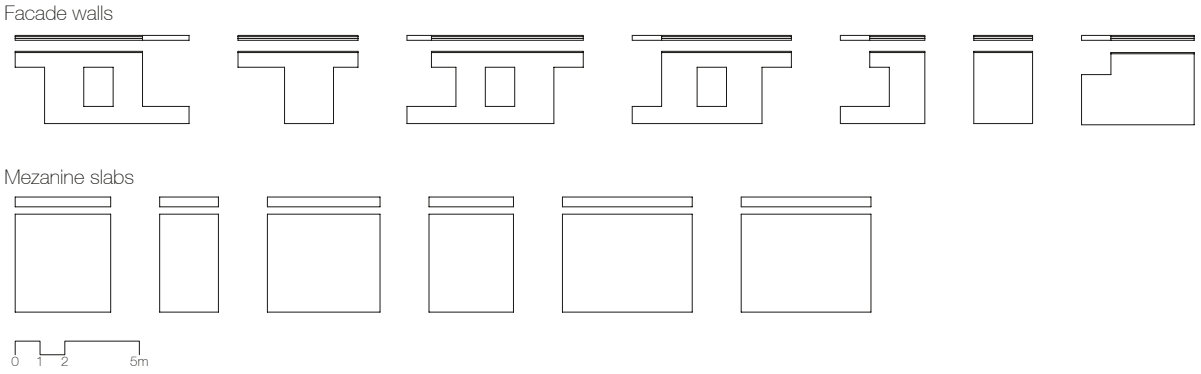
System and building

This set of 198 homes was conceived in eight five-story-tall blocks. Its layout shaped an urban space articulated through passages that crossed the buildings on the first floor. The bases for the summons of the public context, won by the office of Architect Manuel de las Casas, emphasized the rationalization of the construction, the competitiveness of costs and the execution time with an architectural form adapted to residential demands. The building was made up of an open system of structural walls, which permitted the combination of precast concrete with other technical solutions and increased the design possibilities of the interior space.

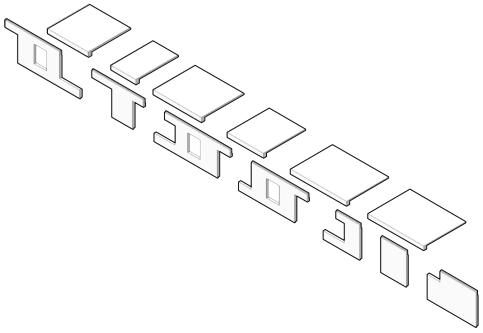
The structural panels were pigmented in a sand color to generate an appearance different from that of conventional grey concrete. The mezzanine slabs were specified to be precast and pre-stressed, ribbed every 70cm, with a width of 210cm and a thickness of 26cm (Bravo, 1997, p. 28). The precast elements were combined with traditional construction procedures. In this case, the uni-directional ribs of the precast mezzanine slabs were designed to rest on the inner structural panels, generating an assembly by geometry, reinforced with metallic connectors that were incorporated from the manufacturing process. These joints were subsequently concreted to stiffen the system. Other joints between the precast pieces were made through welded or screwed anchors to increase the speed of the assembly (Bravo, 1997, pp. 26-33).

In the interior design of the building, two reinforced precast-concrete structural walls, separated 2m from each other and parallel to the longest façades, divide the interior in two corridors measuring approximately 5m. The precast ribbed slab is supported on them. Between these two load-bearing walls, a service band, occupied by the bathrooms and storage areas, is located in such a way that what in principle was a necessary element for the stability of the building becomes a service space that orders the operation of the complex. This distribution favors the grouping of the technical installations, which are placed in this central space and on the stairs.

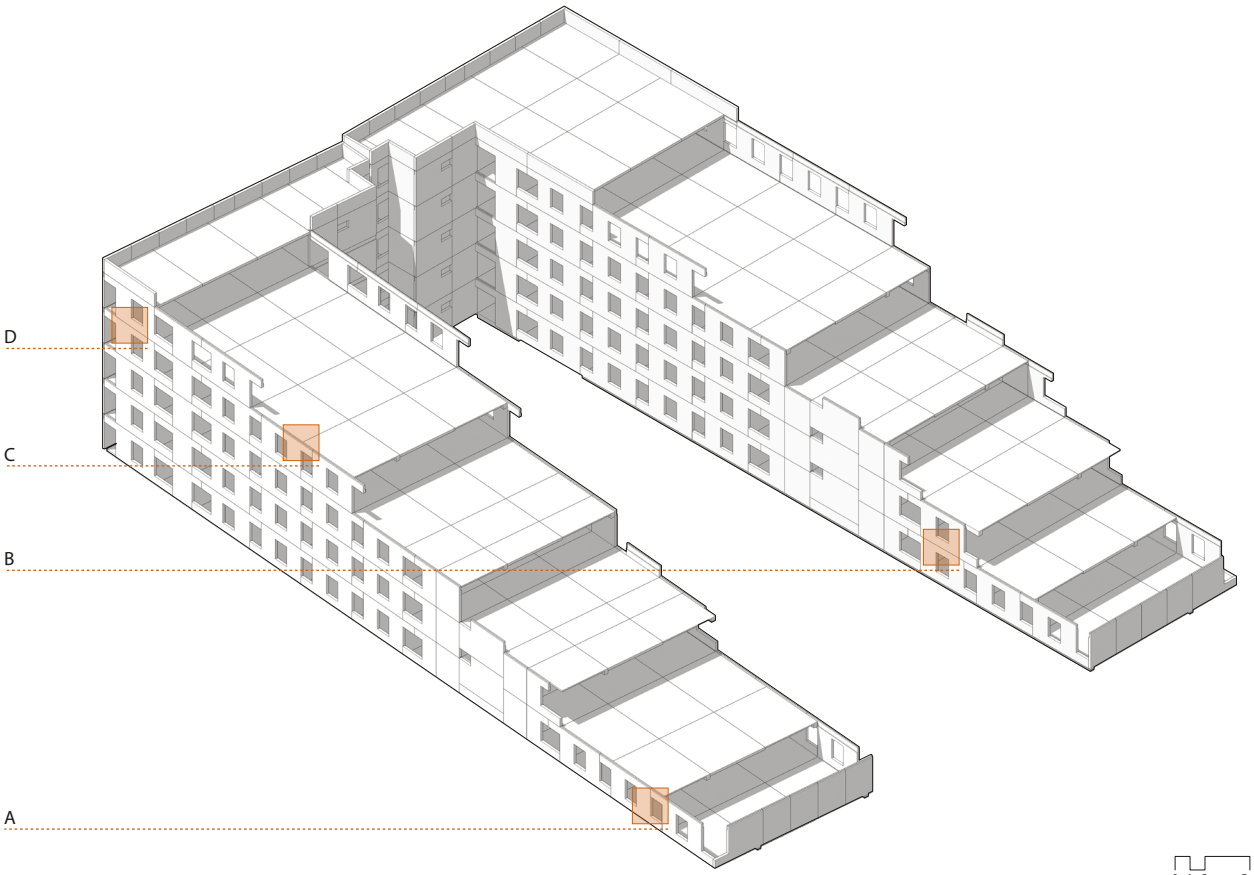
The assembly sequence begins with the exterior and interior precast-concrete structural panels. Then the precast-concrete slabs – the ribs of which are mortised to the panels – are placed on them and then stiffened with perimetral concrete castings. The interior divisions of each dwelling are made in drywall panels, according to the original architectural designs. Subsequently, these can be transformed according to the needs or tastes of the users.



Graphic 191
Components: floor plans and façade



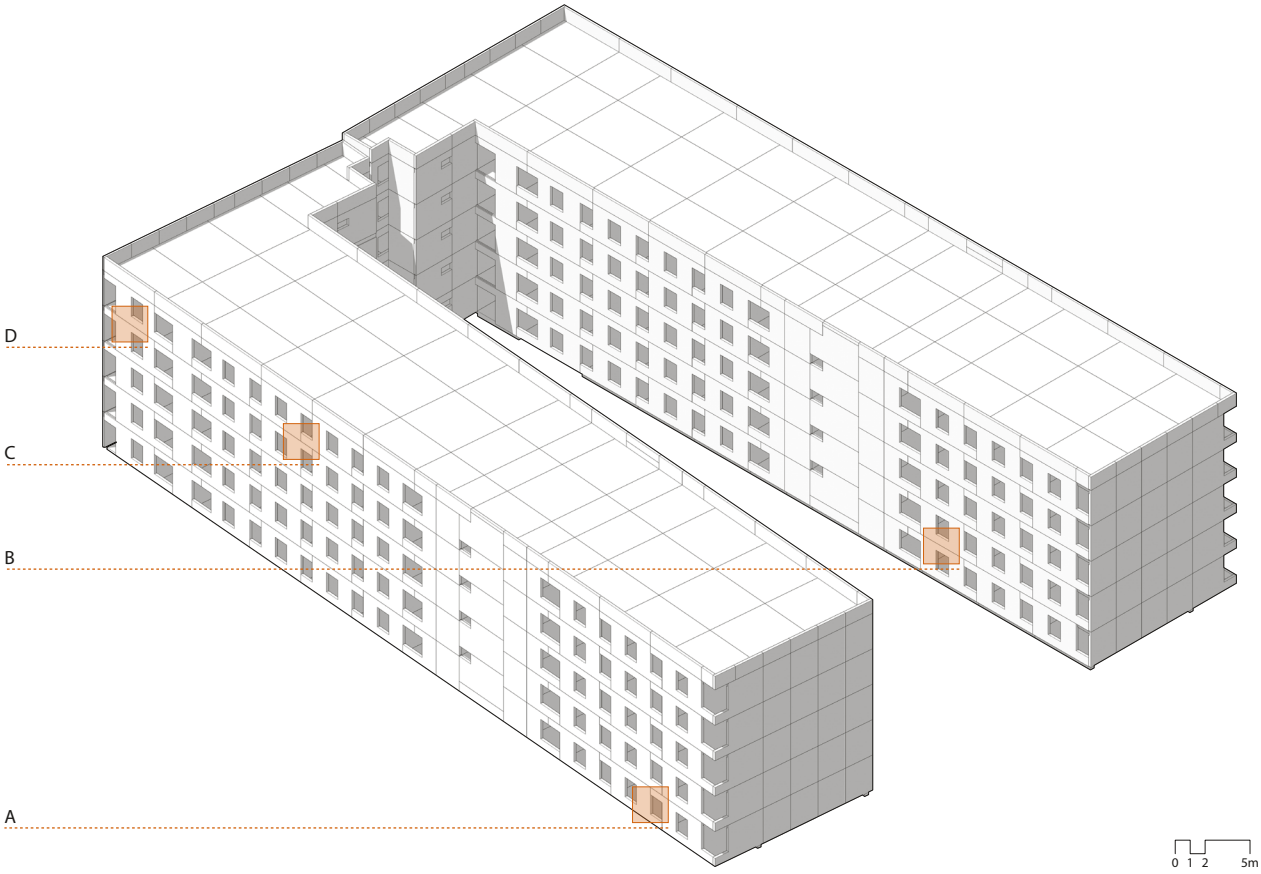
0 1 2 5m



0 1 2 5m

Graphic 192
Components: axonometry

Graphic 193
Construction process



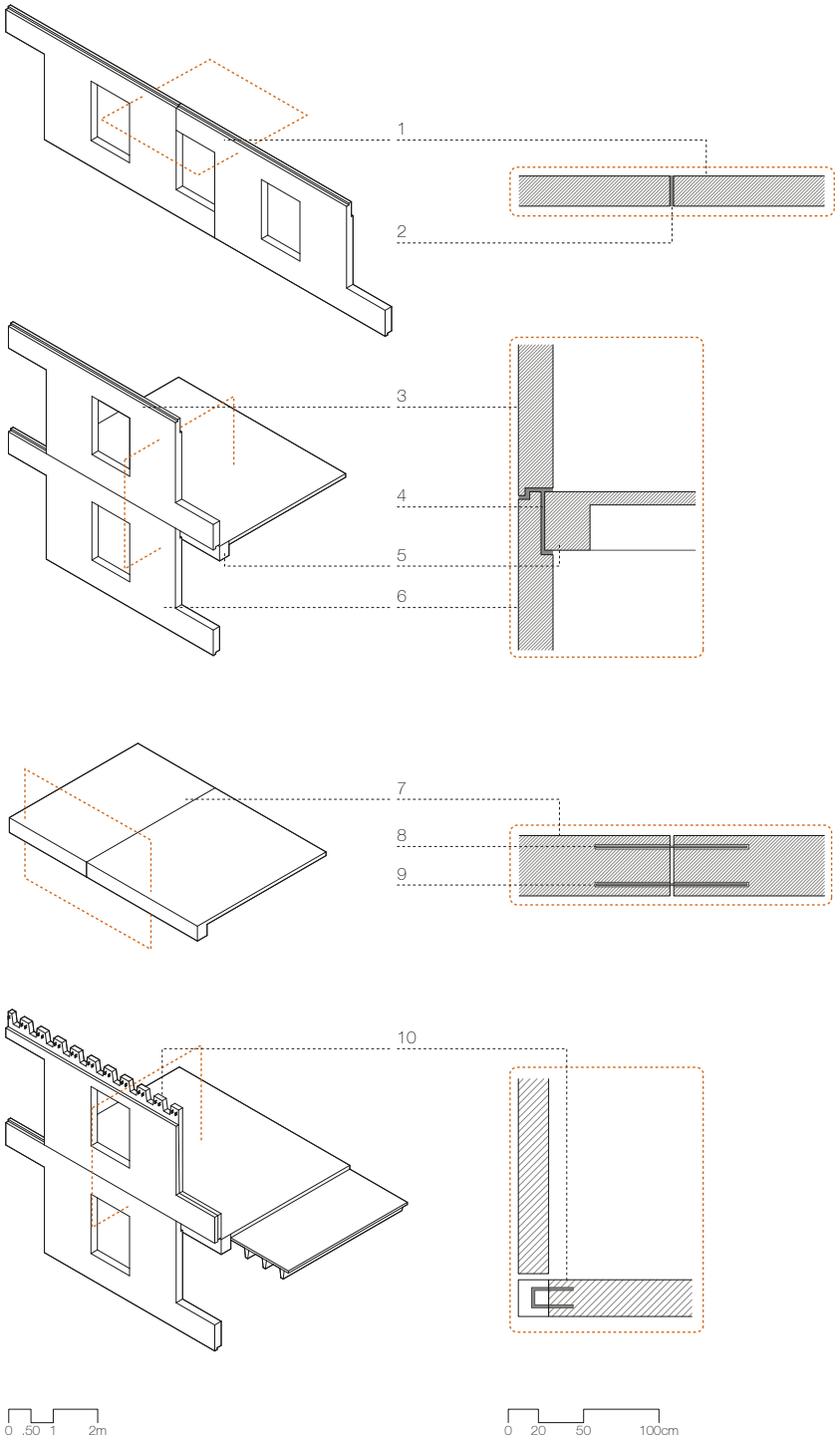
Graphic 194
The technical system and the architectural language

Advantages

- The façade panels and concrete slabs are dimensionally coordinated to form the support structure. The reduction in the typologies of the structural elements and the minimization of the dimensional and geometric variants in the windows allowed constructing the project with a reduced number of constructive elements, which could be coordinated with other types of systems.
- With the structural panel and slab system, it is possible to construct a high number of dwellings, given the repetitiveness of the elements that make it up. The structural typology and the housing typologies can be replicated and modified according to the arrangement of the non-structural interior divisions.
- The size of the panels and slabs (which reach a surface of 10m x 2.90m), condition the conditions of transport to the project site and the assembly process.
- The system of precast load-bearing panels and slabs can be adapted to different topographies, according to the dimensions foreseen for the buildings. In different environmental contexts, the characteristics of sunning and ventilation condition the interior spaces and the openings of the façade elements so that the buildings adapt to their context.
- The dimensions can be adjusted by using non-structural elements, such as drywall panels or other constructive systems, to permit mobility inside the dwellings. To access the upper floors, in addition to their stairs these typologies must gave elevators and ramps.
- The open prefabrication system allows combining the precast-concrete elements with other materials. The location of services as fixed elements makes the design and use of the rest of the interior space more flexible. The non-structural divisions inside the houses with drywall panels allow different typologies of rooms.
- The designs and proportions of the interior spaces of the dwellings can be modified according to the arrangement of the non-structural divisions. Solar incursion and natural ventilation should be addressed through the designs of the structural panels of the façades.
- The open prefabrication system allows the construction of the interior spaces with non-structural elements and, therefore, the modification of the spaces according to the needs of their inhabitants.

Disadvantages:

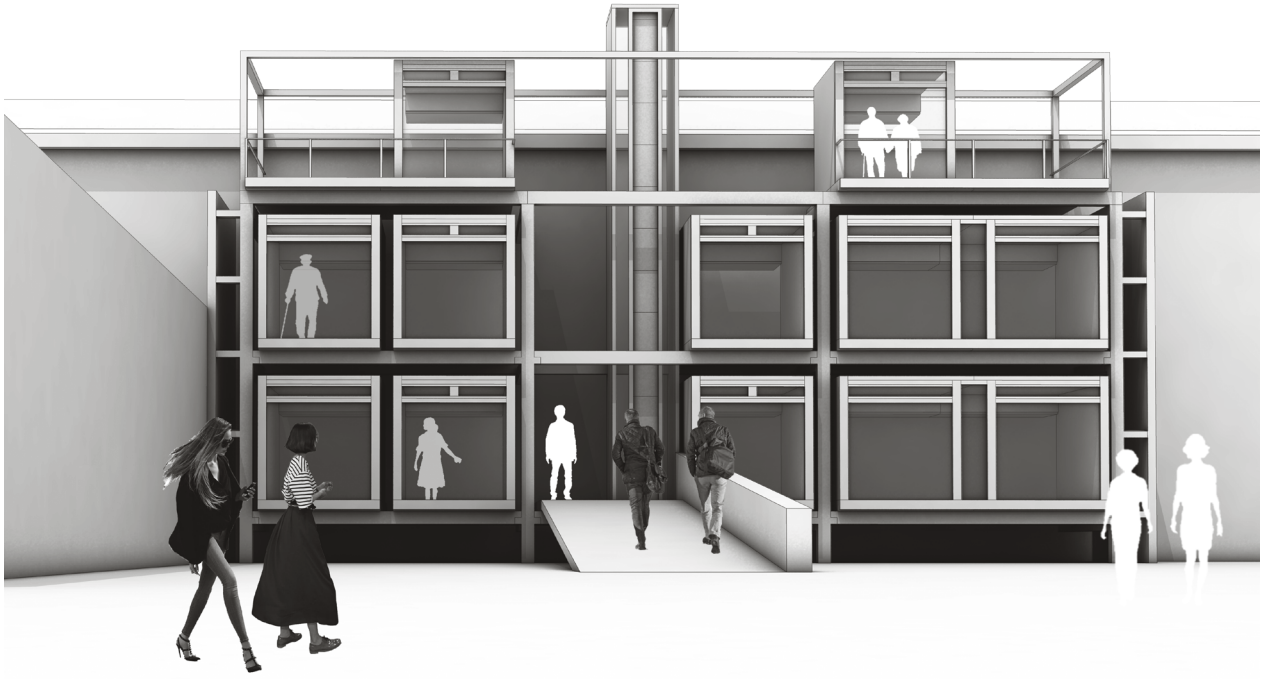
- The installation of the structural panels and slabs separately and with lengths of up to 10m complicates the system of joints among these elements, increasing the amount of activities in the construction process and, therefore, the time.
- The design of the structural panels conditions the language of the building. In this project, the repetitiveness of the geometries and proportions of the windows in the façades generate a monothematic appearance in the building, a situation that moves away from the desires of the users in popular-habitat projects in the local context.



1. Precast concrete facade wall
2. In situ cast concrete
3. Precast concrete facade wall
4. In situ cast concrete
5. Precast concrete slab
6. Precast concrete facade wall
7. Precast concrete slab
8. Steel bars
9. In situ cast concrete
10. In situ cast concrete

Graphic 195
Constructive details

5.4.4. Residential and comercial building, Rathenow, Germany, 1997



Graphic 196
Exterior view

Residential and comercial building. Rathenow, Germany, 1997	
Type of structure	Skeletal
Type of prefabrication	Open
Architect, inventor or designer	K. Sill, J. Keim
Average areas per home (in square meters)	45, 90
Number of housing units (on average, per building)	5
Average height of the buildings (in number of stories)	3
Number of types of precast elements	9
Precast foundations for columns	2
Precast foundation beams for walls or mooring beams	2
Precast foundation slabs	0
Columns	2
Beams	2
Facade panels	0
Interior walls	0
Mezzanine slabs	1
Types of structural elements or slabs for rooves	0
Special elements (ducts, joints, common areas, awnings)	0
Stairs	0
Structural spatial cells	0
Types of joints	Metal anchors

Information taken from: Staib, Dörrhöfer and Rosenthal, 2008, pp. 168-171.

Table 35
Residential and commercial building. Rathenow, Germany, 1997.

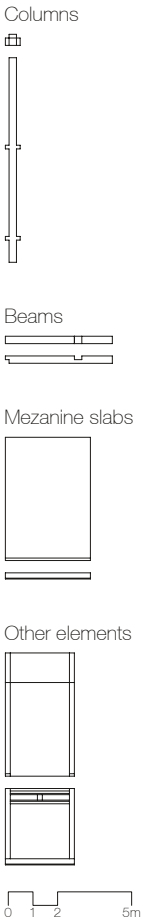
System and building

This project was an addition to an existing building constructed in the 19th Century. This addition was designed by Architects Klaus Sill and Jochen Keim in 1997. Toward the street, the existing building was remodeled, retaining its original characteristics. Toward the patio, the new building was designed with precast columns and beams with a rectangular section that formed a skeletal-support system for the subsequent insertion of containers constructed with metallic structures, glass façades and aluminum with thermal insulation. The addition considered three-story-tall office and housing modules (Staib, et al., 2008c, p. 168). The beams were spliced through a simple support on the brackets of the columns, with metal rods that stiffened the joint between these elements. The twelve containers had a width of 233cm and a height of 355cm; they were installed on the solid 11cm-thick precast concrete slabs that served as additional support and protection against fire. The proportions of the precast concrete elements were defined from the existing dimension of the containers (Prochiner, Walczyk & Hartmann, 2001, p. 706).

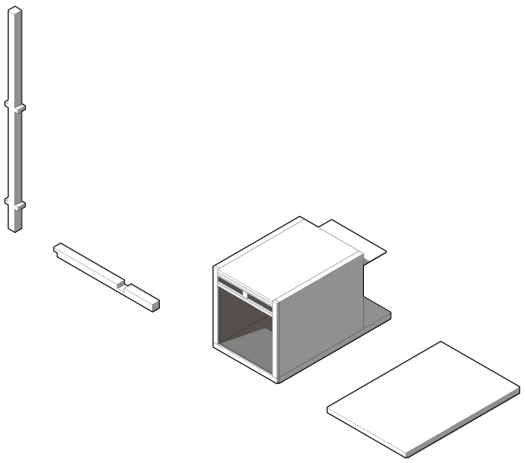
The project uses the traditional characteristics of the neighborhood where it is located, and it integrates the mixture of living and working in an expansion of an existing building. On the first two levels (intended for office space) three duplex apartments between 60 m^2 and 90 m^2 were proposed. The concrete structure that supports the 12 containers functions independently from the rest of the building. The container prefabrication site is located 500km from the project and these units must comply with the dimensions and conditions for land transport. In these modules, the ducts for the technical installations and part of their finishes were foreseen, which accelerated the construction process.

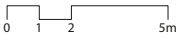
Existing offices and dwellings were complemented with these modules, an aspect that permitted the possibility of having different housing typologies from the number of units that are integrated or grouped. The columns were prefabricated with their final dimensions (two stories high) and the containers were arranged on the beams between the columns. The upper level has a mooring beam between the columns and two modules that leave spaces free for the terraces that serve the dwelling are located on it. The separation between the existing building and the new project is made up of circulations to the office and housing spaces. The reinforced precast-concrete skeleton also meets the insulation and fire protection conditions of modular housing units.[51]

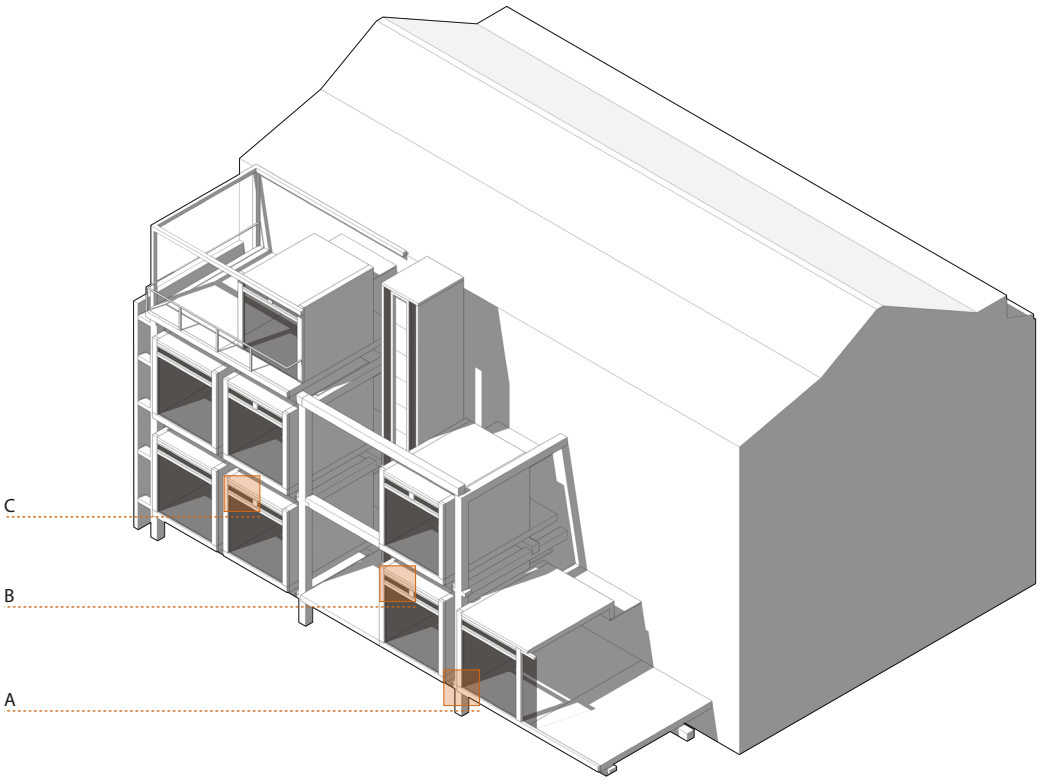
51 Bürohaus Rathenow. Architekten Prof. Klaus Sill + Assoziierte GbmH. Accessed June 10, 2017; available at https://architektenprofsill.de/portfolio/rathenow

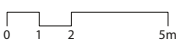


Graphic 197
Components: floor plans and façade



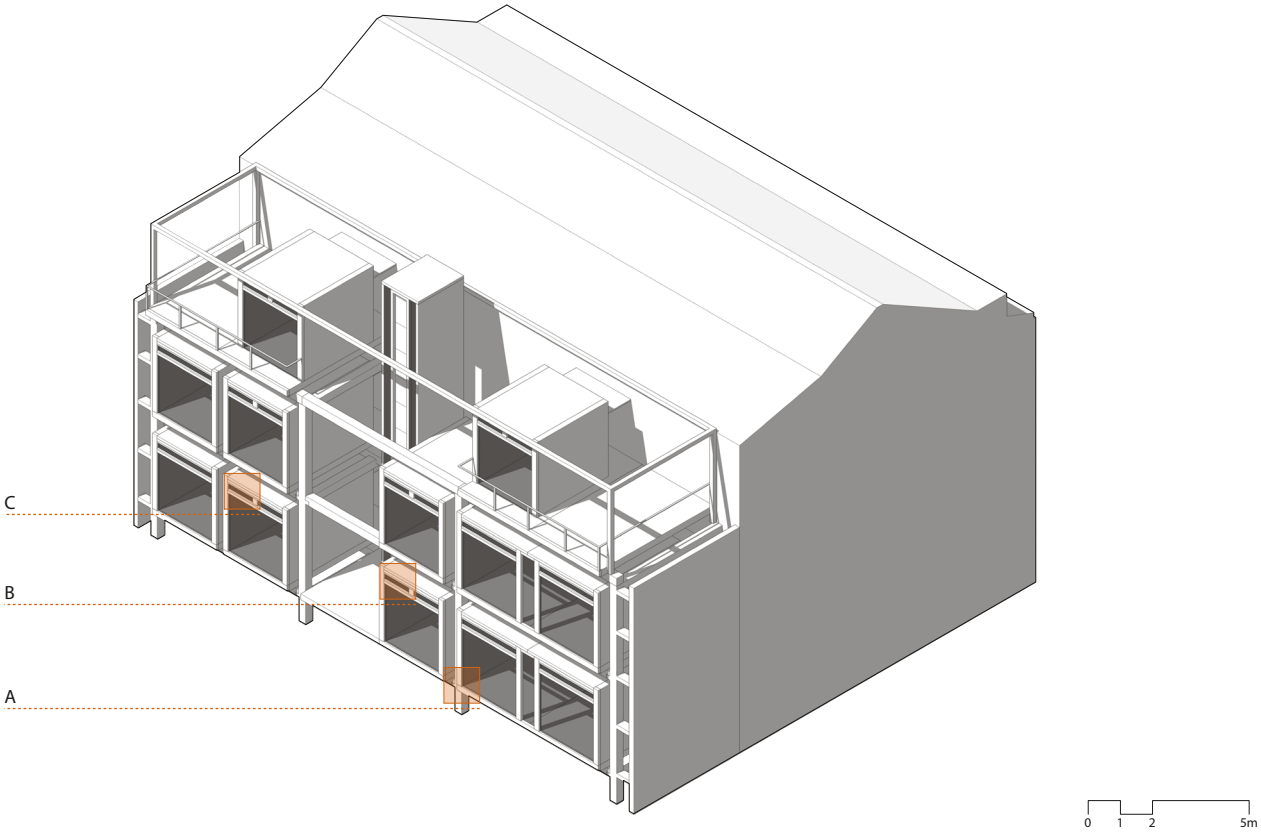






Graphic 198
Components: axonometry

Graphic 199
Construction process



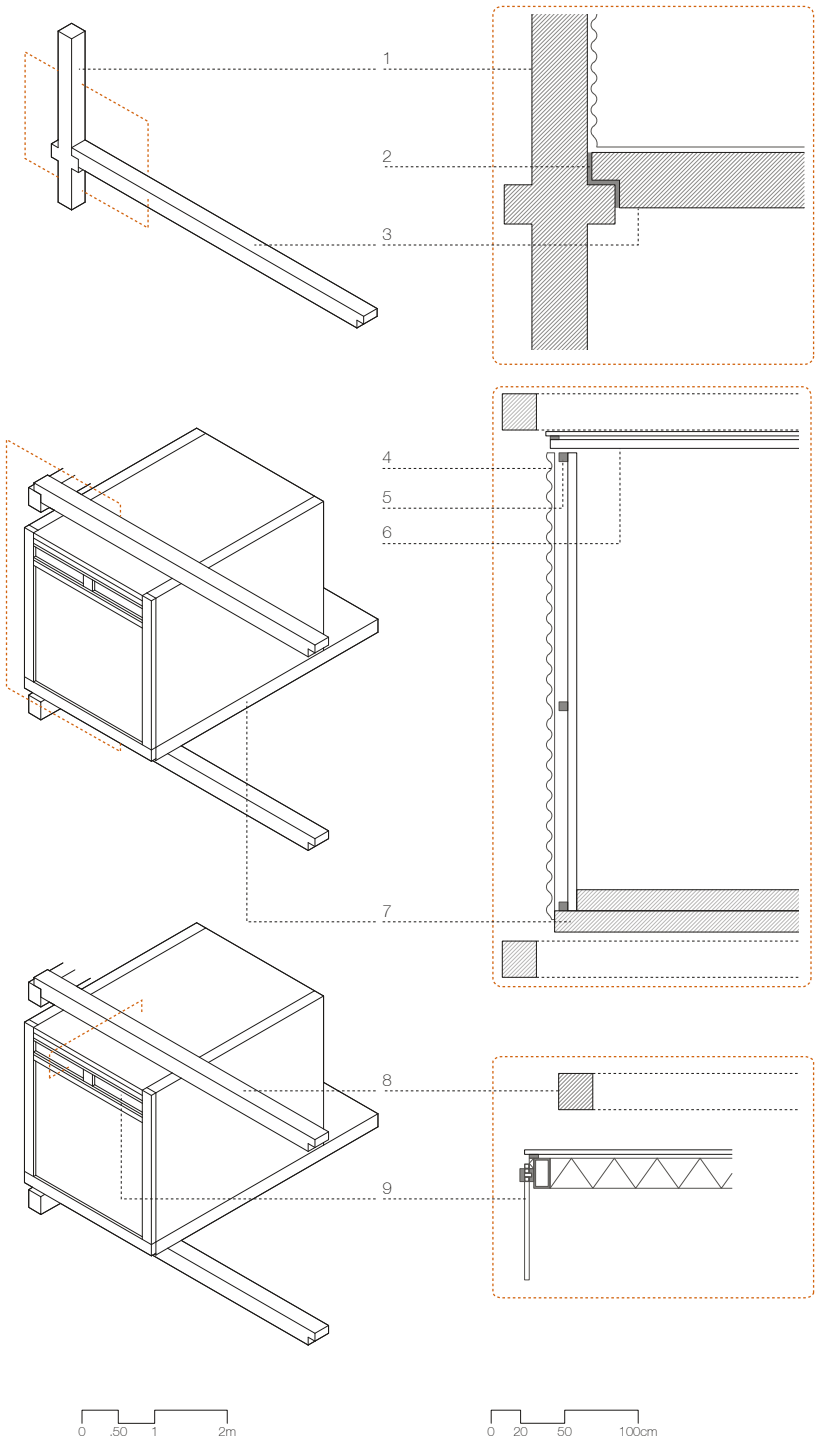
Graphic 200
The technical system and the architectural language

Advantages

- The dimensions of the precast-concrete support structure were designed from the proportions of the prefabricated metal cells that complement the system. The modular coordination allowed the total prefabrication of this building with two complementary industrialized systems.
- In the local context, if the length of a precast-concrete structure is less than 12m, specialized cargo vehicles are not required.
- The girder structures adapt best to different topographies, due to the individuality and volume of their columns and beams. The location of the non-structural elements in the façades and in the interior walls allow adapting the living space to different contexts, using different elements to respond to the desirable sunning and ventilation conditions, or adapting the language to the cultural and social conditions of the setting.
- Open prefabrication permits using other materials or systems in the façade or in the interior space. This condition increases the possibilities of designing other housing typologies, allowing the language of the building to be associated with local traditions and having different architectural responses under the same structural system.
- The proportions of the interior space and the responses to sunning and ventilation can be resolved from the non-structural elements in the façade and interior space (industrialized or constructed with the local traditions), which complement the precast structural system.
- From the precast-concrete structure, the project can use non-structural elements in more of the surface of the façades. This condition generated responses to different social, cultural, environmental and economic contexts. This system of open and partial prefabrication permits the use of traditional materials, the participation of local labor and the consideration of aesthetics from the architectural designs proposed by professional groups or with the participation of the community.
- The precast-concrete structure makes it possible to vary the proportions and uses of the interior spaces from the arrangement of the non-structural elements. According to the configuration of the building, the dwellings can grow, transform their interior space, vary their functions or modify their languages according to the conditions of the project or with the wishes of their inhabitants.

Disadvantages

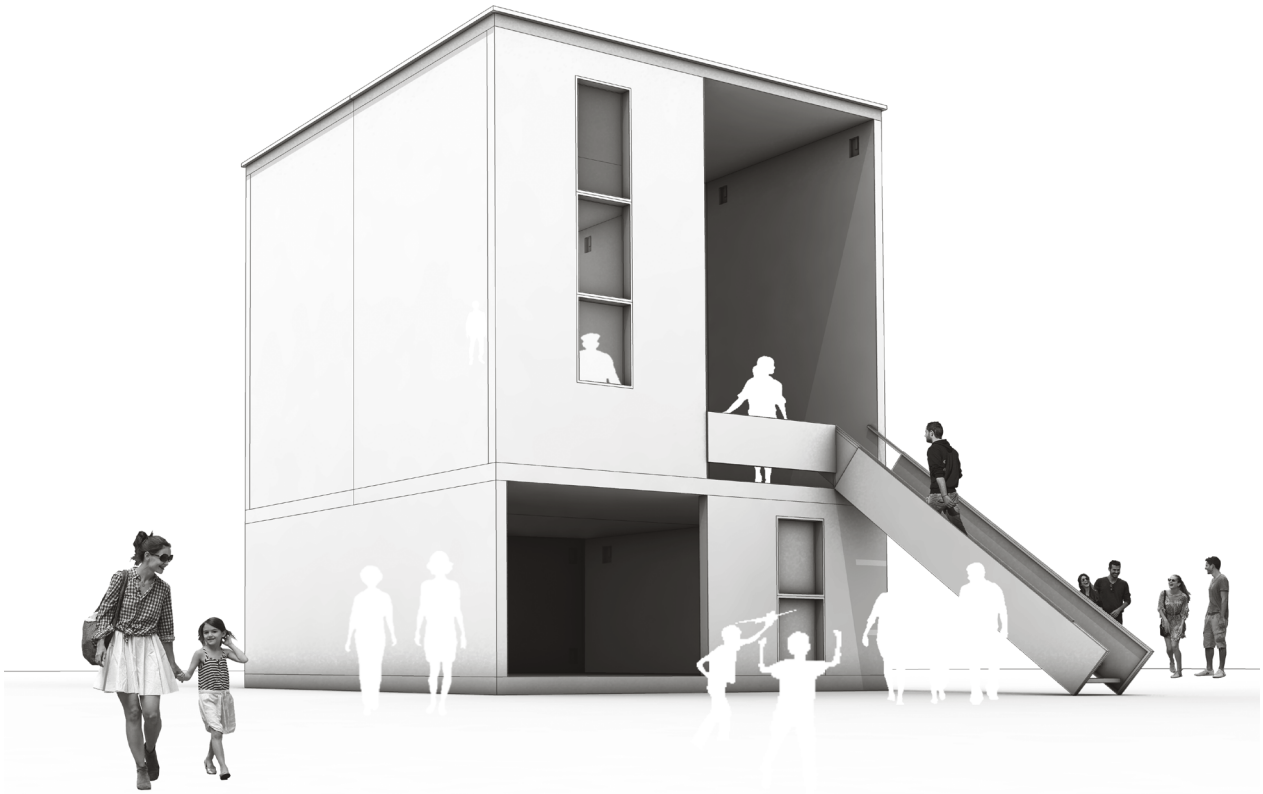
- Although the joint among the structural elements is made simple by means of supports between the beams and column brackets stiffened with metal pins, the foundations for frame systems require depths similar to those used by conventional construction systems. This condition precludes the possibility of using some sites due to their load-bearing capacity, the cost of the construction of the foundations and the time required for excavations.



1. Precast concrete column
2. In situ cast concrete
3. Precast concrete beam
4. Corrugated aluminium exterior
5. Wood spacer
6. Aluminium panels
7. Precast concrete slab
8. Precast concrete beam
9. Aluminium frame

Graphic 201
Constructive details

5.4.5. Elemental - Milan House Prototype. Italy, 2008.



Graphic 202
Exterior view

Elemental - Milan House Prototype. Italy 2008	
Type of structure	Structural walls
Type of prefabrication	Open
Architect, inventor or designer	Elemental – Chile
Average areas per home (in square meters)	18.6 to 62.8 (house) and 26.3 to 71.8 (duplex)
Number of housing units (on average, per building)	2
Average height of the buildings (in number of stories)	3
Number of types of precast elements	10
Precast foundations for columns	0
Precast foundation beams for walls or mooring beams	0
Precast foundation slabs	0
Columns	0
Beams	0
Facade panels	8
Interior walls	0
Mezzanine slabs	1
Types of structural elements or slabs for rooves	1
Special elements (ducts, joints, common areas, awnings)	0
Stairs	0
Structural spatial cells	0
Types of joints	Metal bars and welded joints

Information taken from: Aravena and Iacobelli, 2012, pp. 476-479.

Table 36
Elemental - Milan House Prototype. Italy, 2008.

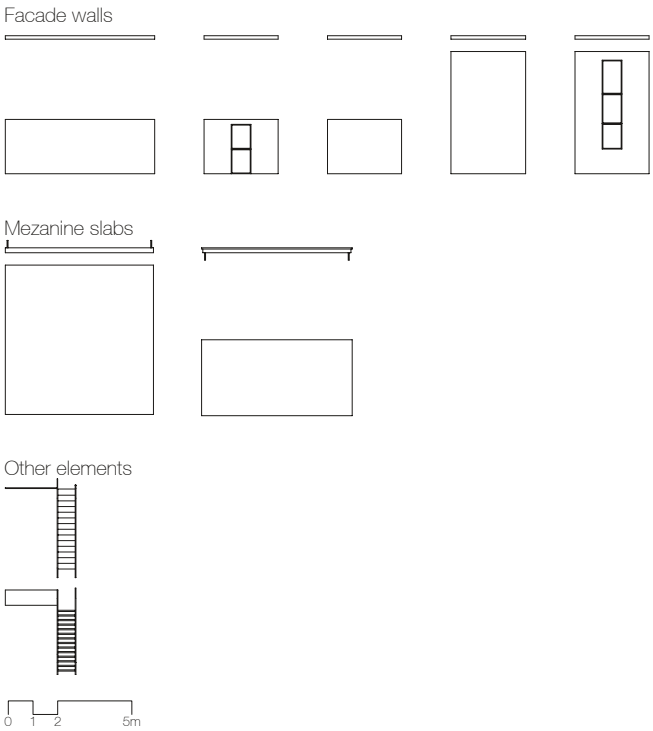
System and building

This prototype explains prefabrication in concrete of a social housing module. Elemental, an architectural "do-tank" (as they define it), headquartered in Santiago, Chile, has addressed topics on the design and construction of social-housing projects with participatory, incremental designs that initially proposed the construction of "half a house" (the support structure, technical installations, façades and roof).

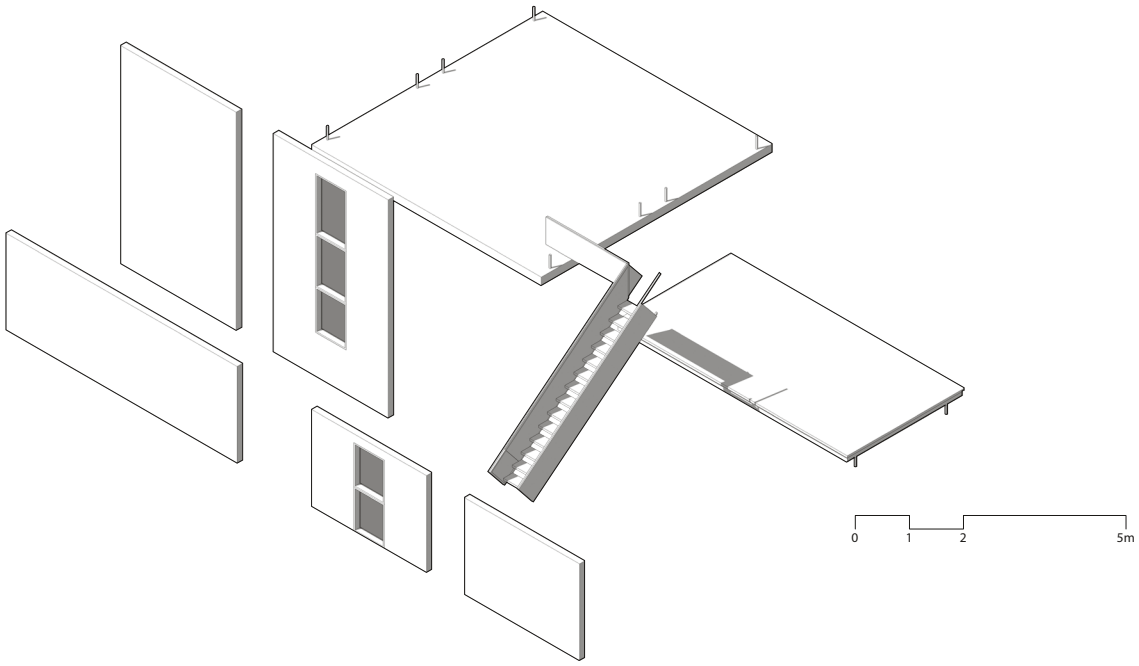
The original area could be increased in the time that was required through self-construction processes, according to the needs of the family group. At the beginning of 2008, Elemental was invited by the Triennial of Milan to participate in the exhibition *Case per Tutti* (Homes for All), which addressed the topic of emergency inhabiting and low-cost housing. The prototype was constructed for two houses: the first on the ground floor, with possibilities of growing sideways; the second, on the top, at a double height, with possibilities to group upwards, in the space delimited between the floor plan and the roof. The project was conceived with structural walls, permitting the elimination of chains and beams and increased the original structural module from 3m to 6m. The walls and structural slabs were joined to the panels through exterior and interior metallic connectors. The construction was conducted by MC Prefabbricati, an Italian company that did the assembly in 24 hours of work (Aravena & Iacobelli, 2012, p. 476).

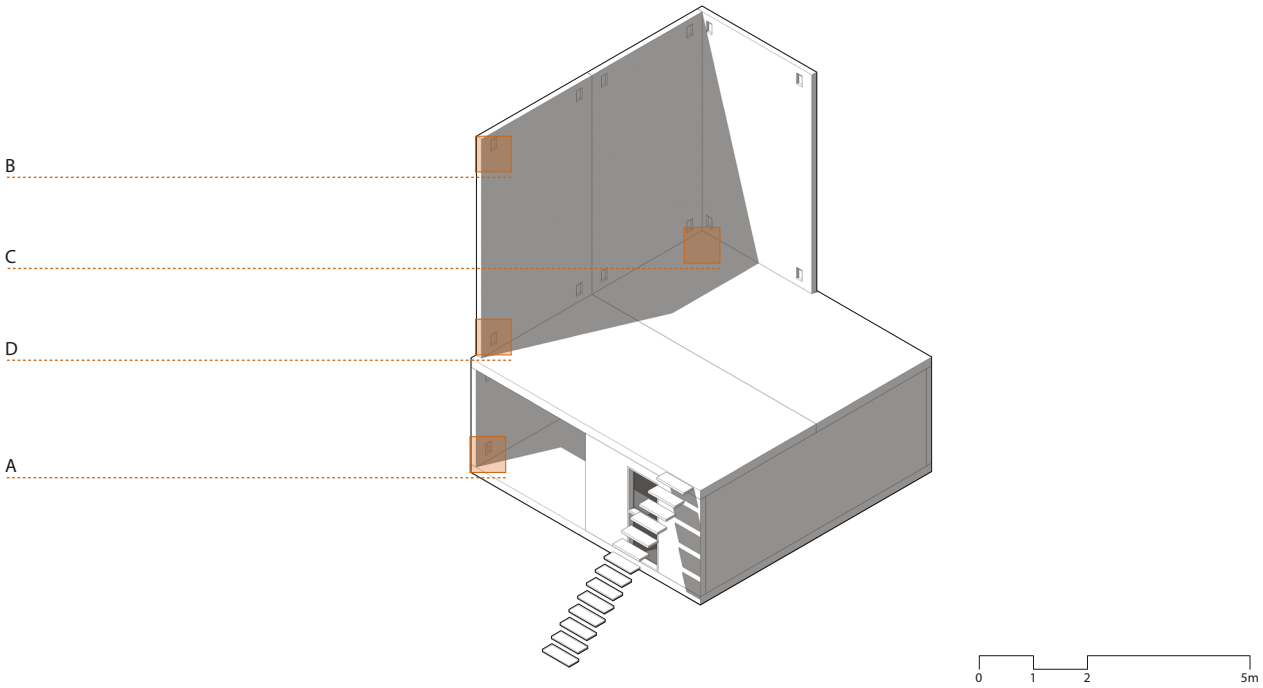
This prefabrication company took over the typology already built in the *Lo Espejo* project in Chile (made with structural masonry and *in-situ* cast-concrete slabs) and adapted it to a construction system of pre-cast concrete structural panels. The thicknesses selected were 20 cm for the walls and 25 cm for the floor slabs.

In the construction of this dwelling, *Elemental* proposed increasing the quality of the typologies in *Lo Espejo* from the prefabrication of the housing module in concrete. Aravena and Iacobelli argue that in the construction of social housing, more than two-thirds of its direct cost can be attributed to the support structure. Therefore, social housing and the *Casa Milán* prototype is a habitable structure, in which architectural-, structural- and constructive-design processes are addressed strategically, precisely and efficiently to reduce deadlines and costs, thus increasing quality (Aravena & Iacobelli, 2012, p. 466).



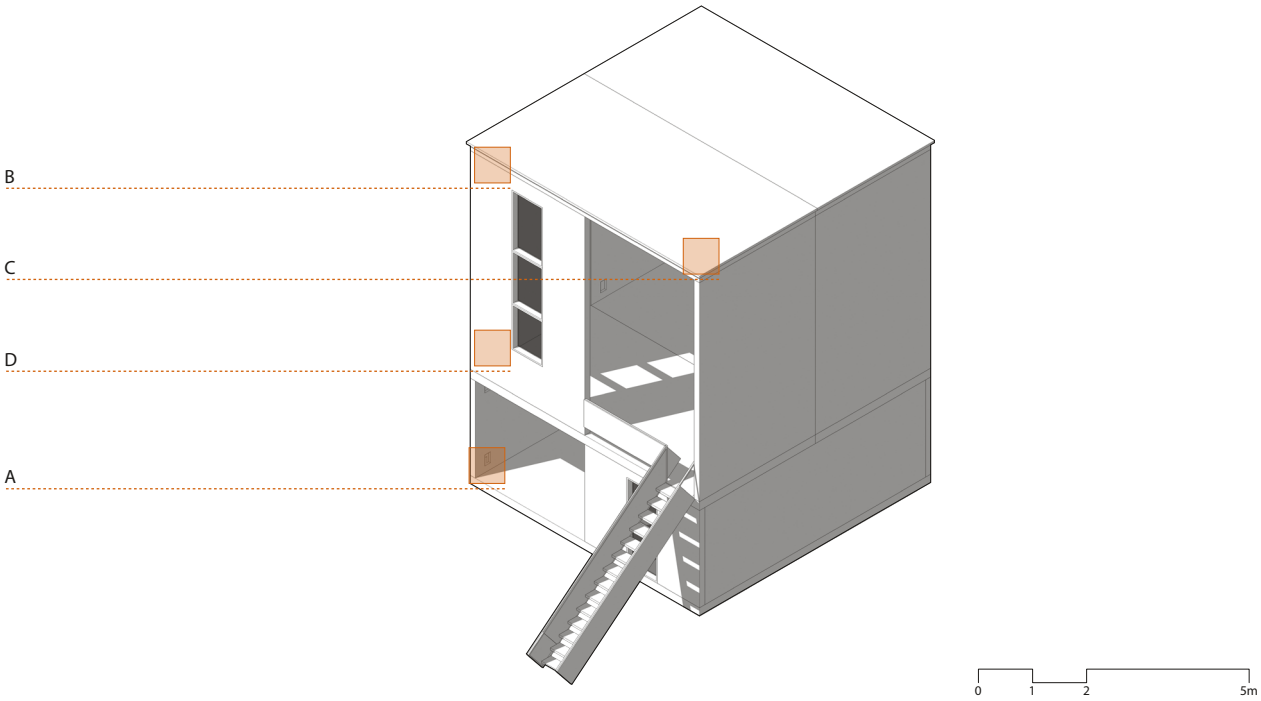
Graphic 203
Components: floor plans and façade





Graphic 204
Components: axonometry

Graphic 205
Construction process



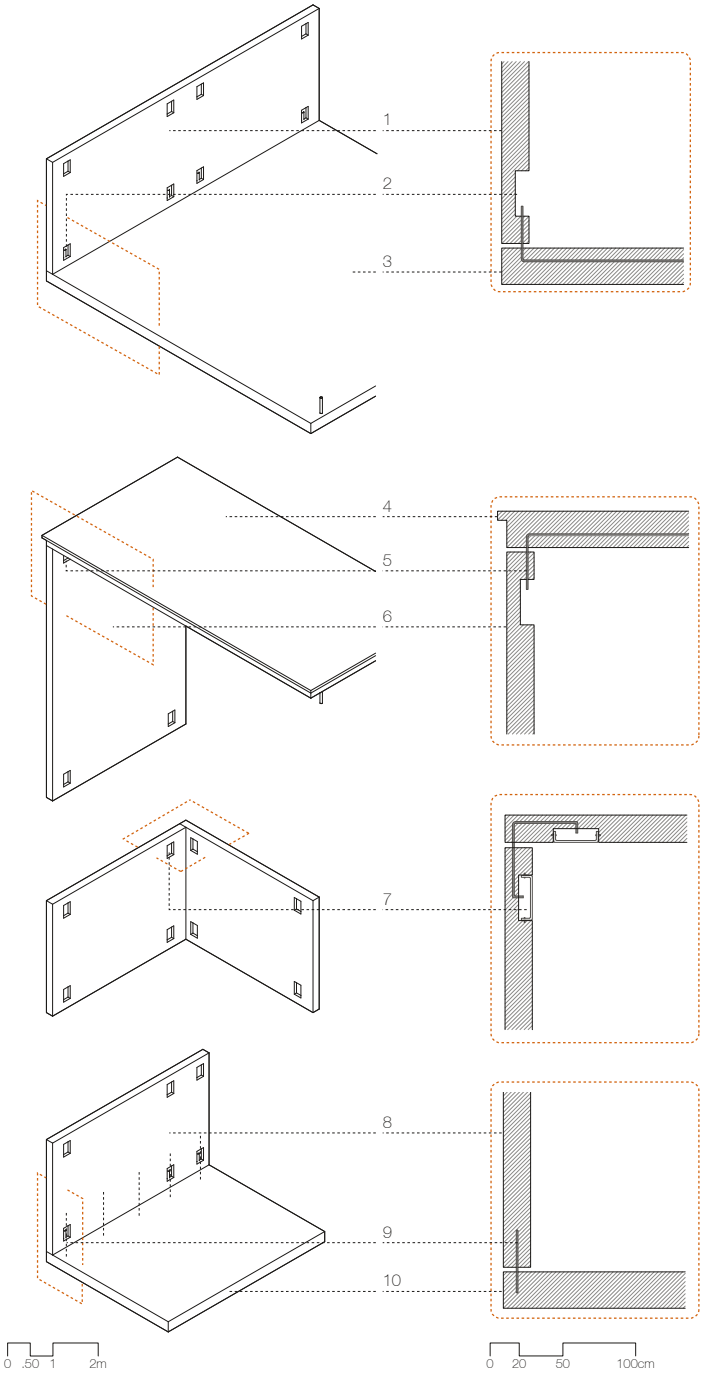
Graphic 206
The technical system and the architectural language

Advantages

- The elements of the system are designed by coordinating the dimensions established for its structural walls, floor slabs and rooves, eliminating waste on site and ensuring modular unity among them.
- The panel and structural-slab systems can be replicated in the massive construction of social housing. This condition allows a reduction in time and standardizes work processes, which is desirable to increase the number of homes built with the same system.
- The dimensions of the structural elements allow their transport from the factory to the construction or their production at the project site.
- In different topographies and social, cultural and environmental contexts, the structural-panel systems used in this project serve to construct a social housing in relation to the setting and with the communities.
- In the installation of non-structural elements in its interior space and in the façades, the half of the house that is left free can find the flexibility sought for social housing. The house constructed with structural panels occupies a wide surface of the façade and, therefore, the language of the project must consider these constructive elements. The interior space of the initial house should be free of structural elements inside to propose a versatile dwelling, capable of responding to the wishes of the users.
- The possibility of increasing the areas offered by the system allows – in the second half of the house – the spaces to be expanded according to the needs of the inhabitants. The response to sunning and the ventilation conditions are solved in the first half of the house with the prefabricated elements, and in the second half, with the façade designs or adaptations of the houses to the environmental conditions of the setting.
- The repeatability of the structural elements on the project façade in combination with the gaps left by the first intervention allow users to determine the materiality and the language of the project in the expansion of the dwellings through self-construction processes, which generate processes of participatory design and increase the sense of belonging through traditional activities with which the popular neighborhoods of Antioquia, Colombia and a large part of Latin America have been built.
- The occupation of the gaps left between the prefabricated houses generates future conditions to take advantage of the free spaces. These transformations are made with the resources, possibilities and time of the communities, who – through self-construction processes – use traditional materials and local labor to adapt the dwellings to their needs, their individual expression and their desires.

Disadvantages

- According to the interior dimensions of the dwelling, the non-structural divisions define the proportions of the circulations, the spaces and the doors. Access to the second-story dwelling is not possible, given that the staircase is the only way to go up.
- The hoisting and installation of each element individually causes the work processes to increase compared to other systems that integrate their components. The foundations in a panel system can be continuous beams, which concentrate the loads and deepen the excavations until stable, resistant terrain is found.



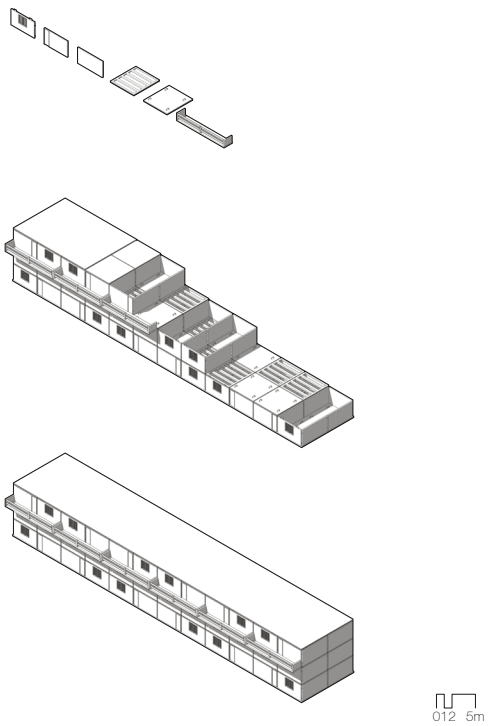
1. Precast concrete facade wall
2. Steel bars
3. Precast concrete slab
4. Precast concrete slab
5. Steel bars
6. Precast concrete facade wall
7. Steel bars
8. Precast concrete facade wall
9. Steel bars
10. Precast concrete slab

Graphic 207
Constructive details

5.4.6. Other projects

5.4.6.1. Ciudad Bachué I. Bogotá, Colombia, 1980.

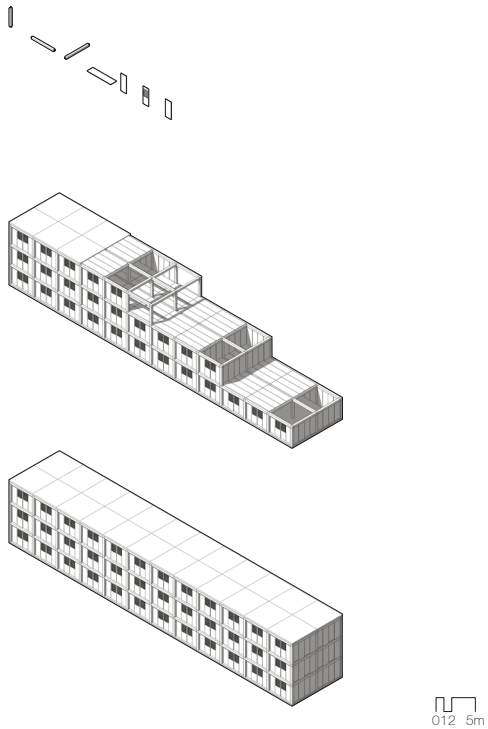
The project was designed by Architects Patricio Samper, Luis Tapias, César Moreno and Gregorio Marín and built with a system of precast concrete structural walls. The housing complex partially defined an urban structure that allowed its inhabitants to enlarge their homes through a progressive development of self-construction (Forero, 2008, p. 128). Productive housing was developed in phases with a sense of dynamic inhabitability, which transformed the original language of the project. Different areas were stipulated for the homes' construction with this structural system. These typologies had living areas ranging from 28 m2 to 98 m2. The façade panels and interior walls were conceived as solid elements with thicknesses between 8cm to 10cm. The mezzanine slabs were conceived as 25cm-thick Type T-T lightweight ribbed plate. The same floor slab, which was waterproofed, was used to build the roof, with slopes of 8%. The drains were placed in a special floor slab with holes for the passage of the installations. The water supply installations were located in the joints between the panels. The electrical installations were placed in the joints of the wall and slab plates (Aguilera, n. d., pp. 23-24). Some wall partitions were constructed in masonry. The finishes that each user wanted to install were optional and influenced the final cost of the home. The elements were fixed together by welding the reinforcements that had been left exposed. The joints were stiffened with cast concrete on the knots (Aguilera, n. d., p. 24).



Graphic 208
Ciudad Bachué I. Bogotá, Colombia, 1980. Construction process

5.4.6.2. Ciudad Bachué II. Bogotá, Colombia, 1980.

The Stage II architectural design group was also led by Patricio Samper. It used a skeletal system of beams and columns in precast concrete, completed by non-structural panels, also produced in the same material. In this stage, 2,888 housing units with areas between 32 and 54 m² were constructed. To keep costs low, no finishes were given; an aspect that was left for the user to terminate. The construction of the field factory reduced transport costs and made the production and installation time more efficient, with a low investment in adapting the space (Aguilera, n. d., pp. 24-25). The foundation was constructed on a reinforced in-situ cast concrete slab in which the first-floor columns were embedded. The project was designed to support a five-story building, although a one-story building was built initially. The joints between the structural elements were made by welding their reinforcements and the subsequent casting of mortar in the joints. This operation was done independently from the installation of the floor slab plates, due to the fact that these slabs were directly supported on the beams. The 4cm thick, high-resistance precast concrete façade walls were joined to the precast concrete structure with previously determined welding points. The joints between the welding points were also filled with mortar. Later, the buildings were enlarged by the community (Aguilera, n. d., pp. 24-25).



Graphic 209
Ciudad Bachué II. Bogotá, Colombia, 1980. Construction process

Summary

Structural system, language and living space

A strategy to reduce the accumulated housing deficit since the first years of the XX Century was the industrialization of construction.[52] After World Wars I and II, Europe began a reconstruction process of the houses that had been destroyed.[53]National authorities proposed selecting technical systems with a certain degree of industrialization, among which precast concrete was one of the most used.[54] This response to the housing deficit had different political, social, economic and technical nuances. The prefabrication of the social housing in reinforced concrete was realized with three fundamental objectives: to reduce costs, to reduce time and to improve the quality of the living spaces. Through these conditions, the industrialization of housing has been replicated to build new solutions massively and in a standardized manner.

Some of these solutions have increased the number of dwellings and reduced time, but have neglected housing-quality conditions; they have not considered cultural traditions, repeated the language of the buildings (associated more with technical criteria than housing criteria) or have distanced themselves from the wishes of their inhabitants. With the aim of increasing efficiency, other systems have developed sophisticated production, assembly and installation processes for the prefabricated parts in the building, which generates a technological and economic distance with the local context and its technical and economic possibilities.

From the case studies analyzed, these experiences show positive aspects and some problems to consider in the design and construction of social housing in the local context.

Modularity

Some projects do not have a modular dimensional unit, which reduces the possibility of combining their prefabricated elements with other materials and with other systems in the design and construction process. Those that propose open criteria of modular coordination between the precast-concrete system and other systems have obtained more versatile results in the living typologies and in the languages of the building.

Replicability

Eighty percent (80%) of the systems analyzed are made up of more than ten typological variants in the prefabricated elements, which reduce the principles of standardization and, therefore, the efficiency in production. The fewer the variants that exist in the prefabricated structural elements and the greater the possibilities of combinations among them to diversify the designs of the dwellings, greater is the efficiency in the industrial production of their components.

Transportability

The dimensions of the prefabricated elements have been considered according to the characteristics of the roads in each context. The location of the projects is one of the factors that makes their own prefabrication viable, since distances to the production plants must be considered and the characteristics of the existing roads to reach the projects must be evaluated. In some cases, the distances from the industrial plants to the projects made it necessary to construct field factories, which eliminated transport costs but increased the industrial production costs.

Adaptability

The systems analyzed adjust to different topographies. The location of structural panels in the façades reduces the possibilities of adapting projects to the environmental, social, economic and cultural conditions in different settings.

Accessibility

The dimensions proposed for the interior spaces in the typologies of housing analyzed allow the displacement of their inhabitants with different conditions of mobility. Only 30% of the projects have elevators or ramps, which permit reaching each of the floors.

Simplicity

The designs of the joints among the structural elements require an accumulation of technical processes, such as moorings between the metallic, concreted or welded reinforcements to stiffen the joints. The foundations of the systems analyzed are complex and expensive. Most are made in *in-situ* cast concrete and require depths similar to those needed for the construction of housing with conventional systems. Reducing the complexity of the joints, maintaining their structural stability and defining a foundation system that distributes the loads uniformly and superficially to the terrain are criteria required to improve the efficiency of the construction process.

Versatility

Structural panels on façades and in interior walls reduce flexibility in the living spaces and in the language of the projects. The frame systems make the typologies of interior spaces and the formal and technical variants of the façades flexible. While permitting versatility in the interior space, the system of housing cells, which considers structural walls on the façades, reduces the possibilities of intervention on the language of the project.

52 *Fédération Internationale du Béton fib,* Task Group 6.7, *Affordable Housing*. Prefabrication for affordable housing. Ostfildern: Document Competence Center Siegmar Kästl, 2011. p. 3

53 Musso, Florian, op. cit., footnote 310, p. 57

54 Graf, Franz and Yvan Delemontey. *Understanding and Conserving Industrialised and Prefabricated Architecture*. Lausanne: *Presses polytechniques et universitaires romandes,* 2012. pp. 40–41

Comfort

Projects that do not use structural panels in the façades and in the interior spaces have a greater diversity in the proportions of the living space and in a better relation with the environmental setting, since the designs respond to design conditions and not only to technical requirements. The responses to the conditions of lighting and natural ventilation come from the coexistence of the prefabricated support structure with non-structural elements in the façades and the interior divisions. In some cases, the service spaces are fixed on the floor, which determine the location of the technical facilities and allows other typologies of habitation to be considered in the rest of the architectural space.

Beauty

Projects that establish the possibility of complementing the support structure with non-structural elements in their façades generate a closer relationship with the environmental, social and cultural conditions of the context and permit formal explorations with other materials and systems. This aesthetic, related to the conditions of the setting and the needs or tastes of the communities, has accompanied the construction of social housing in the local context. Projects with façades in reinforced precast concrete structural panels establish a repetitiveness in the language that reduces the possibilities of formal explorations in the façade associated to criteria of individualization of the collective housing.

Transformability

The projects with prefabricated interior and façade structural panels reduce the possibilities of transforming the housing in its occupation process. In cases where the structural panels leave an empty space between houses, growth is possible. The skeletal systems grant greater facilities in transforming the interior spaces, the areas and the language of the project.

Prefabrication in concrete was used as an expression of rationalization, standardization and efficiency to reduce time and costs in the construction of social housing. It was also used as a means of political and social expression in the search for equity, well-being, and industrial consolidation through technological developments. Precast concrete transcended from an instrumental condition as a constructive system to an ideological condition from which discussions were raised about unity or diversity in housing and in the city. In the projects analyzed, the precast-concrete technique has had three roles: it has been an instrument for the efficient materialization of architecture, an ideology linked to totalitarianism, and a starting point to facilitate diversity in the constructive technique and in architectural language.

Building the largest number of homes in the shortest time and with the lowest costs possible – while maintaining quality – has been an essential condition of prefabrication. In the analysis of these projects, two additional aspects to improve efficiency by reducing time and costs have been considered: the first corresponds to the totalitarian and unitary approach of prefabrication in concrete in political, social and aesthetic terms; the second corresponds to diversity and plurality, where this prefabrication has been articulated with other constructive techniques, expanding the scope of its language and being a means to achieve well being in the living space.

Totalitarism

In the former Union of Soviet Socialist Republics (USSR) and some Eastern European countries, prefabrication in concrete was conceived as a technical response and also as a political expression. Later on, this technique would be adopted by other countries with political influences from the socialist government of the Soviet Union. Having explained the need to build the largest number of homes with the least cost and in the shortest time possible, this condition added another factor: consolidating the standardization of parts through an industrial system, generating a repetitive language and associating these conditions with an efficient, equitable architecture. Closed prefabrication generated restrictions in time and costs, and generated an architecture limited in its formal and aesthetic explorations. One of the most tangible effects was in the mass construction of housing, in which the size of the projects prioritized standardization over individuality. This condition generated a repetitive language with minimal formal variations in the façades and interior spaces to minimize the number of types of elements.[55]

Production plants were installed in order to massify low-cost construction and promote the image of massive, efficient, unitary architecture lined to political and social conditions.[56] In these massive prefabrication techniques, this same language migrated to rural settlements in order to improve the living conditions of farmers. The ideas of modernity were associated with the multi–family building in reinforced precast concrete, while the traditional rural housing, constructed in locally available natural materials that had adequate bioclimatic behaviors, was associated with backwardness and poverty. The lack of a more rigorous contextualization of the architectural solutions did not comply with the climatic, cultural or urban requirements, since their insertion into city spaces, generated a high contrast and rupture with the traditional city.[57]

Diversity

In some countries in Western Europe, Asia and America, prefabrication in concrete was also conceived as an industrial response to rationalize costs and time, generating other technical developments and efficiently and differently resolving the construction of housing for working or low – income populations. In one case and the other, the orientation toward the construction of residential buildings at low costs and in short time determined housing solutions that were subsequently replicated in other contexts. Diversity in the language of prefabrication began with the aim to increase flexibility and offer some variations in the language of the façades and in the use of the interior space. Quality was the

55 *Fédération Internationale du Béton fib,* Task Group 6.7, *Affordable Housing,* op. cit., footnote 311, p. 4

56 Alonso, Pedro Ignacio and Hugo Palmarola Sagredo. *The Soviet KPD Building in Cuba and Chile,* 1963-1973. In: Delemontey, Iván and Franz Graf (Eds.). *Understanding and Conserving Industrialised and Prefabricated Architecture*. Lausanne, *Presses polytechniques et universitaires romandes,* 2012. pp. 299-300

57 Idem.

principal aspect. Some companies that initially produced large-format structural panels offered variety and quick responses to small demands. Others combined their precast-concrete elements with prefabricated elements in other materials through the modality of open prefabrication.[58] Other concepts, such as "subtle prefabrication", in which the large components of prefabrication have practically disappeared, were adopted. Concepts of partial prefabrication were also implemented, where the non-structural elements were specified in brick masonry or concrete blocks. Other projects considered prefabrication in concrete as an instrument for the efficient, diverse construction of social housing through urban developments with low–cost houses, with a concept of low height and high density, with models for future urban expansions.

Recognizing the repetitive, mass and unitary nature in the language of buildings, theories regarding the need for industrialized mass production and the economics of the housing, also questioned the lack of variety, flexibility and adaptation to the context.[59] The ideas were oriented to build open and flexible structural modules to transform the interior space. This permitted moving from a unitary, totalitarian language to the language of the individual and the diverse. The housing was subdivided with lightweight elements, with their equipment and modular prefabricated closures, which would permit variety in the language of the project as opposed to the monotonous solutions that were so questioned in general and so far from the taste of the families.[60]

The industrialization of contemporary social housing in the local context

Reading the case studies poses three considerations for precast concrete: as a building language, as a limit of living space, and as a concept of unity or diversity. In contemporary social-housing architecture, two conditions can be taken in the increase of the efficiency of the project and in the improvement of housing quality: standardization and customization. The former reduces costs, increases yields and improves production and installation conditions. The latter considers the diversity of the social, cultural and technical context. Rationality and diversity in architectural designs and technical processes of social housing are factors that increase efficiency and well-being.

58 Ibid.,p. 42

59 González Couret, Dania, op. cit., footnote 392, pp. 32–35

60 Vejar, Carlos. *Y el perro ladra y la luna enfría*. Fernando Salinas: *Diseño, Ambiente y Esperanza*. 1a. ed. La Habana, *Ediciones Unión*. 1994. 312 páginas. Quoted by: González Couret, Dania. *"Medio Siglo de Vivienda Social en Cuba". Revista INVI*. Volume 24, number 67 (2009): pp. 69–92



Efficiency

Conditions to improve the quantity and quality of social housing

The costs and time used in construction, the non-compliance of minimum social housing requirements and the informal processes of planning and building have been the causes of the increase in the quantitative and qualitative housing deficit registered in Colombia and in Antioquia since 1993. To increase efficiency in the designs and in the construction processes, it is necessary to construct a greater number of housing units with quality criteria, optimizing costs and time.

The word efficiency comes from the Latin *efficientia*. The Dictionary of the Royal Spanish Academy of Language (RAE[61]) defines it as the ability of someone or something to get a certain effect (RAE, n. d. a). In Latin, the term *efficientia* means the ability to execute or produce (De Col, 2007). Some other definitions, in accordance with the context in which it is used, and that also relate the quality of the products desired with the resources used, are:

In administration, according to Idalberto Chiavenato, efficiency means "the proper use of resources available" (2004, p. 52). For Koontz y Weihrich, efficiency is "the achievement of goals with the least amount of resources" (2004, p. 14). Robbins and Coulter define efficiency as "obtaining the most results with the least investment" (2005, p. 7). For Reinaldo Oliveira Da Silva, efficiency means "operating so that resources are used more appropriately" (2002, p. 20).

In economics, according to Samuelson and Nordhaus, efficiency means "the best use of society's resources to satisfy its desires or needs" (2002, p. 4). For Gregory Mankiw, efficiency is the "property according to which society takes advantage of its scarce resources as best as possible" (2004, p. 4). Simón Andrade defines efficiency as "the term used to measure the ability or quality of performance of a system or an economic subject to achieve compliance with certain objectives, minimizing the use of resources" (2005, p. 253).

According to the Dictionary of Marketing, efficiency is the "level of achievement in the realization of objectives with the least cost of financial, human and time resources". It is also defined as "the maximum achievement of objectives in a specific period of time with an established amount of human and financial resources" (Stanton, Etzel & Bruce, 1999, p. 106).

In this design and construction of social housing, efficiency is defined as the *obtainment of the quantity desired of products with a defined criteria of quality, through the optimal use of the resources available*. Quantity refers to the number of products required and to the resources necessary to obtain them. The products are dwellings and their constructed areas. The resources are the costs and time. Products and resources are related to the causes of the quantitative housing deficit analyzed in Chapter 1. Quality is evaluated through objective and subjective criteria. The objective criteria to resolve the non-compliance of minimum social housing requirements are: modularity, replicability, transportability, adaptability and accessibility. The subjective criteria are strategies to overcome the informal processes of planning and building social housing: simplicity, flexibility, comfort, beauty and transformability.[62]

If we consider a mathematical operation in which its factors may be modified to increase efficiency *(e)*, this may be measured as the relation that exists between the quantity of the products expected *(qn)* and the quality desired *(ql)*, in

$$e = \frac{(qn \times ql)}{(r)}$$

relation to the amount of resources *(r)* used to obtain them.

Increasing the quantity *(qn)* and the quality *(ql)* of social housing units, maintaining or reducing the resources necessary for their construction *(r)* will permit calculating the increase of efficiency.

The terms efficiency and efficacy have different meanings. Efficiency is defined as the amount and quality of the products obtained in relation to the amount of resources used. Efficacy measures the objectives' range only. While efficiency evaluates the optimal use of resources, efficacy refers to the ability to achieve an objective, although it has not been obtained through the rational use of the resources available (RAE, n. d. b). In the reduction of the accumulated housing deficit in the local context, the relationship between the quantity and quality of the products, obtained according to the quantity of resources used, evaluates and quantifies the increase in efficiency.

6.1. Quantity *(qn)*

According to the Dictionary of the Royal Spanish Academy of Language, quantity refers to a portion or to a number of units that form part of a set (RAE, n. d. c). In social housing, quantity is related to the products (the number of dwellings and their respective areas) and to the resources (the magnitude of the costs and construction time). The costs and time used by traditional systems for the construction of social housing have been identified in Chapter 1 as the causes of the quantitative deficit.

According to the housing deficit in quantitative terms, in order to increase efficiency in the design and construction of social housing, it is necessary to increase the number of products (dwellings and areas constructed) and optimize the use of the resources necessary for their construction (costs and time). To adapt the budgets available to the projects under development, generally the number of housing units required has not been constructed in the time foreseen or with the quality standards desired. It has been proposed, in the analysis of the problem, that the quantity of houses constructed with the budgets available and the construction time used with traditional systems have not surpassed the speed of the growth of the deficit.

61 For its acronym in Spanish

62 Chapter 1, numerals 1.2.1 The quantitative deficit and 1.2.2 The qualitative deficit

Problem	Response
Total lack of housing	One dwelling per family
Cohabitation: two households in a single house	One dwelling per family
Immitigable overcrowding:	
Homes with five or more persons per room	Housing with maximum three persons per room
Homes in which each person has less than 4 m²	Average space for each person, 6 m²
Homes built with temporary or precarious materials	Constructions with materials approved by the NSR-10
Family groups of any size that share the home with others	One dwelling per family
Homes located in high-risk areas and with conditions of deterioration	Projects in stable geological areas and without deterioration

Table 37
Strategies to reduce the quantitative deficit from the indicators used by DANE.

In order to establish a sustainable strategy to reduce these numbers and stabilize the construction of new housing, one must consider the number of families that are formed each year, and add to that the number of households in deficit. An industrialized system of structural elements, produced in series, is ideal to reduce construction time and costs. Based on the indicators used by the National Administrative Department of Statistics of Colombia (*Departamento Administrativo Nacional de Estadística de Colombia,* DANE) to measure the quantitative housing deficit, Table 37 presents the following responses to improve efficiency in the designs and their construction:

6.1.1. Products *(p)*

Products are the number of dwellings and their constructed areas. Increasing them in order to reduce or eliminate the quantitative deficit means increasing the annual construction of housing in the local context, in order to balance them with the number of families.

6.1.1.1. Dwellings

According to what was explained in Chapter 1, social housing is made up of two types, classified according to their sales price: Priority Social Interest Housing (VIP) and Social Interest Housing (VIS). The VIP Housing has a maximum sales cost of 70 minimum monthly wages and an average minimum area of 45 m² [63]. VIS Housing has a maximum cost of 135 SMMLV and an average minimum area of 50 m². Commercially, the VIS has reached areas of up to 80 m² on average.[64] Increasing efficiency in terms of quantity means increasing the number of VIP and VIS to reduce the accumulated deficit and to cover the demand for new housing required. To gradually reduce the deficit until it is eliminated, this figure should be adjusted according to the number of homes lacking and the annual need for new housing. According to the Colombian Chamber of Construction (Cámara Colombiana de la Construcción, CAMACOL), from 1993 the construction of 84,000 VIP and VIS units has been required annually (Loaiza, 2016).

6.1.1.2. Area

Two types of areas with different scales should be conceived: the areas of public spaces where the projects are located in the urban context and the interior living areas.

The areas of urban space play a decisive role in generating new dynamics in the city, through the construction of social housing projects. The potential for development and the dynamics that new housing projects generate makes the site selection have some special characteristics. One is the generation of urban activities, the inclusion of communities into the city structure and the enhancement of the State and family investment over time. When buying a house, each family expects that it will in increase in value over time. Thus, housing in any type of socio-economic stratum, is always and by definition an investment, a product generating profitability over time. The economic appraisal of the house is a desirable aspect. By locating the homes in spaces with access to urban infrastructures and public service networks, the homes increase their value over time.

Historical criticism about social housing says that, due to the natural tendency to repeat and mass-produce them to reduce costs, the designs are unable to accommodate the diversity of economies, tastes or sensibilities of the residents. The prefabrication in concrete of social housing solves the installation of the structure and generates repetitive patterns that are complemented with non-structural elements that the façades finish solving, according to the environmental, cultural and social characteristics of the context. As mentioned by Otto Steidle in his project located in the Genterstrasse in Munich, in these unfinished prefabrications "the monotony and repetition of the structure can generate a scenario of future expansions with different aesthetics and qualities proposed from the architectural designs or transformed by their inhabitants through self-construction processes" (Steidle, 1974, as cited in Musso, 2016, p. 104).

63 Law 1753 of 2015. Article 90: Social-Interest Housing and Priority Social-Interest Housing (*vivienda de interés social and vivienda de interés prioritario*). The National Development Plan 2014-2018: Everyone for a new country (*Plan Nacional de Desarrollo* 2014-2018: *Todos por un nuevo país*). Congress of the Republic of Colombia.

64 Law 1753 of 2015. Article 90: Social-Interest Housing and Priority Social-Interest Housing. The National Development Plan 2014-2018: Everyone for a new country. Congress of the Republic of Colombia.

According to Alejandro Aravena and Andrés Iacobelli:

Self-construction would cease to be understood as a threat of deterioration and would become an alternative to personalize urban space, the building and the house itself; industrialization processes can be used as elements that, through neutrality and monotony, are the starting point for a diverse, regulated transformation, growth or adaptation to the conditions of the environment, which are key to the valuation of the investment. (2012, pp. 492-493)

The inhabitable interior areas of social housing have been shaped by what the construction techniques and available resources (costs and time) have allowed. VIP Housing, with minimum average areas of 45 m² have been traditionally designed and built with the following spaces: a kitchen, a laundry area, a bathroom, a social area (usually composed of a living room and a dining room), and one or two bedrooms. These homes are usually not delivered complete to their owners, who must finish them on their own. In the elements that are part of the initial delivery are a main door and a door for the bathroom, and installations for water, electricity and telephone. The homes are not provided with finished floors or walls, except in the bathroom, kitchen and laundry area (Loaiza, 2016). VIS Housing, with average construction areas between 45 m² and 80 m², commercially offers a kitchen, a laundry area, one or two bathrooms, a social area (usually composed of a living room, a dining room and sometimes a study and a balcony) and one, two or three bedrooms. They are delivered to their owners with a main door, a door in each bathroom, a door in each bedroom, installations for water, electricity and telephone, and finishes in the bathroom, the kitchen and the laundry area. According to the commercial offer, some homes are delivered with finished floors and walls throughout the house (Loaiza, 2016). To increase the number of dwellings and their inhabitable areas, it is necessary to project them with appropriate interior proportions, allowing the correct interaction of daily domestic activities and understanding social housing as a space in which each family can live differently. To increase efficiency in social housing designs, it is desirable that the areas designed exceed the established minimum standards, which would improve the quality of living conditions.

6.1.2. Resources *(r)*

Resources are the quantifiable, measureable elements that are required to construct social housing. They are measured in economic values (costs) and in the duration of the construction process (time). The inefficient use of these resources has been linked to the causes of the quantitative housing deficit. To increase efficiency in the design and construction of social housing, these resources should be optimally used and ideally reduced in relation to the costs and time used by traditional techniques.

6.1.2.1. Cost

Costs are defined as the expenditure made to obtain or acquire a thing or a service, as the amount given or paid for something (RAE, n. d. d). To make decisions in construction processes, it is necessary to know the value that money has over time.

In construction processes that seek efficiency, identifying the behavior of each one of the types of costs permit the optimal use of the resources necessary for the construction of the projects.

In the production, transport and installation processes of the precast concrete elements, for the construction of social housing, costs are classified as follows:

6.1.2.1.1. According to the function

These are made up of production and distribution costs:

- Production costs are generated in the process of transforming raw materials in precast elements (García & Gutiérrez, 2008, pp. 12-14). Raw-material costs are composed of the materials that make up the mixture and form part of the final elements: cement, aggregates, reinforcements, additives, additions and water. Labor costs are directly involved in the transformation of the product, such as the salary of workers in the plant, transport and assembly. Indirect manufacturing costs are those related to the transformation of products, except for raw materials and direct labor, such as supervisor salaries, energy or depreciation costs (Ramírez, 2000, pp. 27-33).
- Distribution or sale costs are those generated from the factory to the project site (Ramírez, 2000, p. 33).

6.1.2.1.2. According to their identification with an activity

These consist of the direct and indirect costs in the production, transport and installation processes of precast concrete elements:

- Direct costs are those that can be identified or quantified with the finished products. Materials, tools, transport and labor form a part of this group.
- Indirect costs are those that cannot be completely identified or quantified with the finished products. These costs are assigned to general criteria that depend on the type of production. In the industrialization of precast concrete elements, electricity, storage and physical space are indirect costs (García & Gutiérrez, 2008, p. 16).

6.1.2.1.3. According to the moment in which they were calculated

These are made up of historic costs or predetermined costs:

- Historic costs are those that are calculated after the element has been produced and that are part of a good or service in a given time.
- Predetermined costs are calculated before or during the prefabrication of an element. They are classified in estimated costs or standard costs. Estimated costs are those that are calculated on an empirical basis, budgeting the approximate cost of the elements that comprise it before producing the element or during its transformation. Standard cost is the calculation made on each one of the elements that make up the product, to determine how much it should cost (Funes, 1994, pp. 14-22).

6.1.2.1.4. Types of costs according to their behavior:

These consist of fixed, variable and mixed costs:

- Fixed costs are those necessary to support the operation of the industry. There are two categories with fixed costs: Discretionary fixed costs are susceptible to being modified, for example: salaries and building rent. Committed fixed costs are those that do not accept modifications, for example: the depreciation of machinery.
- Variable costs are those that change in direct proportion to the volume of operations made. This activity may refer to production or sales.
- Mixed costs have the characteristics of being fixed and variable, throughout different ranges of operation (Funes, 1994, pp. 14-22).

6.1.2.1.5. Types of costs according to the time or construction periods:

These are made up of the following types of costs: financial, administrative and anticipated revenue from sales:

- Financial costs are those originated with the external resources that the company needs for its development, and are directly related to the value of money over time. Juan García Colin argues that these costs arise from obtaining outside resources that the sector or specific building company needs for operating (García & Gutiérrez, 2008, pp. 12-14).
- Administrative costs are those that relate to the direction and management of the overall operations of the construction. They are comprised by the salaries of the administrative staff and workers, by the payment of public utilities, office rental and other expenses that must be made throughout the time that the construction of the project lasts (García & Gutiérrez, 2008, pp. 12-14). Administrative costs are directly related to the construction time and with the work periods of personnel.
- Anticipated revenue from sales in commercial projects for social housing can occur before beginning construction, in the construction phase of the project or when the building is completed. The anticipated collection of funds for the completion of the contract (when it is an official project) or through sales of the housing units (when it is a commercial project) generates economic benefits with different proportions for the project and its investors.

6.1.2.2. Time

The word time comes from the Latin tempus (Del Col, 2007, p. 1250). It is the duration of the processes of things; it is the physical magnitude that orders the sequence of events (RAE, n. d. e).

In the analysis of the problem, it has been suggested that the speed of growth of the housing deficit in the local context has been higher than the speed with which the housing projects have been constructed with conventional construction techniques. Therefore, if you want to reduce costs and the speed of growth of the social housing deficit, it is also necessary to reduce the time in the construction process.

From the social and economic point of view, it is desirable that the relocation of communities in new housing is done in the shortest time possible, which reduces rental periods and prevents displacement to other areas of the urban environment, where unplanned settlements increase the housing deficit, the risks and the informal developments, with all the problems that this entails.

To increase its efficiency, social housing must be built through standardized processes and the serialized production of the elements that make it up. It has been explained that traditional techniques, selected to build social housing, have caused periods of time in the construction processes to be uncertain.

Saving time means saving financial costs (the value of money over time), administrative costs (fixed costs that are required for the operation of the work during the period of construction) and increasing liquidity through advance sales.

Although the periods of management are expanded and the working time in the factory must be taken into consideration, industrial production should permit controlling the periods of each phase of construction and the reduction of construction time. Controlling time also allows maintaining the architectural and technical quality of the project, which increases the productivity of the construction process (Zamora et al., 2004, pp. 10-12).

6.1.3. Minimum quantities required

Quantity *(qn)* Minimum requirements for architectural design	*VIP* existing	*VIP* proposed	*VIS* existing	*VIS* proposed
Products (p)				
Dwellings	*VIP* traditional	*VIP* industrialized	*VIS* traditional	*VIS* industrialized
Area: minimum constructed area (m²)	42	45.2 (+ 5%)	50	55 (+ 10%)
Spaces				
Kitchen	1	1	1	1
Laundry area	1	1	1	1
Bathroom	1	1 or 2	1 or 2	2
Living room	1	1	1	1
Dining room	1	1	1	1
Study	0	0 or 1	0 or 1	0 or 1
Balcony	0 or 1	0 or 1	0 or 1	1
Bedrooms	1 or 2	2	2 or 3	3
Elevator	No	No	No	No
Parking spaces	No	No	No	No
Resources (*r*)				
Cost: Maximum selling price in monthly wages	70	68 (- 2.5%)	135	128 (- 5%)
Time (in weeks for a 20-dwelling project)	40	8	40	12

Table 38
Minimum quantitative requirements for the construction of precast-concrete social housing in the Department of Antioquia.

6.2. Quality *(ql)*

According to RAE, quality is the set of properties that allows judging the characteristics and value of a product or a process (n. d. f). In the design and construction of social housing, quality is made up of objective and subjective criteria. Objective criteria of the qualitative deficit indicate the non-compliance of minimum social housing requirements in the local context. To solve it, the following conditions are proposed: modularity, replicability, transportability, adaptability and accessibility. Subjective criteria of the qualitative deficit have been originated by the informal processes of planning and building. The conditions proposed to solve it are: simplicity, flexibility, comfort, beauty and transformability. The increment of the number of houses and the reduction of costs and time is desirable if the quality criteria are maintained.

Prefabrication is not comparable with other types of construction systems if quality is excluded.

To reduce the qualitative deficit, the houses must have floors, walls and rooves. In environmental terms, they must have adequate ventilation and natural lighting to ensure the conditions of health and comfort necessary. It is necessary that a kitchen exists in each home and that it has public utilities such as water and electricity. None of the houses should be overcrowded and its rooms should be occupied by a maximum of three people (Freire et al., 2009, p. 15). Self-construction processes must be directed and programmed. New housing must be designed and built with the conditions of comfort and safety established in existing regulations. Based on the indicators used by DANE, Table 39 presents the problem and responses to reduce the qualitative housing deficit:

Problem	Response
Deterioration in floors, walls and rooves	Construction with materials approved by NSR-10
Mitigable overcrowding: homes that have four persons per room	Houses with a maximum of three people per room
The absence of a kitchen or deficiencies in this space	Kitchens used with technical specifications
Homes with no provision of public utilities	Houses with electricity and water
Homes that need to be improved or have their area increased	Minimum constructed area of 45 m²
Deficiencies in lighting and ventilation	All spaces with natural lighting and ventilation

Table 39
Strategies to reduce the qualitative deficit, based on the indicators used by DANE.

These responses should be incorporated into the principles of urban, architectural and technical design to solve the deficit in quantitative and qualitative terms, delivering the highest conditions of well-being to the inhabitants of these projects.

6.2.1. Objective criteria

The objective criteria to improve the quality of social housing and increase efficiency, in its designs and construction, are related to the qualities of its precast concrete: modularity, replicability, transportability, adaptability and accessibility.

6.2.1.1. Modularity

This is the set of proportions related to a measurement pattern. It is a model that is repeated systematically and in a coordinated manner in the building to make it easier and more economical (RAE, n. d. g). With these measurements or proportions, which are grouped in dimensional or modular coordination, the urban space, the building and its interior space are designed and built. The problem that has indicated deterioration in the quality of the living space, overruns and increases in the periods of time of the construction process, are related to the absence of modularity and of the dimensional coordination among the structural and non-structural elements that make up the project.

Through the modular coordination of reinforced precast concrete pieces, it is possible to standardize the structural and non-structural elements, eliminate reprocessing, reduce the volume of waste, optimize time, coordinate technical processes and industrialize the construction of social housing. In urban projects, modularity poses the proper occupation of the territory based on the relationship among the dimensions of the building, the urban space and the proportions of the construction modules.

In architectural projects, modular coordination defined a dimensional pattern to articulate structural and non-structural elements with various techniques or materials that make up the living spaces. In the structural project, closed, open or partially industrialized prefabrication works with the principles of modular coordination to ensure the harmonious union among the components of the building. This is the first requirement of precast concrete to achieve the quality standards desired with the optimal use of the resources available.

The improvement of efficiency in social housing should begin with a module that allows different combinations and is aimed at optimal use without wasting any part of the project. Modularity is a geometric agreement among all the elements that are used in the design and construction process (Zamora et al., 2004, p. 8).

A prefabricated construction is, essentially, a modular construction, coordinated from the proportion of the structural and non-structural components to optimally use the resources necessary.

6.2.1.2. Replicability

Repetition implies doing what has been done (RAE, n. d. h). In the prefabrication of social housing, replicating means building in different contexts with the technical principles of the system. Each project has different environmental, cultural, social or economic conditions that must be known and adapted to. Faced with a previously studied urban, housing and technical strategy, replication generated similar, adaptable, and modifiable –but not equal– responses. The condition of replicability is to eliminate repetitive responses that are removed from the conditions of the context. This is the ability of the project to be adapted to other environments, maintaining its urban, architectural and structural principles. With this criterion, precast social housing can be constructed in different areas and modified in specific aspects according to the topography, climate, culture and the load-bearing capacity of the terrain. Understood in this manner, replicability drives the standardization of the processes and increases efficiency in the design and construction processes.

Replicating the essential components of the system permit modifying the complementary elements to adapt them to different environments. Replicating the criteria of location of the buildings on the terrain maintains the conditions desired for the urban space. In architectural design, replicability considers housing aspects to implement different programs or uses in similar areas. In structural design, replicability involves adjusting the production, transport, installation and assembly processes of the precast elements to the conditions of the context. Security, resistance and durability criteria must be met to ensure the replicability of the support structure. The design of the joints, among the structural and non-structural elements, must be replicable under similar conditions and must ensure the structural continuity of the building.

6.2.1.3. Transportability.

Transporting is taking the prefabricated elements from one place to another (RAE, n. d. i). Therefore, the urban contexts of the projects must be accessible and must offer conditions that allow the entry and exit of the cargo vehicles and equipment for assembly. In the architecture of social housing, the qualitative deficit is generally associated with informally developed territories, to the extent that it is difficulty to carry constructive elements, or in places where urban public utilities such as water and electricity have not yet been installed. These conditions make the transportation of materials to the projects difficult and generate informal construction processes in unstable areas with high geological risks.

It is necessary that in each location, the housing groups have a location in which the supply of material of different formats is guaranteed or where raw materials can be brought to transform them into construction elements. The architecture of social housing must consist of pieces coordinated with the formats permitted for their transport from the plant to the site. In the local context, the maximum size of transportation is 18.50 m long, 2.60m wide and 4.40m high. This volume must not exceed 52 tons in weight among all the elements that are being transported. The precast concrete elements must also be calculated to withstand the loads and stresses that arise from in-plant manipulation, in the transport and in the installation on site. One condition of prefabrication in concrete is that its pieces must be produced in plants and then they can be transported to the site where they will be installed. Producing these elements in industrial plants, under the standards of quality required, and transporting them when ready, eliminates intermediary activities such as costs and transformation of raw materials, reducing reprocessing and optimizing construction time.

6.2.1.4. Adaptability

The property of accommodating or adjusting the elements that make up a construction system to other urban, environmental and technical conditions increases the qualities of the structural model. Adaptability is the property that allows an object or mechanism to perform functions different from those for which it was constructed (RAE, n. d. j). In social housing, the construction and industrialized systems have been proposed so that –with minimum possible variations– they may be adapted to different contexts. Due to the shortcomings in the adaptation of different urban and architectural typologies to topographic, environmental or cultural conditions, the architecture of social housing has lost the possibility of being replicated and adapted to different contexts. Structural systems and non-structural elements must be adapted in the same way to the different geotechnical conditions offered by the terrain.

In urban terms, the principles of groups of houses must respond to the different conditions posed by their sites. On flat or sloped terrains, the building must maintain its principles of inhabitability, adapting the technical possibilities to desired urban conditions. The architectural designs, developed simultaneously with the precast elements of the system, must be adapted to the technical and spatial conditions that are achieved through the union and the combination of the pieces or the materials that make them up.

The adaptability of prefabrication in concrete to the design of social housing allows the coordinated production of its elements, with the shapes and dimensions designed, to ensure the accuracy of the joints and permit the installation of other materials or pieces that complement the construction process. Adapting the structural elements to other technical systems and other materials is crucial to expand the architectural and constructive possibilities and the language of the housing constructions.

6.2.1.5. Accessibility

Designing accessible social housing involves defining conditions to enter or pass through all its spaces (RAE, n. d. k). Accessibility involves an urban and architectural design for people with diverse physical or mobility capabilities. Dimensions in the urban spaces, in common areas of buildings and in the houses, must consider the presence of people in wheelchairs or who should be helped by any type of assistance to move around.

Social housing and its urban space must be adapted and should consider the physical conditions of those who inhabit it. In the local context, some topographic, urban or architectural conditions have restricted the possibility of access to public spaces or to dwellings.

Urban designs should be considered in areas where their topographies allow access to public and private transport, and where all people can use the outdoor space and access roads. The presence of ramps or elevators should be evaluated according to the economic possibilities of the project. At the very least, a first floor –accessible to all people– must be considered. In interior spaces, the dimensions of corridors, doors, bathrooms, kitchens, laundry areas, social areas or bedrooms should allow the circulation of people with different physical capabilities. Structural designs should consider dimensions that harmonize with the architectural spaces and that maintain the proportions of circulations and room areas specified in the architectural designs.

6.2.2. Subjective criteria

The causes of the qualitative housing deficit are related to the informal processes of planning and building. These practices have caused physical deterioration in the built houses and have generated adverse conditions in the quality of life of their occupants. The subjective criteria to improve quality and increase efficiency in the design and construction of social housing considers aspects associated with prefabrication in concrete, such as simplicity, flexibility, comfort, beauty and transformability.

6.2.2.1. Simplicity

The quality of simplicity refers to being constituted by one or few elements (RAE, n. d. l). It expresses the attainable and the replicable, which eliminates complexities to concentrate on the precision of the objectives. Architectural designs, materialized with complex constructive processes and systems –without an adaptation to the economic, technical and housing conditions–, have increased the value of the budgets and execution time. To meet the costs and deadlines established, technical quality and supply specifications have been reduced and some projects have been left unfinished.

Social housing should be designed with as few elements as possible. Prefabricated elements must have a reduced number of variants to standardize their production and solve their connections in the plant. The support structure must be formed by modular elements that allow different configurations when they are joined. Building the essential involves solving the problem of its fundamental components and allowing the individualization and modification of housing over time. Simplicity induces designs with criteria of modularity and adaptability, with comfortable areas that can be transformed over time according to the taste and needs of the inhabitants. The architecture of the essential eliminates the unnecessary and relines on the aesthetic expression of its structural components. This condition generates a language that shows the relationship between the rational and the emotional, between structure and space. In structural terms, simplicity involves working with the least amount of elements and eliminating variants in forms and their unions. The foundation system must superficially distribute loads to the terrain and its components must not differ from the geometries of the structural elements. Architectural designs should appropriate the aesthetic expression of its structural elements and should be complemented with non-structural elements. The installation process should be as agile and simple as possible to reduce processes, time and costs.

6.2.2.2. Flexibility

Everything that is not subject to strict rules, which has the possibility of changing according to circumstances or needs, acquires the condition of flexibility (RAE, n. d. m). This implies having a starting point, and a beginning in which the variations adapt the house to its surroundings. Industrialized housing must be adapted to different housing, technical, aesthetic or

environmental circumstances. Some constructive systems or typologies, in the local context, have used structural elements that have not allowed the transformation of the language of the building or the uses of their interior spaces. Housing must be adapted to changes in time, such as the growth of the family group, the adaptation of workspaces, commercial uses toward the façades or increases in the areas of housing. The location of the structural elements should allow the condition of repetitiveness on the façades to be complemented with the individuality of other non-structural materials.

Making the design more flexible means thinking of the house with new possibilities of use, expression and relation with its inhabitants. The structural system must allow variations in the use of the interior space; therefore, it must be located in the perimeter of the house. The flexibility of the system should allow its adaptability and variability in different environments. If housing can be shaped with structural elements, commercial spaces can also be formed on the first floors of the buildings. The grouping of the structural elements in the building defines an order through which the conditions of use, language and the relationship of the building with public spaces are defined. With flexibility, the architectural design proposes free, modifiable or transformable interior spaces. This condition involves the concentration of service areas of the house (kitchens, laundry and bathrooms) so that the rest of the living spaces have free areas and different programs, uses or configurations. The manner of grouping the structural elements can generate different architectural configurations in the building and its responses to the environment. The presence of non-structural elements and their relationship with the elements of the structure make up a diverse language, not conditioned by a unique position of the structure modules. Although prefabrication in concrete of social housing is aimed at the standardization of elements and processes, flexibility permits the individualization of language and the transformation of its spaces.

6.2.2.3. Comfort

Comfort is the quality of the habitat associated with well-being (RAE, n. d. n). It is the conditions that generate environmental quality through the use of natural resources in designing living spaces. With passive climate strategies, such as controlling solar incursion and natural ventilation, the use of mechanical heating or cooling equipment can be eliminated. These natural components establish a relationship between the habitat and the surrounding conditions. Some social houses have shown the absence of environmental quality and comfort in living spaces, due to the orientations of buildings, architectural designs that do not consider aspects of lighting or natural ventilation and the constructive materials or systems used.

The layout of the buildings, their orientation and the manner in which the houses are grouped should generate shadows and natural ventilation in collective and private spaces. In this case, the grouping of the houses defines conditions of comfort, safety and environmental quality. In architectural design, the elements that make up the building are conceived to control the entrance of natural light, generate cross-ventilation currents through the openings in the façades and define ranges of indoor temperatures. In the design of the house, comfortable indoor temperatures must be reached. In addition to complying with stability and safety requirements, the elements of the support structure can be conceived as environmental filters that allow the controlled passage of sunlight and air into the interior space. With the support structure, solar protection elements, balconies or elements that define the language of the building in harmony with the environmental context can be generated.

6.2.2.4. Beauty

In social housing, the quality of beauty (RAE, n. d. o) links the aesthetic condition of the language to the cultural, social and environmental conditions of the context. Adapting the traditions or desires of the community through participatory designs bring the human condition closer to technical and aesthetic components. In 1967, Carlos Raúl Villanueva argued that – as a reflection of lift itself – architecture is linked to economic and social problems, and not just to aesthetic standards (Villanueva & Macía, 2000, p. 87). The discussion between unity or diversity in the local context is oriented so that unity, in terms of language, generates responses far from the aesthetic beauty desired by its occupants, who for decades have dressed their neighborhoods and surroundings with colors and individual expressions.

In the architecture of industrializing social housing with precast concrete, the conditions of modularity and replicability generate two complementary conditions: homogeneity and versatility. While the conditions of homogeneity of a rational, repetitive support structure implies their standardization to reduce costs, versatility of the house is identified with the cultural traditions of the community. In the urban and architectural project, the homogeneity and repetitiveness of the support structure is combined with the versatility and individuality of the non-structural elements. The monotony of the structure must be understood as a starting point to compose the language of the building with non-structural elements associated with environmental, cultural and economic conditions. The support structure is a framework that orders a sum of variants that come from the architectural design, made by professionals, or from the wishes of the communities (Aravena & Iacobelli, 2012, p. 468). Beauty in social housing is determined by the conditions of variability and adaptability to environmental and cultural context, to the possibilities it offers its inhabitants as an instrument of their expression. The relationship between the support structure and the non-structural elements is the factor that defines the beauty of social housing, which is measured by its harmonious relationship with the environment and by its adaptability to different human and environmental conditions.

6.2.2.5. Transformability

This condition involves changing the form or the space, to modify the already existing (RAE, n. d. p). The transformation of social housing is the set of variants – such as expanding their areas or changing their language – that its inhabitants can do in the built space. This informal practice is usual in the architecture of traditional social housing and is a manifestation of the identity of the communities: the inhabitants transform their homes to the required conditions or the spaces they dream of, adapting them to their needs and their tastes. These modifications are due to the changes of use over time, to the desire to individualize language in the middle of the housing

cluster or to the growth of interior spaces. Social housing is a grouping of houses occupied by diverse families. In identifying the causes of the qualitative deficit, the conditions of overcrowding or the undesirable uses for the interior space occurred because the architectural designs or construction techniques did not establish a relation between the support structure and the living space. This practice restricts the possibilities of transformation of the interior space after it has been occupied. The transformation implies modifying the elements that delimit the interior spaces or induce the programmed growth of the houses, which must be made through criteria proposed in architectural designs.

Transforming the house allows adapting the areas and conditions of the project to the needs of each family. In an urban project, the transformation of the exterior space is made according to the habits or needs of the communities. One of the most recurrent cases is the modification of the use of the houses on first floors, places where complementary commercial spaces are usually generated. In the architectural project, the transformation of interior spaces by means of the modification of the distributions in plant or by the growth of the constructed area is a practice that occurs when families increase their number of members. In social housing, the growth in height or towards the unoccupied areas of the land is frequent. These growths have served to locate other members of the family group, to offer a housing solution to new families, to build rental spaces or to add spaces that were not initially built to the existing dwellings. The structure of the industrialized precast concrete housing must be calculated to receive the modifications of its interior spaces and for the growth of the constructed areas. It should be designed considering the final occupation and the complete areas of the houses after their expansion processes. The transformability raised in social housing induces that the processes of industrialization of the construction are a rational support to the modifications controlled over time.

6.2.3. Minimum qualities required

Quality *(ql)* Minimum requirements	Problematic causes of the qualitative deficit	Guiding Principles
Objective criteria	Lack of dimensional coordination	Modularity
	Lack of technical models. Unplanned self-construction	Replicability
	Land without access roads, areas with geological risks	Transportability
	Projects with urban or architectural contextualization	Adaptability
	Public space and buildings with entrance barriers	Accessibility
Subjective criteria	Complexity of traditional constructive elements and systems	Simplicity
	Buildings without urban or architectural variants	Flexibility
	Lack of environmental quality in the urban space and in the housing	Comfort
	Architectural languages without community participation	Beauty
	The structure restricts modifications of the interior space	Transformability

Table 40
Minimum qualitative requirements for the construction of precast-concrete social housing in the Department of Antioquia.

Summary

Conditions to improve the quantity and quality of social housing

Improving efficiency in the design and construction of social housing means increasing its quantity with quality criteria. The increase of the products (understood as the number of houses and their constructed areas) considers objective and subjective criteria of *quality* optimizing the *resources* necessary (costs and time). Therefore, efficiency *(e)* is the relation that exists between the quantity of products expected *(qn)* with quality criteria *(ql)* with respect to the amount of resources *(r)* used or necessary to obtain them.

$$e = \frac{(qn \times ql)}{(r)}$$

Talking about quantity and quality implies reducing the quantitative and qualitative housing deficit through increased efficiency. The quantitative deficit is the number of dwellings lacking, caused by the costs of traditional constructive techniques and for the periods of time used, which surpass the budgets and expected periods.[65] The qualitative deficit is the set of households that do not meet minimum standards of quality and do not provide suitable living spaces for its inhabitants. They have caused conditions that have deteriorated the quality of life of the communities, the non-compliance of minimum social-housing requirements and the informal processes of planning and building.[66]

Social housing is the sum of the structural and non-structural elements that make up a living space. The first technical component is the support structure, which assumes the security and stability required by the project. In buildings with limited budgets, the structure addresses various conditions simultaneously: it receives the loads and forms the largest number of elements of the building: façades, interior walls, dividing walls, floor slabs and eventually the rooves. In social housing, the structure develops a double condition: support and divide. Therefore, it can account for 50% to 70% of the direct costs.[67] The second component is the non-structural elements (windows, doors, façade walls, interior walls, balconies, finishes, kitchen furniture and sanitary furniture). When the budgets intended for the construction of social housing are not sufficient, the non-structural elements reduce the quality of the specifications or are eliminated. This has caused the families to transform or install them later, according to their needs or their tastes. If some non-structural elements of social housing already come from the industry (windows, doors and kitchen or sanitary furniture), the support structure should be produced industrially. This component, which accounts for the highest direct costs and which must guarantee the safety of the buildings, should be produced in factories without rigorous control of its quality, time or costs.

Therefore, industrializing the structure is a desirable condition to ensure quality compliance through budgetary control with defined deadlines. The non-structural elements can be installed at any time using traditional techniques or through self-construction processes. The industrialization of the structural elements in precast concrete must comply with the following basic conditions to improve efficiency and increase the quantity of the products with the optimal use of resources. Improving the quantity and quality of social housing poses a relationship between the quantitative and qualitative aspects and defines the basic conditions that must be fulfilled in the urban, architectural and structural designs of social housing in the local context.

In *quantitative* terms, the basic conditions that must be implemented to improve efficiency in the design and construction of social housing are:

Quantity of products

- *Housing:* Increasing efficiency implies increasing the number of housing units, considering the quality standards as a response to the quantitative deficit and to the need for new housing for the households that are formed.
- *Areas:* The living areas should be maintained or increase with respect to those offered by regulatory or commercial conditions in the Priority Social-Interest Housing (VIP) and the Social-Interest Housing (VIS).

Amount of resources

- *Costs:* To make any project feasible, it is essential to optimize and reduce the costs of housing, maintaining or increasing the number of units and maintaining quality criteria.
- *Time:* The industrialization of production, transport and assembly of the structural elements reduces the periods of time in comparison to traditional construction systems. This condition accelerates the reduction of the deficit and decreases financial and administrative costs, a desirable aspect in increasing efficiency in the construction of social housing.

In *qualitative* terms, the basic conditions that must be implemented to improve efficiency in the design and construction of social housing are:

Objective quality criteria

- *Modularity:* Prefab housing is, in essence, a modular construction based on a dimensional and geometric pattern with which the proportions of structural and non-structural elements are established. When repeated systematically, the module defines the proportions and forms of the project components. The modular unit must be compatible with other materials and local construction systems, enable partial industrialization schemed and configure the least number of variants in the prefabricated elements, in order to increase efficiency in the production process.

65 Freire, Eduardo et al. Housing Deficit Methodology., p. 15. Cited in Chapter 1

66 Freire, Eduardo et al. Housing Deficit Methodology. p. 15-16. Cited in Chapter 1

67 Conversation with Iván Asuad. Housing Manager of the Family Compensation Fund (*COMFAMA*). Medellín, June 2016

- *Replicability:* In the prefabrication of social housing, to replicate is to use the essential components of the system in different contexts. This is the ability of the project to adapt to other settings, maintaining its urban, architectural and structural principles. With this criterion, industrialized dwellings in prefabricated concrete can be constructed in different areas and some of their conditions can be modified according to the topography, climate, culture and load-bearing capacity of the terrain. The maximum number of urban and architectural combinations must be achieved with the minimum number of variants of the prefabricated structural module. The same industrialized element must be conceived, which, when added and combined, adapts to different topographies and social, cultural and environmental contexts. The structural and constructive response must be used in other contexts without substantially altering the principles of urban, architectural and technical design.
- *Transportability:* The urban contexts of the buildings must be accessible and offer conditions that permit the entry and exit of cargo vehicles and assembly machinery. The concrete prefabricated elements must be calculated to support the loads and stresses when being handled or transported. In order for the transport process to be efficient, the prefabricated elements must respond to the maximum dimensions allowed for cargo vehicles to reach urban settings: 18.50m long, 2.60m wide and 4.40m high. This volume must not exceed 52 tons in weight among all the elements that are being transported. The projects should be located in settings where the roads permit the transport, unloading and assembly of the prefabricated elements. According to the characteristics of the roads in the local setting, the projects should be no more than 150km from the place of production. If this distance is exceeded, consideration should be given to the construction of satellite plants, which serve different municipalities or field factories, at the project site, which must consider manouevering yards, storage of the prefabricated elements and space for the installation of the hoisting cranes.
- *Adaptability:* With the minimum variations possible, industrialized social housing must be adapted to the different characteristics of other technical systems. The adaptability of prefabricated concrete to different housing typologies or construction systems extends the possibilities of its language, its architectural variants and its relation with other techniques. The prefabrication system should be open, permit the use of different materials and the participation of local labor in the construction process, as an activity that improves economic conditions and qualifies the population in labor terms. Projects must adapt to different social, cultural, economic and environmental contexts with minimal variations in the structural system and adapt to different topographies, in flat or sloped terrain and with soils that have different load-bearing capacities.
- *Accessibility:* The dimensions of the common areas, the interior spaces of the dwellings and the elements that make them up should allow the circulation of people with different physical conditions. In the housing complexes, at least the first floor of public space and houses should be proposed as completely accessible, without the presence of stairs or any type of urban barriers in each of their levels. The urban and architectural configurations should allow the routes through the public space and the private space, with universally used widths in corridors, doors and furniture.

Objective quality criteria

- *Simplicity:* Social housing should be designed with as few elements as possible. The prefabricated elements must have a reduced number of variants to standardize their production and to solve their connections in the industrial plant. The support structure must be made up of typical modular elements with their walls and floor slabs joined in the factory to avoid any other type of work process, with free interior spaces that permit different configurations in floors and heights, such as the system of spatial cells. The foundation system must distribute the loads to the terrain superficially and its components should not differ from the geometries of the structural elements. Deep foundations should be avoided, as they can increase project costs and make it unfeasible. Architectural designs should appropriate the aesthetic expression of their structural elements and be complemented with non-structural elements. The installation process should be as agile and simple as possible to reduce processes, time and costs. The geometry of the precast-concrete structural elements must be simple and specify joints by simple supports or continuous, through post-tensioning, with the least amount of additional technical specifications to guarantee the stability of the system. The on-site processes should be minimized and solved as much as possible at the plant. The joining of slabs and walls in industrial plants generates structural frames, which must have the least number of variants to standardize their production in the factory. In the work process, the combination with non-structural elements and materials traditionally used in the environment, from other constructive systems, should permit the participation of local labor and consider the traditions of the context where the building is being constructed. The geometries and connections among the precast-concrete pieces should be safe and simple, to reduce costs and streamline construction processes.
- *Flexibility:* This is the capacity of the project to adapt to different housing conditions, according to the needs or wishes of its inhabitants. The structural system should be made up of typical modular elements, such as spatial cells, with walls and floor slabs joined from the industrial plant, with their walls and slabs on the perimeter of the dwellings to permit variations in uses and the generation of free, modifiable or transformable areas. This condition involves concentrating the service areas (kitchen, bathrooms, laundry) so that the rest of the livable spaces have different programs, uses or configurations. With the least amount of variations in the forms and dimensions of the structural elements, a greater amount of housing typologies must be obtained. The language of the residential buildings should be based on open prefabrication processes, in which the combination of structural elements and non-structural materials define different façade typologies. Thus, the structure and the service units will be the fixed elements, so that the rest of the surface is a free floor plan. Interior spaces and the façades are flexible non-structural elements that can be specified with different materials and

construction systems, and respond to different cultural and social contexts, climatic and economic conditions or participatory design processes with the communities.

- *Comfort:* Industrialized social housing should be designed with environmental-quality criteria through the use of passive climate-control strategies, such as the control of solar incursion and natural ventilation. The projects establish a permanent relationship between the housing and the environment. The layout of the buildings must generate controlled natural lighting and ventilation in the collective and private spaces to achieve the temperatures desired without the need for mechanical equipment. The layout of the structural elements (structural walls and floor slabs that separate one house from another) on the perimeter of the dwellings allow the inner spaces and the façades to be specified with non-structural elements, with local materials and designs in accordance with the environmental context, the solar incidence desired in the interior space and the ventilation conditions. Therefore, the openings of the façades and the distribution of the interior space respond to conditions of well-being and not only to structural conditions. Despite having a defined, invariable and rigid structure, the non-structural elements permit adapting the living space to the desired comfort conditions through different materials and openings in the façades. In their relationship with the non-structural elements, the structural systems must allow the adaptability of the interior space to different climates, dimensions, extensions and appropriations by users.
- *Beauty:* The beauty of social housing is determined by the diversity of the environmental, cultural and social conditions of its setting. The prefabricated structure is a set of repeated, modular elements that order the non-structural elements, shaped from the traditions and desires of the communities, with participatory designs. The language of residential buildings is the combination of the support structure and the façades are composed of non-structural elements in response to different environmental, social and cultural conditions. The participatory designs add the precision and security of the support structure with the aesthetics of the non-structural elements, associated to the traditions and desires of the community. With an open prefabrication system, where part of the façades can be solved with non-structural elements, the conditions of beauty are linked to the context, social traditions, climate, economy and housing dynamics. According to the degree of community participation, this system privileges individuality over generality with the prefabrication systems that resolve the essential and permit individualizing the space and its language. The beauty of the buildings will be the result of partial industrialization, the individualization of interior designs and the façade according to the context and the transformation from the dreams and needs of the communities. Social-housing architecture should permit different languages in their façades, the appearance of non-structural elements as part of the configuration of the project, the individualization of responses according to the social, cultural and climatic traditions or with the taste of the inhabitants. In a massive housing project, individualizing or differentiating the façades so that the replicability of the system can have variants is necessary in a context in which each family can have its own identity. The support structure must occupy the smallest surface in the façades.
- *Transformability:* Once the dwellings have been occupied, families can modify the space constructed, expand their areas or change the architectural language. This practice is usual in the architecture of traditional social housing and is a manifestation of the identity of the communities. These modifications are due to changes in use over time, to the desire to individualize the language or the growth of the interior space. Transforming the house allows adapting the areas and conditions of the project to the needs of each family. The precast-concrete structure must be calculated to receive the modifications of its interior spaces and for the growth of the areas constructed. Transformation processes show the needs of families, their progress, a flexible architecture, interior and exterior boundaries that can generate different responses to the needs and desires of the communities. For this condition, the structural systems must allow different interior designs, present different possibilities of occupation of the living space, facilitate the growth of the dwellings (actions that frequently occur in popular habitats) and – through the language of the façades – express different responses based on climatic conditions, social traditions or the wishes of the communities.

Industrialization of the structure (*production process*): prefabrication in the industrial plants.

Individualization of the interior space and the façades as a response to the context and the communities (*design process*): participatory design among professionals and the community.

Transformation of the architecture (*occupation process*): done by the community.

To achieve these principles of design, prefabrication must be *partial*. This industrialization of the support structure permits guaranteeing the security of the dwellings and in the first moment, what the communities cannot do for themselves is delivered to them.

The essential is industrialized in highly qualified and technified processes. This allows the interior non-structural walls or the façades to be built with materials that have traditionally been used in the local context (concrete-block or brick masonry), propitiate self-construction processes with non-structural elements and permit the participation of local labor in the process, a desirable aspect in construction processes.

The necessary is individualized: the façades, the language and the use of the interior space. This facilitates participatory design activities and brings communities closer to the construction process. The presence of non-structural elements in the façades and in the interior divisions allows the transformation of the space once it is inhabited by the families.

Transformation processes of the use of interior spaces, the growth of the dwellings, modifications of the façades to establish commercial spaces or different languages can be done by the communities once they have occupied their dwellings. This action of transforming the space according to what is required or ideal is given from the process of occupation of the dwellings.

The ideal systems for the prefabrication of the structural elements are those that reduce the joints in the work to a minimum, superficially distribute the loads to the terrain, move the support structure (walls between the dwellings and floor slabs) to the perimeter of the space, that do not occupy surfaces of the façades and also do not occupy interior space, to permit their modification over time, according to the needs of the family group.

This structural system is the spatial cells, which solve the perimeter of the space by themselves, which can configure a system in which empty spaces can be left between them to be filled with non-structural elements in the façades and that distribute the loads superficially to the terrain, avoiding deep foundations that do not guarantee the control of time and the costs of their construction.

For the prefabrication of the support structures, in the designs of the mixtures, materials must be used that allow obtaining the resistances required by the Colombian Earthquake-Resistant Construction Regulations NSR-10. In the constructions of the prefabricated structural elements, the need to obtain high strengths early for the manipulation of the elements in the plant can increase the concrete resistance to more than 35 MPa at 28 days. Cements, reinforcements, aggregates, additives, synthetic fibers, lightened concrete, concrete with recycled materials, textile reinforcements and prestressed and post-tensioned concrete, among other advances, can be used according to the costs of their production and according to the benefits that these advances can deliver to the project in structural, technical and economic terms.

New developments of mixtures, concrete reinforced with natural fibers or nanoparticles and formworks that use textile elements that make up the structural elements from their interior stresses and reduce the amounts of mixtures that are not necessary make up the next step in the exploration of new industrialized structural systems for the construction of social housing.

Conclusion

How to improve efficiency in the design and construction of social housing?

In the design and construction of social housing, efficiency has been defined as obtaining the desired or required quantity of products, with defined quality criteria in relation to the volume of resources used. The volume of the products required and of the resources necessary to obtain them is measured in quantitative terms. The objective and subjective criteria that determine the characteristics of these products are measured in qualitative terms.

The products required are the dwellings and their constructed areas. The resources that must be used to obtain them are costs and time. Quality is characterized with objective criteria (which permit projecting the dwelling in terms of modularity, replicability, transportability, adaptability and accessibility) and in subjective terms (that define the project in terms of simplicity, flexibility, comfort, beauty and transformability).

According to the above conditions, the increase in efficiency *(e)* is measured through a mathematical operation in which the factors that make it up can be modified: the quantity of products required *(qn)* and the quality criteria established *(ql)* in relation to the volume of the resources *(r)* used to obtain them.

$$e = \frac{(qn \times ql)}{(r)}$$

Ideally, the highest standards of efficiency are obtained by increasing the quantity of homes and their quality, reducing costs and the time necessary for their production. Having analyzed these characteristics of the context of Chapter 2 and their technical conditions in Chapter 4, precast concrete is proposed as the system to increase efficiency in the design and construction of social housing. One of its principal characteristics is the control of quality of the structural elements and the reduction of the construction time, since – by being produced industrially – the components are ready to be assembled on site. Having defined these conditions, two factors must still be considered: the first is building the largest number of dwellings; the second is producing, transporting and installing the support structure with the lowest cost and time possible. Accordingly, the increase in efficiency can be measured by modifying these factors in the following operations:

7.1. Increasing quantity and quality

The ideal strategy to increase efficiency in the design and construction of social housing is to increase the number of dwellings, increase their quality and reduce construction costs and time in comparison to traditional non-industrialized systems.

More quantity x more quality / fewer resources:

$$e = \frac{(+qn \times +ql)}{-(r)}$$

It is also possible to increase efficiency by increasing the quantity of homes constructed, increasing their standards of quality while maintaining the costs and time used in comparison to conventional constructive systems.

More quantity x more quality / same resources:

$$e = \frac{(+qn \times +ql)}{(r)}$$

7.2. Increasing quantity, maintaining quality

Another possibility to increase efficiency consists of increasing the number of homes constructed and maintaining the standards of quality compared to non-industrialized systems. The ideal condition in this case is to reduce the costs and time of the construction process.

More quantity x same quality / fewer resources

$$e = \frac{(+qn \times ql)}{-(r)}$$

If the quantity of dwellings constructed is increased, while maintaining their standards of quality, it is also possible to increase efficiency by maintaining costs and execution time compared to non-industrialized construction systems.

More quantity x same quality / same resources

$$e = \frac{(+qn \times ql)}{(r)}$$

7.3. Maintaining quantity, increasing quality

It is possible to increase efficiency if the same number of dwellings is built but their standards of quality are increased in contrast to conventional systems. The ideal operation in this case is to reduce construction costs and time.

Same quantity x more quality / fewer resources

$$e = \frac{(qn \times +ql)}{-(r)}$$

Building the same quantity of homes and increasing the quality of their components also permits increasing efficiency, if costs and time are maintained in comparison to conventional construction processes.

Same quantity x more quality / same resources

$$e = \frac{(qn \times +ql)}{(r)}$$

7.4. Maintaining quantity and quality

Another operation to increase efficiency is to construct the same number of homes with the same standards of quality, but with lower costs and in shorter periods of time than with non-industrialized systems.

Same quantity x same quality / fewer resources

$$e = \frac{(qn \times +ql)}{-(r)}$$

In the architecture of social housing, due to budgetary conditions, the structure meets two requirements simultaneously: support and divide. Given the technical and spatial condition that is met, its industrialization would control the quality of the project; it would reduce periods and would optimize costs.

Industrializing the support structure involves partially prefabricating the social housing. This operation must control the quality, optimize costs and reduce the construction periods of the project. In posing an unfinished industrialization, the non-structural elements complement the support structure and may be proposed with conventional construction techniques, using traditional labor. Thus, the architectural designs can be adapted to different environmental contexts, and based on social and cultural traditions, can generate different languages in the buildings, and approximate the architectural response to the constructive rigor and the dreams of the communities from the quality criteria specified. Precast concrete uses qualified labor in the production plants, ensuring the quality of the elements and their execution time. Simultaneously, maintaining or increasing direct and indirect jobs for working communities that have learned and worked in traditional techniques is a desirable condition that complements the industrialization of social housing with traditional on-site constructive processes.

7.5. Industrializing, customizing, transforming

Three moments make up the precast-concrete social-housing design and construction process. It begins with the systematic, standardized production of the construction elements (industrialization). It is complemented with the urban and architectural designs as a response to the environmental, social and cultural conditions of the context (customization), and continues with the adaptation of the space and language to the needs or tastes of its inhabitants in the process of occupation (transformation).

7.5.1. Industrializing

The industrialization of the structural elements controls quality, reduces time and optimizes production costs. Having obtained these conditions, it is possible to improve the efficiency of the process according to the volume of elements produced. This is done in precast-concrete companies through technical processes and skilled labor. The industrialization of the support structure increases the safety conditions, the precision of the joints and the durability of the buildings. It is desirable that it can be built with the highest quality, in the shortest time and with the lowest costs possible, as this component resolves an important proportion of the building and its living spaces. This condition implies the design and production of modular elements, dimensionally coordinated with other components of the projects. They are replicable, transportable, adaptable to other technical systems, simple and have aesthetic criteria defined since the architectural and structural designs.

7.5.2. Customizing

Having industrialized the support structure, the next step is to complement it from the urban and architectural design with non-structural elements to respond to the contextual and housing variants. This is the response to the environmental characteristics of the surroundings, social conditions, cultural traditions, economic possibilities and the needs of families. Customization is the strategy to diversify the language of the home and to adapt the interior spaces to different uses or programs. In Chapter 5, how the architecture of precast concrete social housing has been conceived, between criteria of unity or diversity, has been analyzed. The support structure is the rational component; the customization of the language or the interior spaces are relative, variable and adjustable components. The rationality of industrialization and the diversity of customization are conditions to design and construct projects with criteria of quality that incorporate conditions of accessibility, flexibility, comfort, environmental quality, cultural traditions and community wishes. These technical and aesthetic components of housing diversify their language and the characteristics of the interior space.

7.5.3. Transforming

After industrializing and customizing, the next step is inhabiting, and with it the transformation that its inhabitants can make by modifying the uses, expanding the areas or individualizing the language of the houses. The adaptation of commercial spaces on the first floors is a frequent transformation in the local context. While the customization process generates variability in the architectural and design processes as a functional, aesthetic response of the project to its surroundings, the transformation or the personal contribution of the families that live in the houses will adapt these spaces to their needs or preferences. These modifications, made in the inhabiting process without the presence of skilled labor, are an adaptation of the structures and spaces to the needs and preferences of each family, in the search to improve their quality of life through conditions of adaptability, accessibility, flexibility, comfort, beauty and transformability.

Operation	Component	Activity	Condition
Industrialize	Support structure	Business production	Essential
Customize	Architectural design	Architectural design	Necessary
Transform	Language and interior space	Community inhabitating	Desired

Table 41
Industrialize, customize and transform: components, actors and conditions.

7.6. Industrializing the essential, customizing the necessary, transforming the ideal

In essence, social housing is structure, space and life. Through *industrialization,* the support structure is produced. With *customization,* architectural designs respond to the environmental, cultural, social and economic conditions of the context. Through *transformation,* communities modify the houses according to their needs and desires.

The structure is industrialized. It is the essential component. It resolves conditions of stability and safety; it orders the physical space and is the first step in the construction of the project. Designed using rational, technical conditions, it can be standardized ensuring conditions of quality and allows controlling costs and time. It is produced in precast-concrete companies with the specifications defined through architecture and civil engineering: modularity, replicability, transportability, adaptability and simplicity.

The architectural design is customized. It is the component that adapts to the structural order and intervenes in the necessary. It is the diverse, relative response to environmental, cultural, social and economic conditions. It assumes the diversity of the contexts and communities, and – through its non-structural elements – defines the language of the building and the initial conditions of inhabitability. Adapting the architectural designs to the conditions of the environment defines criteria of accessibility, flexibility, comfort, beauty and transformability.

Daily use transforms the urban project and interior spaces. It is the component that is idealized and dreamt of by communities. It adapts the language and areas of the home to the uses and habits of the people, who modify the space according to their needs and tastes with criteria of adaptability, accessibility, flexibility, aesthetics and transformability.

Table 41 indicates the operations in the process of industrializing the support structure, the customization of the architectural designs and the transformation of the inhabited space and environment.

7.7. Rationality and identity

The standardization of social housing, desirable to respond quickly and inexpensively to a housing shortage, has been criticized historically for its inability to accommodate the diversity of the users it serves. Its uniformity has sacrificed individuality through efficiency measured from quantitative aspects (Harlander, 1999).

The proposal of this research to increase efficiency and promote different responses in the architectural language of social housing is to *rationalize* the designs, production and installation of the support structure (which should occupy only the perimeter of the living space) and the service units with their technical facilities (bathrooms, kitchens and laundry area). Once the structure and the services are located, the walls of the façades and the dividing walls of the interior spaces are conceived as non-structural elements, adaptable to the context in which the dwellings are located and transformable over time, to establish conditions of individuality and identity in massive solutions based on the physical characteristics of the context, the economic conditions, the cultural traditions and the wishes of the communities.

To achieve this condition, the unfinished or partial industrialization is the starting point for the customization of designs that adapt social housing to different contexts. Once inhabited, the transformations of the living spaces are carried out by the families themselves. Based on structural *rationality,* the architecture of social housing must respond to different variables, such as the control of costs and technical quality, and offer conditions of well-being for communities that, based on their traditions, hopes and *identity,* evidence their ideal ways of living.

Summary

Efficiency in the design and construction of social housing

The increase of efficiency can be measured through a mathematical operation in which all its factors can be modified, according to the conditions of urban, architectural and technical design. This operation is the relationship among the quantity of products (dwellings) and their quality, in relation to the quantity of resources (costs and time) used. The quantity of the products and of the resources for the construction of social housing can be measured in quantitative terms. The quality of these products is measured in qualitative terms with objective criteria (modularity, replicability, transportability, adaptability and accessibility) and with subjective criteria (simplicity, flexibility, comfort, beauty and transformability).

The increase of efficiency through prefabrication in concrete is done through the fulfillment of the following conditions, compared to the traditional systems (such as in-situ cast-concrete structures or structural masonry) used for the construction of social housing in the local context:

Increasing the number of houses and their quality, reducing the resources necessary (costs and time) for the construction of the project.

$$e = \frac{(+qn \times +ql)}{-(r)}$$

Increasing the quantity of houses and their quality, achieving the same costs and time used in the traditional construction systems.

$$e = \frac{(+qn \times +ql)}{(r)}$$

Increasing the quantity of houses and maintaining their quality, reducing costs and time.

$$e = \frac{(+qn \times ql)}{-(r)}$$

Increasing the quantity of houses, maintaining their quality, costs and time.

$$e = \frac{(+qn \times ql)}{(r)}$$

Maintaining the quantity of houses and increasing their quality, reducing costs and time.

$$e = \frac{(qn \times +ql)}{-(r)}$$

Maintaining the quantity and increasing the quality of the dwellings, maintaining costs and time.

$$e = \frac{(qn \times +ql)}{(r)}$$

Maintaining the quantity and quality of the houses, reducing their costs and time.

$$e = \frac{(qn \times ql)}{-(r)}$$

To increase efficiency in the construction of social housing in the local context, three moments make up the process:

Industrialize the essential (the support structure).

Customize the necessary (interior walls, living spaces and façades).

Transform the ideal (living spaces and the language of the building).

Industrialize the essential: the support structure

The support structure must be standardized and *industrialized* to increase the quantity of its elements, control its quality and reduce costs and time in the *production process,* which is done in industrial plants. This is the technical process aimed at ensuring conditions of safety and durability, which comprise between 50% and 70% of the direct costs of construction and which can be reduced through industrial criteria of prefabrication and standardization.

Individualize the necessary: interior walls, living space and façades

The interior space and the language of the façades must be *customized* according to each context and the characteristics, needs and aspirations of the communities. These conditions can be achieved in the *urban and architectural design process,* ideally with participatory and cooperative dynamics with community members, to adapt the non-structural elements to social needs in the construction of living spaces and in the language of the buildings. The interior divisions and façades can be constructed with materials that have traditionally been used in the local context (masonry in concrete blocks, bricks and other materials). Customization allows the participation of local labor and propitiates self-construction processes with non-structural elements, a situation that generates employment and qualifies the population in terms of labor, a desirable aspect in the social-housing construction processes.

Transform the ideal: living spaces and the language of the building

The dwellings can be *transformed* and adapted to the needs of the communities through the modification of the

non-structural elements that make up the interior spaces and façades. This activity is carried out in the *process of occupying the dwellings,* where the communities themselves can intervene by increasing the areas or modifying the original characteristics of the living space.

The industrialization systems of social housing in the local context must appeal to two conditions: *rationality* and *identity*. Although it can increase the conditions of efficiency and generate savings in costs and time in the process of prefabrication and construction, industrializing all the structural and non-structural elements of the project reduces the possibilities of participation by communities in the design process and distances the results of these dwellings from the conditions of individuality and identity desired in each context. Industrialization must be partial and focus on the support structure with precast-concrete elements: rationalized, modular, replicable, transportable and adaptable with simple installation processes. This condition generates flexible, comfortable, accessible, individualizable and transformable spaces, which respond to the physical characteristics of each context, to the economic conditions, to the cultural traditions, to the dreams, identity and needs of the communities.

Partial industrialization is the starting point for the customization of designs that adapt social housing to different contexts. Through structural *rationality,* the architecture of social housing can be complemented with traditional construction systems in the non-structural elements to adapt to diverse settings and to the *identity* of communities.



Experimental Research

The urban, architectural and structural project

Given the conditions to increase efficiency in the design and construction of social housing in the regional context, this research proposes a structural system that adapts the criteria to *industrialize* the essential (the support structure), *customize* the necessary (interior walls, living spaces and façades) and *transform* the ideal (living spaces and the language of the building).

This system is made up of precast-concrete structural frames that are grouped in different ways to generate urban and architectural responses according to the context. Because of their configuration, they can be supported on soils with particular geotechnical and topographic characteristics to distribute their loads and reduce the depth of the foundations. Being conceived from the beginning of partial prefabrication, their versatility is increased through the use of non-structural elements in interior divisions and façades that complement the modular, rational and repetitive support structure, which allows the participation of different professionals and the communities in the design and construction process.

Through industrial production, the slabs and walls that make up the precast-concrete structural frames are conceived as a single element, occupying only the perimeter of the living space and from this arrangement generate free floor plans, with areas and languages according to the physical context, the needs of the inhabitants and the cultural traditions.

The precast-concrete structural frames meet the objective criteria of *rationality* by solving the structural elements with *modular, replicable, transportable, adaptable* and *accessible* pieces. They also meet the subjective criteria of *identity* by complementing the system with *simple* production and assembly processes, with which *flexible, comfortable, beautiful* spaces – aesthetically associated with the wishes and traditions of the community – and *transformable,* which can be intervened by their inhabitants during the time of occupation.

This structural system, conceived to increase efficiency in the design and construction of social housing, has obtained a national invention patent in the Republic of Colombia, registered with Number (11): 15096687. This decision was published by the Colombian Superintendency of Industry and Commerce (SIC) on December 8, 2017, with the title *Prefabricated Modular Building System*. The international classification of the patent has codes (51): E04B 1/00, E04B 1/04.

In this experimental process, structural, urban and architectural designs were made, which were then verified in two prototypes built in April of 2015 at *Universidad Pontificia Bolivariana* UPB; on its campus in the municipality of Marinilla, located 45km to the east of Medellín.

8.1. Concept

With the precast-concrete frame system, the support structure is industrialized; projects are customized through the architectural designs and their spaces, and languages are transformed based on the needs and preferences of their inhabitants.

8.1.1. Industrialization

Structural elements are produced industrially. They are hyper-static, self-bearing frames in precast concrete, composed of monolithically joined structural walls and slabs. Their configuration defines free interior spaces and open façades, which permit different interventions in the use and language of the project. These structural frames can be horizontally and vertically connected to one another, and reach heights of up to ten stories according to the load-bearing capacity of the terrain and the structural specifications. Their means of connection are interior rigid joints, such as reinforcement steel, welding fixings, assemblies, mechanical joints through bolts or screws, post-tensioning cables, glue mortars and combinations thereof. The dimensions of these frames are coordinated with transport systems.

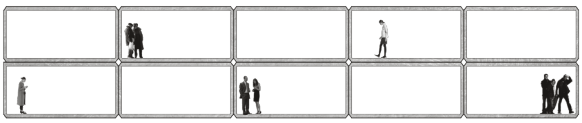
The installation of the precast concrete frames on the ground does not require deep foundations, since the system itself distributes its loads through the support surface. By improving the load-bearing capacity of the terrain, up to a confinement proctor of 98% with coarse and fine-grain crushed material, the depth of this site reaches an average of 60cm for one- and two-story homes, 1.20m for buildings up to five stories tall and 2.00m for buildings up to ten stories.[68]

Each structural element transfers an average of one ton per square meter of load to the land. Therefore, the lots that were originally rejected for their geotechnical conditions against conventional foundation systems can be evaluated once again to study their load-bearing capacity in relation to the load transmitted by the system of structural frames. This condition permits enabling 80% of the terrains available in the Department of Antioquia for the construction of housing up to five stories tall.

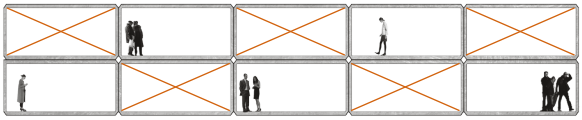
When the structure of a building is designed in precast concrete, on-site operations are essentially assembly. Prefabrication improves the physical characteristics – such as mechanical resistance and the surface finish – of its elements in relation to the *in-situ* castings (Gómez-Jauregui, 2009, pp. 33-46). The structural frames must be installed with cranes or mechanical hoisting equipment with a capability to lift from 15 to 60 tons, which are the average weights of 6m and 12m long elements. Once located in the ground, in the grouping, the intermediate structural frames can be eliminated and maintain the rigidity of the system by matching their walls in height. Using the structural elements necessary and eliminating the construction of additional components for the foundations entails considerable savings in direct costs.

Prefabrication in concrete presents an architecture without coatings, in which the design and architectural language are found in the form and the finish of the structure itself. Having the least number of joints is desirable to increase constructive yields, reduce on-site activities and lower costs. Standardization in the production, the massive repetition of the structural elements and the quick assembly allow the prefabrication of the structure to become an effective, safe solution (Araújo, 1997, pp. 5-7).

68 Soil studies and structural calculations made by Jorge Eduardo Arbeláez Rojas. Medellín, January 2014



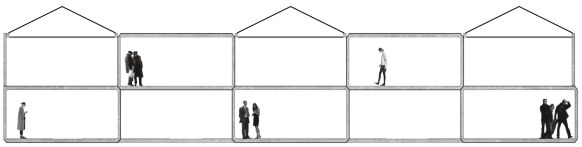
Graphic 210
Industrialization: For the construction of 10 homes, 10 groups of structural frames are needed.



Graphic 211
The intermediate frames can be eliminated, using only the structural elements necessary.



Graphic 212
If the system is configured with five groups of frames, the continuity of the structure remains. The upper frames may be closed or eliminate the upper concrete slab.



Graphic 213
Two floor slabs, two walls and the rooves are necessary to go from five to 10 homes.



Graphic 214
Customization: The diversity of the facades adapts the project to other environmental, social and cultural contexts.



Graphic 215
Transformation: Identity and individuality after occupation.

8.1.2. Customization

After the industrialization of the support structure, architectural designs can respond to the environmental, cultural, social and economic conditions of the setting with non-structural elements. Different housing typologies, with areas for future growth, can be proposed. The façades can have different forms and materials, according to the characteristics of the site. This condition can generate a different language in each project, which is desirable given the characteristics of the social housing in the local context. In the architectural designs, the service areas (kitchens, bathrooms and laundry) should be grouped to generate free floors and different housing typologies. The structural solution is complemented with other elements that permit the intervention of conventional labor in the construction process. The architecture of the social housing in precast concrete finds its own solutions between the structural and non-structural elements, which can result in different architectural types according to the environmental context and the aspirations of their inhabitants (Araújo, 1997, pp. 4-13).

8.1.3. Transformation.

After the industrialization and customization of the houses, through the architectural designs, the families that inhabit them transform the areas by expanding them or modifying the distribution of interior spaces, by varying the uses or intervening in their language according to their needs or with their aesthetic preferences, in the search for well-being and identity. In social housing, it is common for the first floors to incorporate commercial uses into the public space after they are inhabited, modify their programs or increase their areas due to family growth or the search for other possibilities to increase their economic income. Social housing is a space in permanent transformation. The means by which it is designed and constructed must be understood and must provide the dynamics that adjust their characteristics to the characteristics of the families that inhabit them.

8.2. System

8.2.1. Quantities *(qn)*

With the necessary structural elements, the system permits increasing the number of dwellings and their areas with a rationalized use of the materials that comprise them, thus optimizing costs and reducing construction time.

8.2.1.1. Products (p)

The products are the number of dwellings and their constructed areas. Increasing them in order, to reduce or eliminate the quantitative deficit, means increasing the annual construction of housing and the living areas in the local context.

8.2.1.1.1. Dwellings

The system of self-bearing frames resolves the support structure, defines the limits of inhabitable space and optimizes the use of structural and non-structural elements. This optimization permits increasing the number of houses and their areas, defines their standards of quality, controls costs and reduces the construction time.

8.2.1.1.2. Area

According to the modulation of the structural frames, the areas constructed can be increased through the use of conventional constructive systems in the processes of customization or transformation of the dwellings. This system must maintain or increase the inhabitable areas in relation to those offered in VIP and VIS housing. Urban designs can contribute to the generation of collective activities, include communities in the process and establish relations of proximity and continuity with the city and its surroundings.

8.2.1.2. Resources (r)

The costs and time required to construct social housing can be optimized through the industrialization of the support structure and the use of non-structural elements with traditional materials, specified in the customization of the designs or used in the transformation processes with the use of local labor.

8.2.1.2.1. Cost

The production in series of the support structure, through industrial processes, aims to reduce construction costs. If the structural components serve to delimit the living space, and also function and foundation systems that uniformly distribute loads to the ground, the structure will have a double function: support and divide. The reduction of costs, processes and time, while maintaining the standards of quality defined, are the objectives of this structural system. Budgetary exercises, made with the construction of prototypes, resulted in a VIP built with precast-concrete self-bearing structural frames that can reduce construction costs by between 8% and 12%, compared to traditional constructive systems.

8.2.1.2.2. Time

According to the prototypes built, the assembly of each of the structural frames in the building can take between 15 and 30 minutes. In the same proportion, attending contingencies, pauses and alternate processes, ten homes can have their support structure ready in five hours of work. This implies an estimated reduction of 80% of the time in comparison to the construction of the support structure using traditional systems

8.2.2. Qualities

The characteristics of the structural system, measured in objective and subjective criteria, respond to the conditions set out in the conclusions of this research, discussed in Chapter 7:

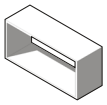
8.2.2.1. Objective criteria

The objective criteria to characterize the system are associated with conditions of modularity, replicability, transportability, adaptability and accessibility.

8.2.2.1.1. Modularity

The auto-bearing precast-concrete structural frames are conceived with criteria of modularity and dimensional coordination in relation to the other elements that make up the urban and architectural designs. The orderly arrangement of the structural modules, to generate housing groups, is the principle of the design process. Their proportions are proposed according to the maximum dimensions permitted and the weight limit for transport in cargo vehicles.

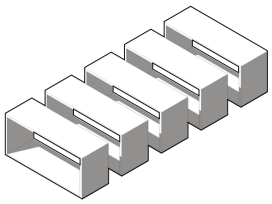
The geometry of the structural frames allows them to support each other in different manners and to maintain their stability. The coordination between them allows the relation with the non-structural elements and generates urban and architectural responses through modular repetitions.



Graphic 216
Modularity. Geometry and dimensional coordination.

8.2.2.1.2. Replicability

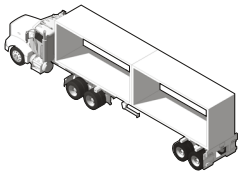
From their dimensions, geometries and systems of union, precast-concrete frames can be replicated in industrial production, in occupation strategies of urban space or in the grouping schemes to form the building. Replicating the urban or architectural designs with the system permits modifying its non-structural elements to adapt to different settings.



Graphic 217
Replicability. Industrialized production.

8.2.2.1.3. Transportability

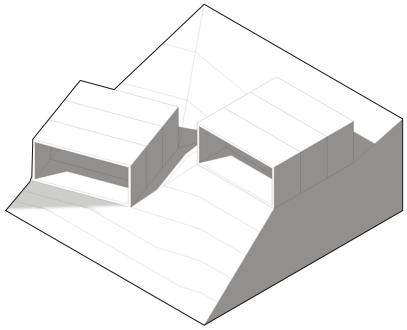
According to the maximum dimensions permitted for cargo transportation, on national or municipal roads, structural modules can be up to 18,50m long, 2.60m wide and 4.40m high, with the maximum weights permitted of up to 52 tons. For the semi-tractor-trailer-trucks the maximum dimensions can be up to 12,20m long, 2.60m wide and 4.40m high and the maximum weights permitted are between 27 and 52 tons. The urban contexts selected for the construction of the buildings must be accessible, and must ensure all the conditions that permit the entrance and exit of cargo vehicles and machinery to assemble the structure.



Graphic 218
Transportability. Delivery.

8.2.2.1.4. Adaptability

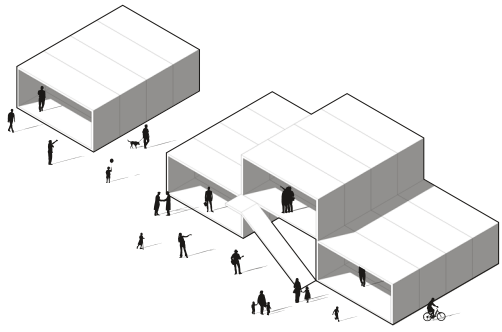
The geometry and proportions of each structural frame allow the system to be adapted to different urban, topographic, environmental and technical conditions with the minimum variations possible. The soils must have a structural replacement in fine and coarse-stone materials, with depths determined by their load-bearing capacity and the height of the buildings. Once adapted to the profiles of the terrain, the precast-concrete structural frames allow the installation of non-structural elements in different materials. The configuration and characteristics of the system allow it to be adapted to different topographies, incorporate different housing typologies to its geometry and expand the possibilities of its language.



Graphic 219
Adaptability. Placement in different contexts.

8.2.2.1.5. Accessibility

Urban designs are proposed in sectors where the topography and the conditions of the roads allow the access of public- and private-transport cargo vehicles. Structural frames allow having a configuration of open, accessible façades on the first floor of buildings and that do not have elements that make human mobility difficult. In each building, accessibility to the urban space and the first floor are ensured, according to the current regulations in the local context. The dimensions with which the structural frames are designed allow people with different physical or mobility capabilities to move about inside the houses. The dimensions of corridors, each living space and the doors have minimum widths of 90cm.



Graphic 220
Accessibility. Urban design.

8.2.2.2. Subjective criteria

The subjective criteria, to characterize the precast concrete structural frame system, are associated with conditions of simplicity, flexibility, comfort, beauty and transformability.

8.2.2.2.1 Simplicity

The support structure is configured by a single self-bearing frame typology that is repeated a certain number of times until the grouping is comprised. This construction system resolves the foundations of the building and the support structure with its horizontal subfloor, mezzanine and roof slabs, and with its vertical slabs or walls. In the terrain, the set of frames is situated with simple supports that are stiffened with edge beams at the ends. The system permits the horizontal or vertical connection between the structural frames for the construction of buildings of one or more floors, according to the quality of the land and with the technical specifications of the elements that make it up. Structural frames can be joined in three ways: simple support, external joints and internal assemblies.

The union by simple support is given when the terrains present high conditions of stability, when they are found in zones of low or intermediate seismic areas and when the buildings are no more than two stories tall. External joints, such as metal strips or metallic angles, are left embedded in the concrete from the production process to join the frames through welding or bolted fixings, located according to the structural calculation.

The assemblies or internal connections are given by metallic rods that are up to one inch in diameter, embedded in the concrete with an average depth of one meter; another meter is left exposed to fit into the upper frame.

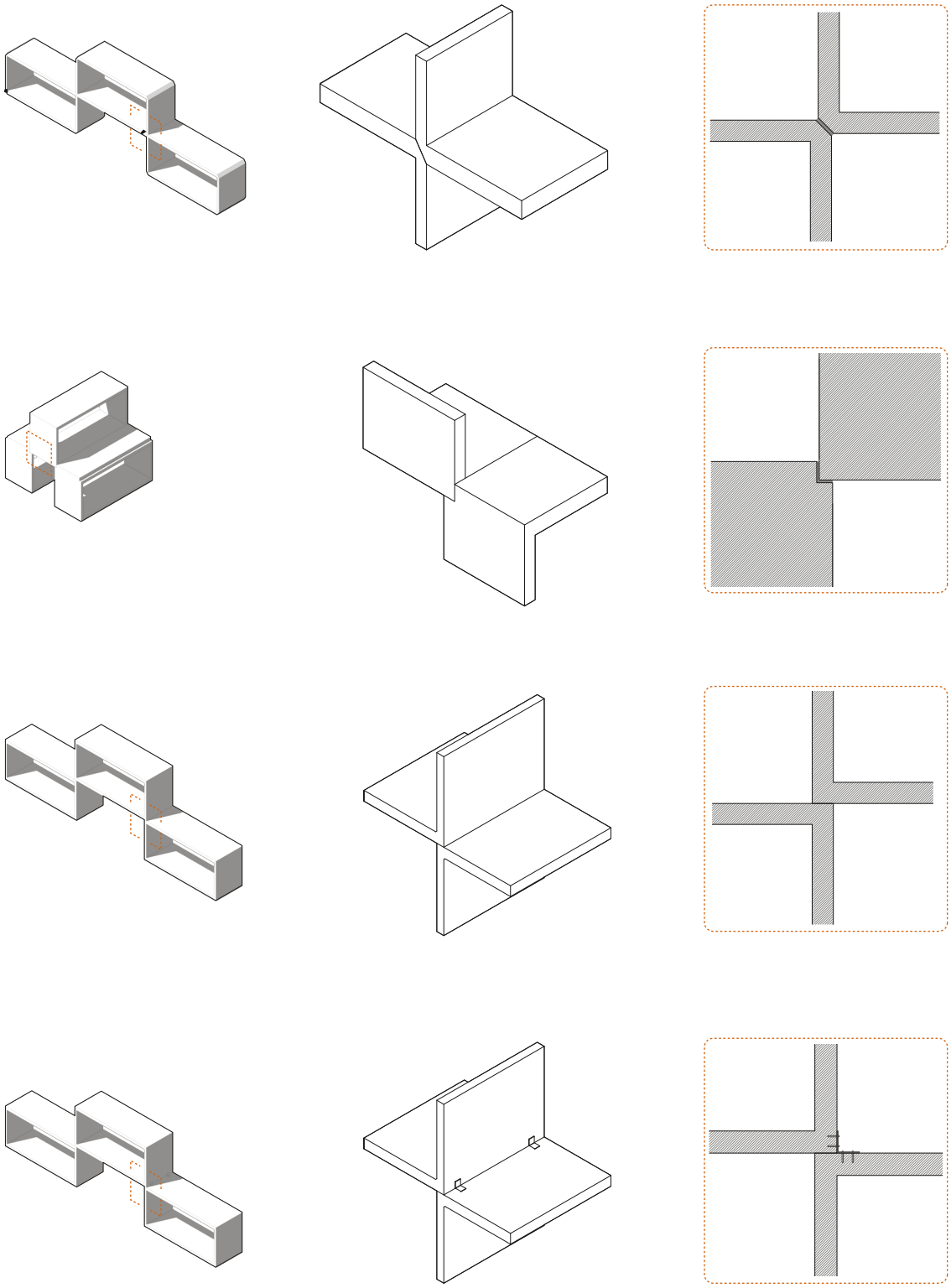
They are rigidized with epoxy fillers or with high-strength concretes. The lower horizontal slabs of the floor frames differ from the upper horizontal slabs for the arrangement of their structural reinforcement: in the lower part, they have a preferred diameter of 3/8"; in the upper part, the preferred reinforcement diameter is 1/2". In the aerial slabs, the lower part has 1/2" reinforcements; in the upper part, the reinforcements are 3/8".

The walls of the subfloor or aerial frames are reinforced by a 1/2"-diameter double mesh, separated 2.50cm from the surface, with moorings between 10cm and 20cm between the horizontal and vertical rods. The ranges of these diameters go from 1/8" to 3" and vary according to the load-bearing capacity of the terrain, the seismic area, the height of the building and its structural design.

According to the structural designs, the connections between the structural frames can have these specifications:

- Bevel-edge or tongue-and-groove assemblies between the vertical and horizontal slabs, with simple supports or mortars.
- Simple supports between the vertical and horizontal slabs with no geometric assemblies, which can be reinforced by using mortar between the vertical and horizontal slabs.
- External joints with metal plates, with preferred dimensions of 10cm x 10cm and 2mm calibers (ranging between 2cm x 2cm to 30cm x 30cm of area and calibers between 2mm and 10mm).
- Unions through metallic rods with a preferred diameter of 1/2", with ranges between 1/4" and 2".

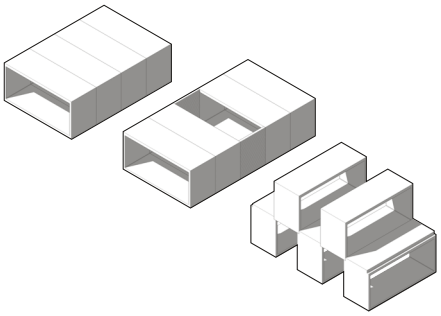
- Unions through bolts or screws, with preferred diameters of 1/2", with ranges between 1/4" and 2"; and preferred lengths of 10cm, with ranges between 5cm and 20cm.
- External unions with metallic plates welded together, with preferred dimensions of 10cm x 10cm and 2mm calibers, with ranges between 2cm x 2cm to 30cm x 30cm of area and calibers between 2mm and 10mm.
- Interior unions with overlapping reinforcement metallic rods at the corners in the form of a hook or cane, welded or joined through structural moorings with metallic wires. The preferred length of the overlap is 20cm , with a range between 5cm and 50cm.
- Flexible interior structural elements, such as textile reinforcements or post-tensioning structural cables.



Graphic 221
Simplicity. Connections and sealing.

8.2.2.2.2. Flexibility

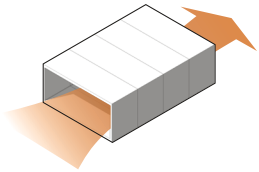
Once the support structure is installed, it can be arranged longitudinally with open façades or transversally with semi-open façades, generating different conditions in the language of the building and free plants in the interior space, that can be designed according to the requirements of the project. Flexibility in the designs allows the installation of different materials on the façades that complement the language of the support structure and respond to the environmental, cultural, social, technical or economic conditions of each setting. Free spaces may be left between the sets of structural frames that make up the living spaces to form courtyards or areas for growth.



Graphic 222
Flexibility. Housing typologies

8.2.2.2.3. Comfort

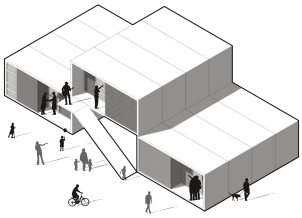
The presence of non-structural elements, complementary to the auto-bearing frames, allow the houses to resolve their language and environmentally qualify the living space, generating conditions of well-being through the control of solar incursion and the generation of cross ventilation. Thus, elements of shade, textures or different uses of the non-structural elements on the façade and in the interior space allow bioclimatic design and the correspondence of the building with the conditions of its surroundings.



Graphic 223
Comfort. Bioclimatic and sustainability

8.2.2.2.4. Beauty

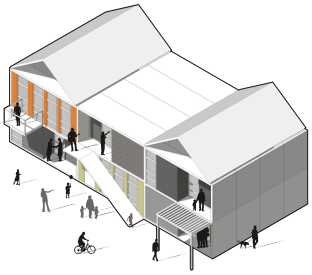
In social housing, beauty is a response to the environment, the climate, the culture, the ways of life and the identity of its inhabitants. The architectural designs and the customization or transformation processes that complement the language of the precast-concrete frames are the means to achieve diverse, unique and transformable languages. The architecture of popular housing is the expression of identity of those who live there. In the regional context, diversity is a condition that is achieved with the designs and the subsequent processes of transformation.



Graphic 224
Beauty. Architectural languages

8.2.2.2.5. Transformability

Through the processes of transformation, families can modify the built space, expand their areas or modify their language. The system permits the presence of non-structural elements to define the language of the home or to condition the interior space. When the houses are occupied by the communities, they can make the decision to open their façades to exterior spaces, generate commercial activities on the first floors of the buildings, expand or modify the interior areas or condition the architecture of the house to their needs or wishes. Transforming the house allows adapting the areas and conditions of the project to the needs of each family.



Graphic 225
Transformability. Improvements after occupation

8.3. Typologies

Different groupings, with non-structural enclosures that respond to the conditions of the environmental, cultural, social and economic contexts, can be proposed with the same structural element. Three variants are proposed, each of them with a height of two and five stories. The first is made up of linearly arranged structural frames with open façades; the second groups the frames transversally with semi-open façades, while the third combines the linear and transversal arrangement.

8.3.1. Social Housing A. Linear industrialized frames

In this typology, the frames are arranged in a linear manner, leaving their façades open toward the front and back. Through the non-structural elements, the façades and interior spaces of the homes are then finished. Each structural frame has a preferred measurement of 5.80m front, 2.00m in depth and 2.70m high, which can be varied according to the characteristics of the architectural project and the dimensions required for transport and assembly. The two walls and the two slabs have a thickness from 12cm to 20cm, according to the load-bearing capacity of the terrain, the seismic zone and the height of the building. In height, the frames are joined through assemblies and metallic rods (when these are required) that rigidize the unions between them. Horizontally, it is recommended that the frames be joined through post-tensioning cables, which ensure the continuity of the joint. Each house is modularly shaped by the dimensions occupied by these four frames. On average, if the preferred measurements are used for each frame, interior space of each house is 5.50m by 7.80m deep. Counting the average area of the lateral walls, each home can achieve an area of 45.20 m² built and an interior area of 42.90 m². The kitchen, laundry area and bathroom are grouped on one of the sides, generating a free floor where the social area and two bedrooms are located. The façades are made up of non-structural elements (masonry, panels and glass), which permit cross-circulation of air.

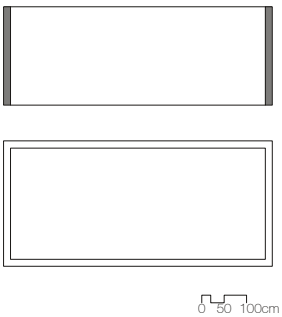
8.3.1.1. Two-story house

The linear distribution of the structural elements makes use of an average of two precast-concrete self-bearing frames per dwelling. On the first floor, there are five homes that are solved with three sets of four frames, open toward the front and back façades. On the second floor, there are five other homes that are solved with two sets of four frames, also open toward the frontal and posterior façades and supported by the structural frames that are located on the first floor. The first-floor homes are accessed through a front yard that communicates the social area of the house with the exterior space; the second-floor homes are accessed through a staircase that is built on the yard of the first-floor home. Inside the houses, a central courtyard can be designed, with a third room that can be constructed in the process of enlarging the house. The interior divisions and spatial configuration can be modified according to the needs or desires of the users.

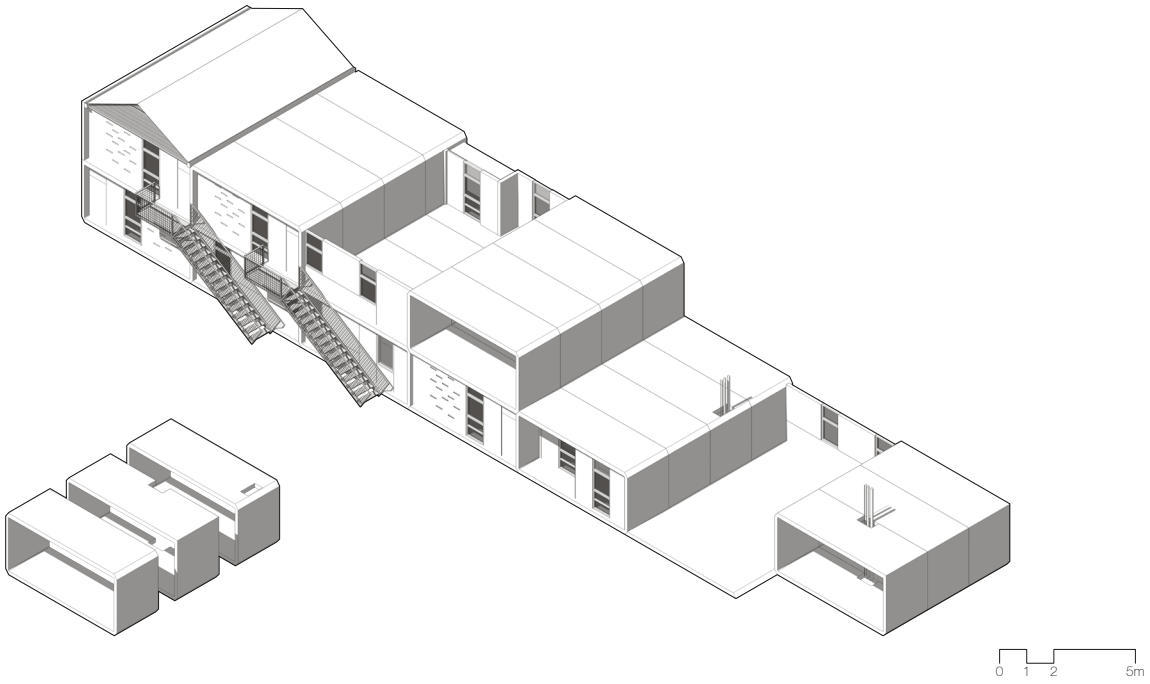
In this type of housing, the design of its interior space is also conditioned by the location of the service unit, consisting of the kitchen, a laundry area and a bathroom. The rest of the domestic space is a free floor, where the social area and private area can be located toward the open façades on the front and back of the houses. The union between the structural frames can be used in several ways. The preferred modality in two-story dwellings is through post-tensioned cables to join the frames located at the same level. The structural calculation determines the number and diameter of these elements. In height, according to the seismic zone, the load-bearing capacity of the terrain and the number of floors, the specifications for the joints between the frames can be modified. The preferred modalities are the simple support, the assembly between the pieces or the union through metal rods and mortars between the structural elements located at different heights.

Indicators	
Type of structure	Spatial cells
Type of prefabrication	Open
Number of housing units (on average, per building)	10
Height of the buildings (in number of stories)	2
Number of types of precast elements	1
Structural spatial cells	2 per dwelling
Frontage (in linear meters)	5.80
Depth (in linear meters)	8.00
Living Room - Dining Room (in square meters)	15.60
Bedrooms (in square meters)	18.80
Kitchen (in square meters)	3.80
Bathroom (in square meters)	4.80
Laundry Area (in square meters)	2.20
Patio	11.00
Initial area	45.20
Constructed area with growth	50.20
Area constructed per home (in square meters)	45.20

Table 42
Areas of the housing project (including facade walls, dividing walls, interior walls and circulations).



Graphic 226
Components: floor plans and façade



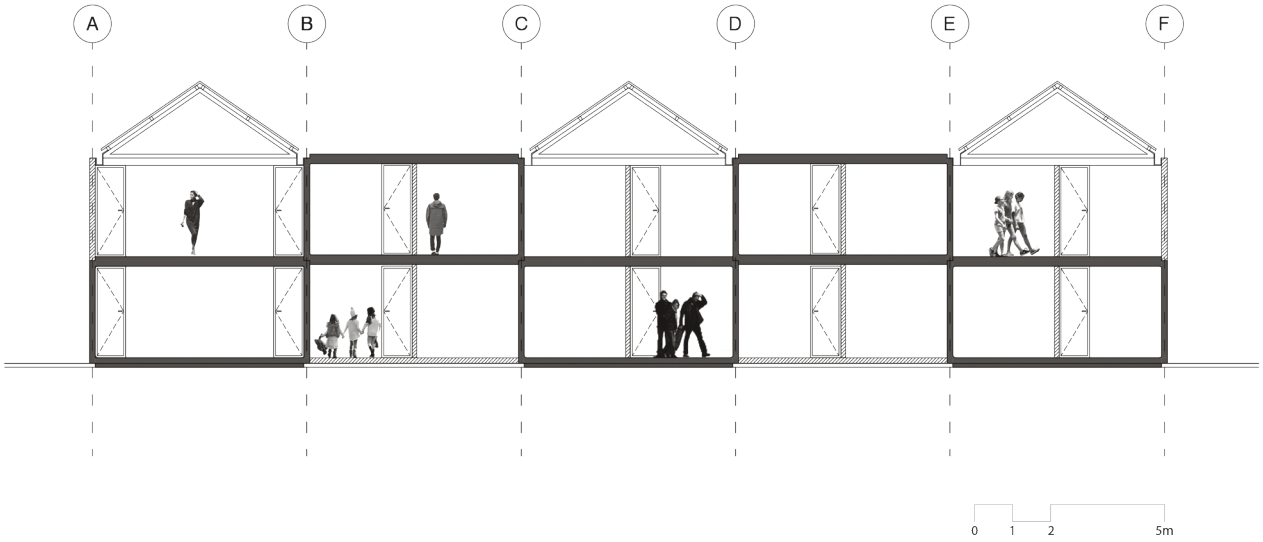
Graphic 227
Constructive process



Graphic 228
General floor plans: ground level and upper level

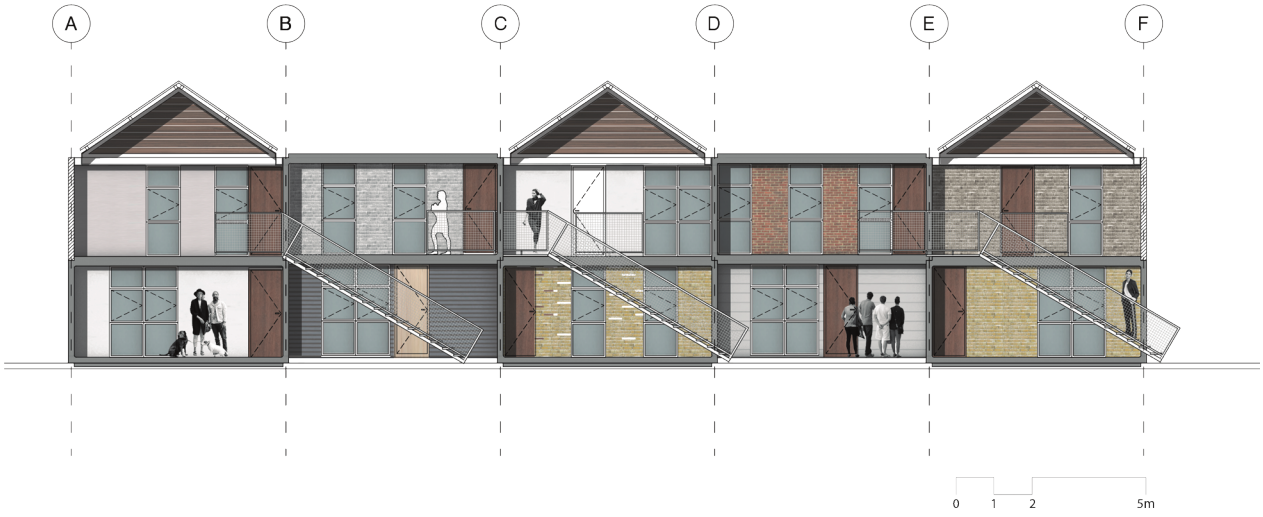


Graphic 229
Typologies of housing

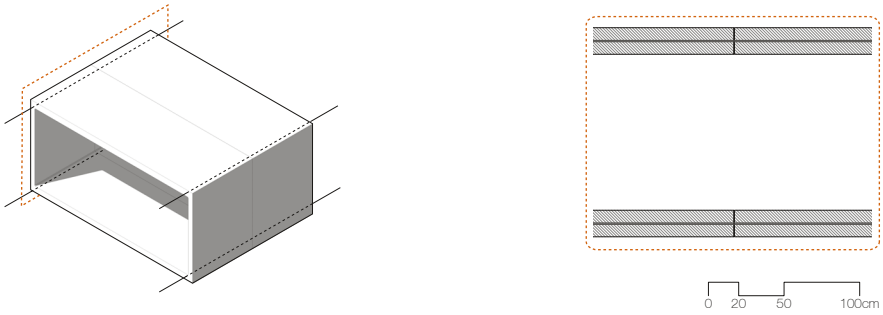


Graphic 230
Sections





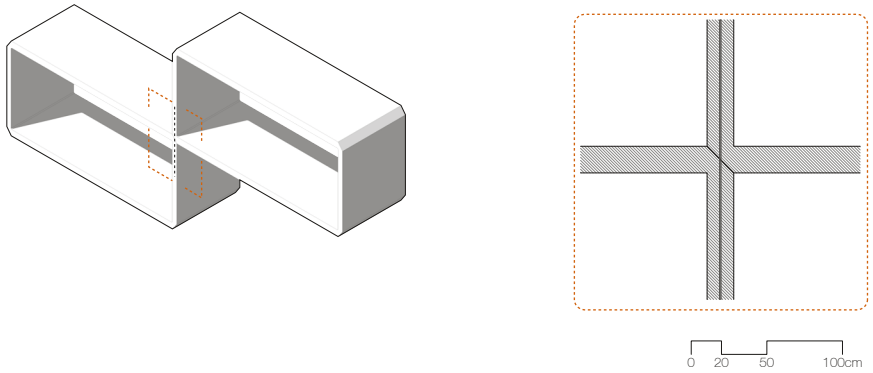
Graphic 231
Façades



Graphic 232
Constructive details



Graphic 233
Constructive process: installation of prefabricated structural elements



Graphic 234
Constructive details



Graphic 235
Constructive process: installation of non-structural elements (walls and façades)



Graphic 236 The technical system, the architectural language and the public space



8.3.1.2. Five-story house

This grouping is made up of 25 houses. On the first, third and fifth floors, there are three sets of four precast-concrete structural frames, open toward the main façade. On the second and fourth floors, two sets of four frames, also open toward the main façade, are supported on the structural frames of the first and third floors. Accesses to the houses are located next to a naturally illuminated and ventilated interior corridor where there are stairs, elevators (if specified in the project) and collective circulations. According to structural calculations, the façades can be formed by non-structural elements. Through the opening in the first-floor façades, the homes can complement the domestic use with commercial activities.

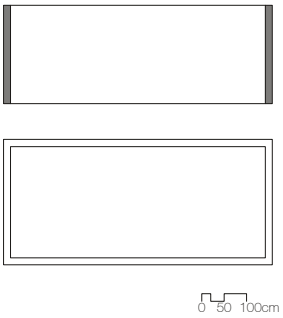
The configuration of the houses in height also depends on the location of the service unit, consisting of a kitchen, a laundry area and a bathroom. This service unit is installed once the assembly of the support structure that forms the building is completed. Therefore, from its production process in the structural frameworks, the gaps through which the electrical installation, the voice- and data-networks, and the hydrosanitary pipes of each house will pass must be foreseen in order to avoid reprocessing and additional activities during the construction period.

Once the service units are located, the interior spaces of each house are delimited with non-structural walls, generating different possibilities of use according to the needs of each family. The service unit, the social areas or a bedroom can be located toward the interior façade, while the social areas or the private area can be located toward the main façade. The façades are designed with non-structural elements so that the environmental conditions of the house and its language can be adapted to different geographical and cultural contexts.

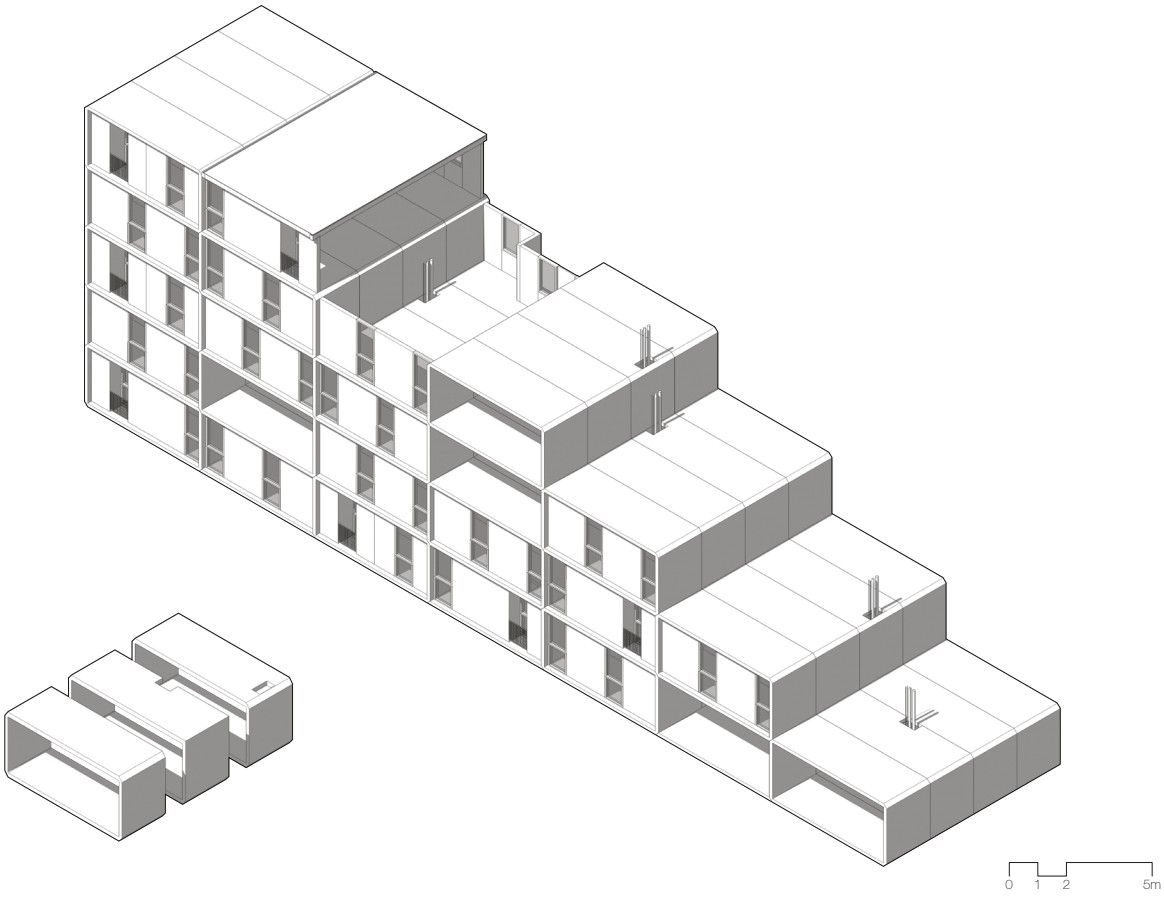
The union between the structural elements is done in the same way as in one- and two-story dwellings. The joints of the frames located at the same level are preferably resolved through post-tensioned cables, located according to the conditions defined by the structural calculation. Assemblies between parts, metal connectors, plates or joints with mortars can also be used. In height, the union is preferably resolved with metal rods and mortars connecting the frames. According to the structural calculation, the number and diameter of the metal connectors can vary, having one meter per frame as preferred embedding lengths, with a one-inch diameter and a minimum of two connectors between modules.

Indicators	
Type of structure	Spatial cells
Type of prefabrication	Open
Number of housing units (on average, per building)	25
Height of the buildings (in number of stories)	5
Number of types of precast elements	1
Structural spatial cells	2 per dwelling
Frontage (in linear meters)	5.80
Depth (in linear meters)	8.00
Living Room - Dining Room (in square meters)	15.60
Bedrooms (in square meters)	18.80
Kitchen (in square meters)	3.80
Bathroom (in square meters)	4.80
Laundry Area (in square meters)	2.20
Area constructed per home (in square meters)	45.20

Table 43
Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)



Graphic 237
Components: floor plans and façade



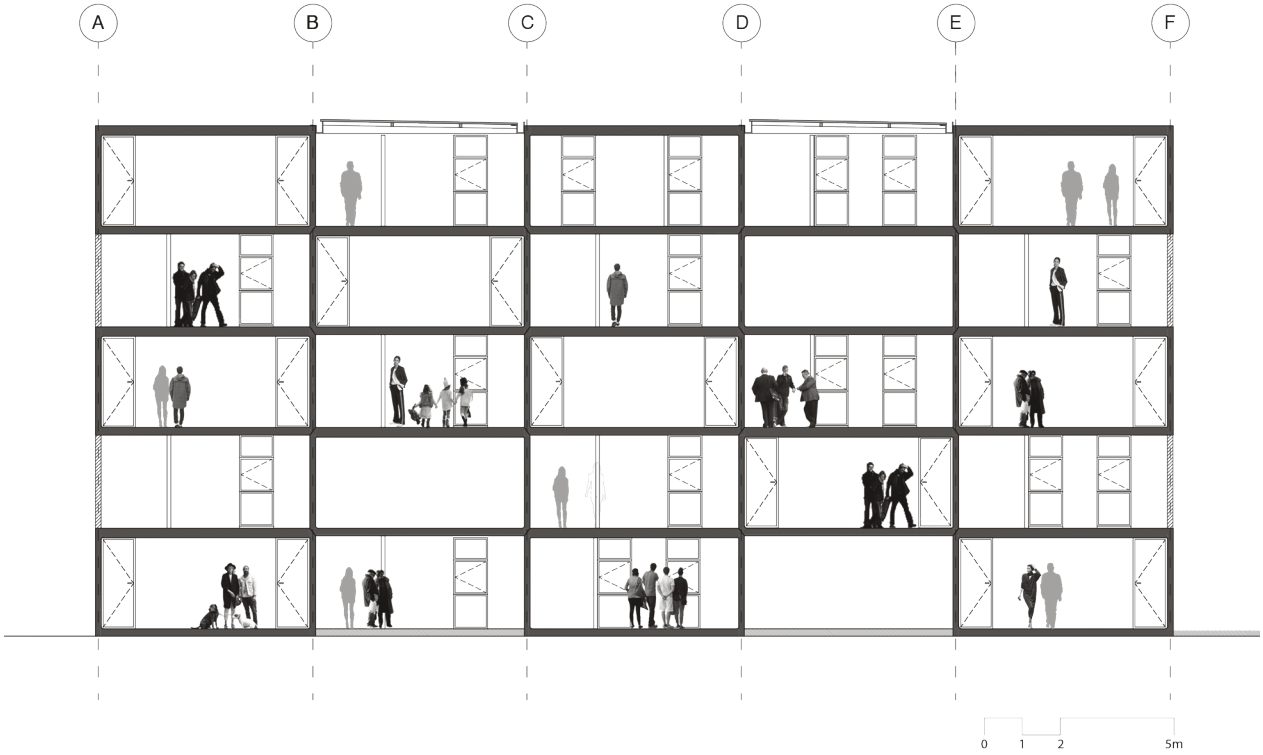
Graphic 238
Constructive process



Graphic 239
General floor plans



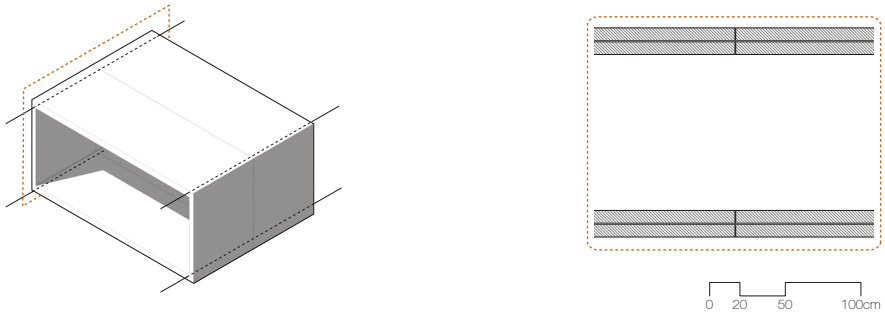
Graphic 240
Typologies of housing



Graphic 241
Sections



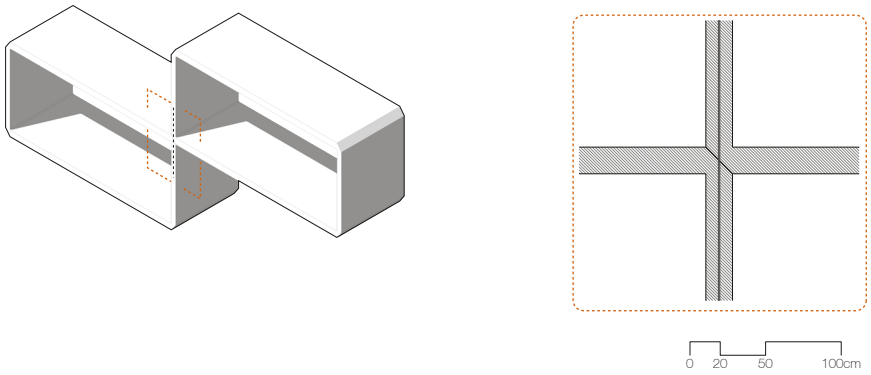
Graphic 242
Façades



Graphic 243
Constructive details



Graphic 244
Constructive process: installation of prefabricated structural elements



Graphic 245
Constructive details



Graphic 246
Constructive process: installation of non-structural elements (walls and façades)



Graphic 247 The technical system, the architectural language and the public space



8.3.2. Social Housing B. Transversal industrialized frames

In this grouping, the concrete structural frames are arranged transversally, orienting their side walls toward the main façade. Among them, non-structural walls or windows are installed to finish configuring the façade system and interior spaces. In this typology of housing, two- and five-story buildings are proposed. Each structural frame has a 5.80m depth, 1.80m facing the main and back façades, and 2.70m in height. The two walls and the two slabs have a thickness between 15cm and 20cm. In height, the frames are joined preferably through metallic rods that rigidize the unions between them. Each house is also formed modularly by the dimensions of the frames and by the gaps between them. The only fixation between the frames is given in height, due to the configuration of the system. The houses conformed by these frames have 5.50 free meters of depth by 8.10 free meters of width. Counting the average area of the lateral walls, each home has an area of 47.85 m² built and an interior area of 44.53 m². The service area (kitchen, laundry and bathroom) is grouped on one of the sides of the house, which permits concentrating the water, electricity and voice- and data-network installations in the same point. The location of the service units toward the front and back façades guarantees the natural ventilation and illumination of these spaces. This condition displaces the support structure to the perimeters and generates a free plant, which also permits permanent natural illumination and ventilation in all the spaces of the house, a desirable situation for bioclimatic designs and for the environmental qualification. The façades are initially formed by the order and rhythm established by structural elements, which occupy 50% of the front and back façades. They are complemented with the presence of non-structural elements, which occupy the other 50% of the façade, and which could guarantee the natural lighting and ventilation of the interior spaces. The design and materiality of the interior divisions can be defined according to the needs or wishes of the users.

8.3.2.1. Two-story house

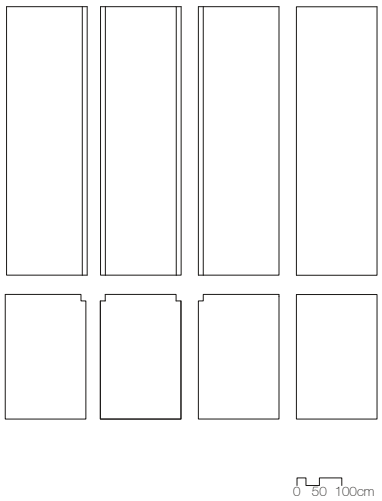
The transversal arrangement of the structural elements means that each house uses an average of 2.5 precast-concrete structural frames. In the first floor, five homes are solved with 13 frames. The separation between them generates the openings that are then used as accesses to the housing on the first or second floor, or as windows. On the second floor, 12 structural frames, supported on the first-floor structural frames, complete the conformation of the group of houses. In two-story homes, areas of future growth can be proposed between the social area and the bedrooms.

This type of housing illuminates each one of its interior spaces from the front and back façades. The service unit (consisting of a kitchen, a laundry area and a bathroom) can be located at one end of the house or in its central part, which generates different occupation models, according to the architectural designs or the preferences of the inhabitants. The social area and the bedrooms can be located in different ways, since the remaining space is a free floor that can be divided by non-structural elements.

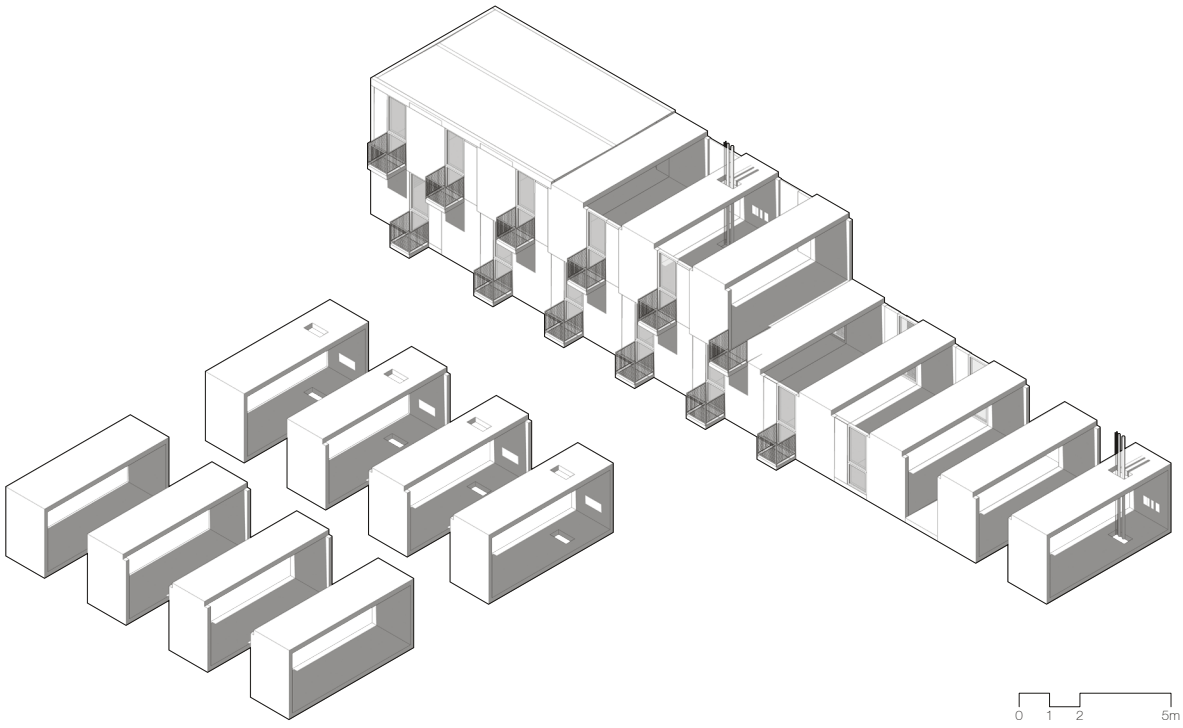
In the two-story dwellings, the union between the structural frames that are located at different levels is preferably done by geometric assemblies and metal rods that reinforce the union and restrict the movements of the structure. The specifications of the elements for the union of the frames are specified from the structural designs, which consider the load-bearing capacity of the terrain, the height of the building and the zone of seismic risk. Horizontally, the arrangement of the frames does not require additional fixation, since the union in height through the structural reinforcements and the geometric assemblies guarantee the restriction of the movements of the elements that make up the structure of the building.

Indicators	
Type of structure	Spatial cells
Type of prefabrication	Open
Number of housing units (on average, per building)	10
Height of the buildings (in number of stories)	2
Number of types of precast elements	4
Structural spatial cells	2.5 per dwelling
Frontage (in linear meters)	8.40
Depth (in linear meters)	5.80
Living Room - Dining Room (in square meters)	19.20
Bedrooms (in square meters)	17.85
Kitchen (in square meters)	3.80
Bathroom (in square meters)	4.80
Laundry Area (in square meters)	2.20
Area constructed per home (in square meters)	47.85

Table 44
Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)



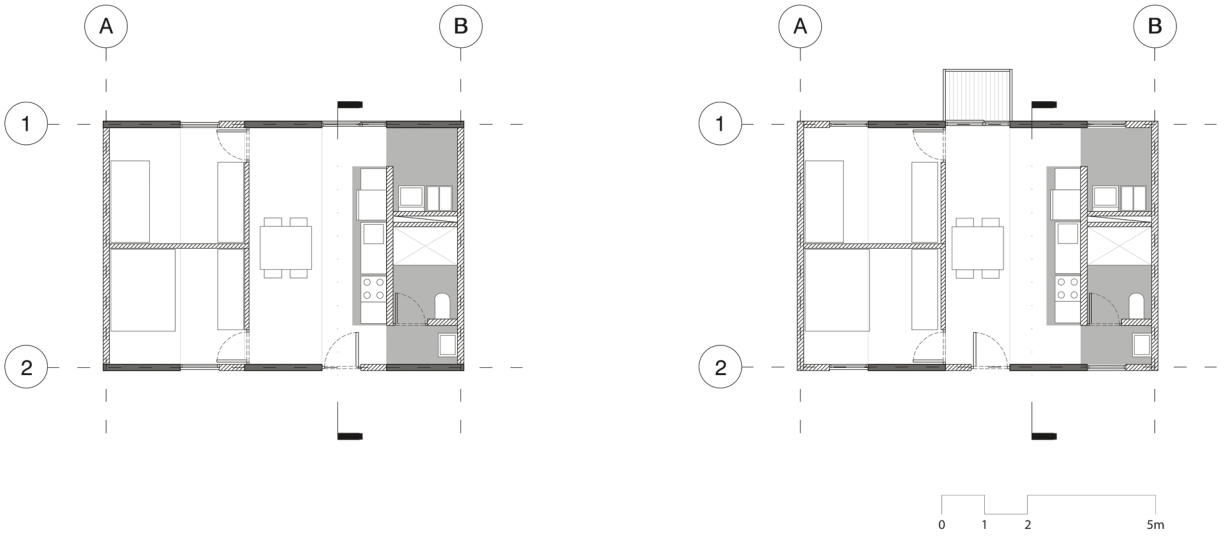
Graphic 248
Components: floor plans and façade



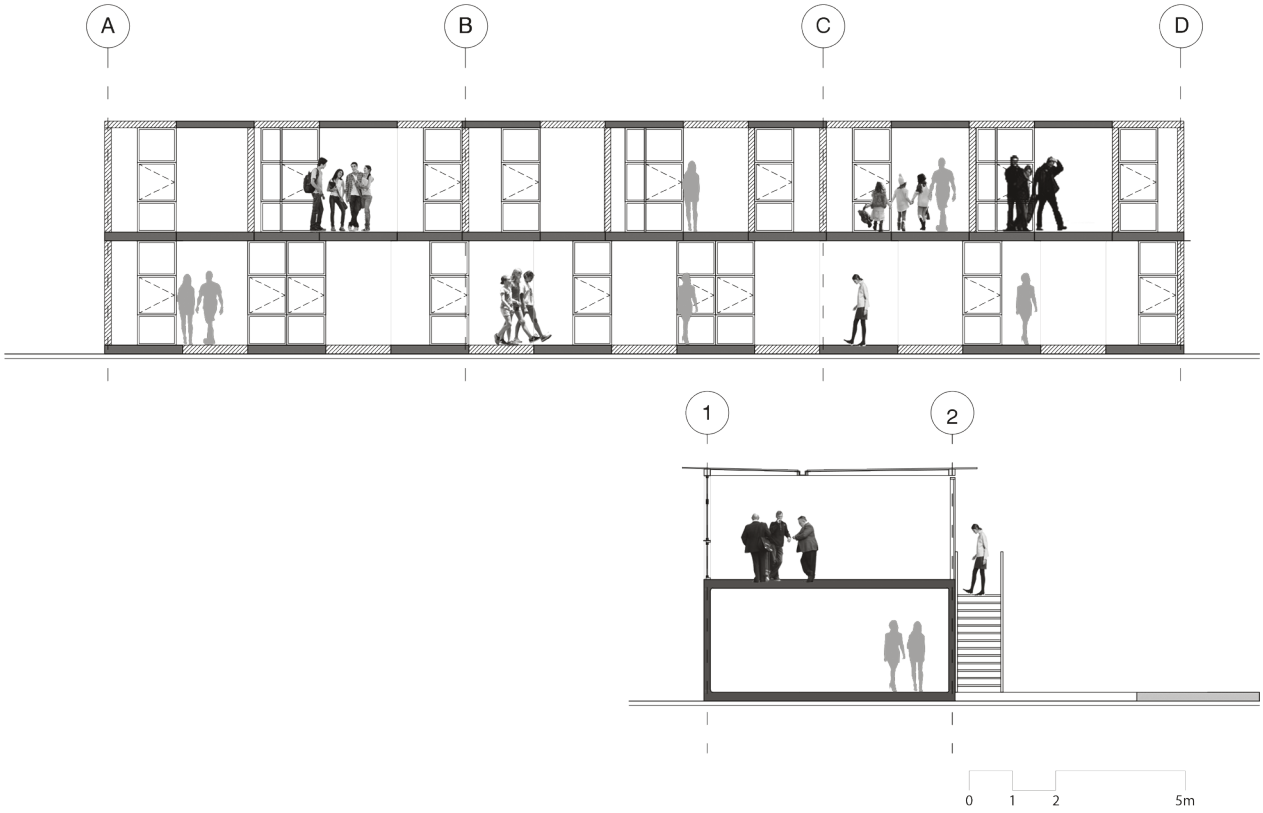
Graphic 249
Constructive process



Graphic 250
General floor plans: ground level and upper level



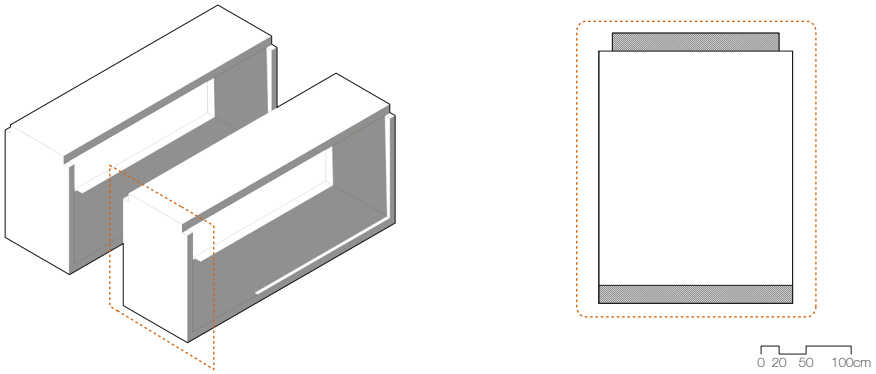
Graphic 251
Typologies of housing



Graphic 252
Sections



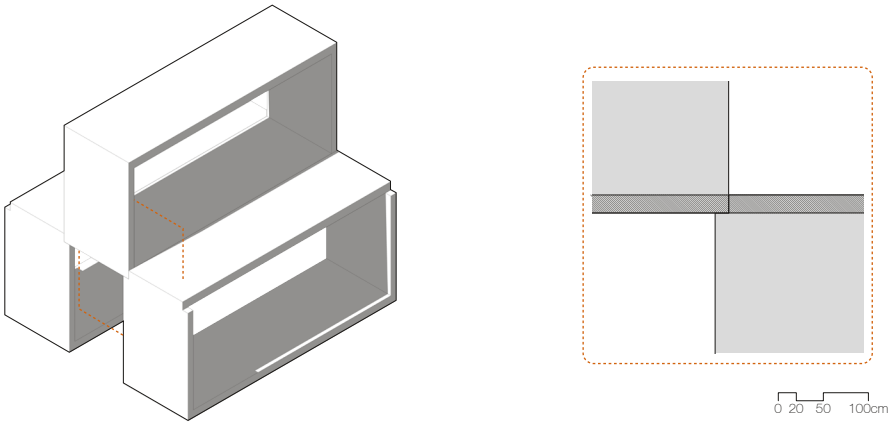
Graphic 253
Façades



Graphic 254
Constructive details



Graphic 255
Constructive process: installation of prefabricated structural elements



Graphic 256
Constructive details



Graphic 257
Constructive process: installation of non-structural elements (walls and façades)



Graphic 258 The technical system, the architectural language and the public space



8.3.2.2. Five-story house

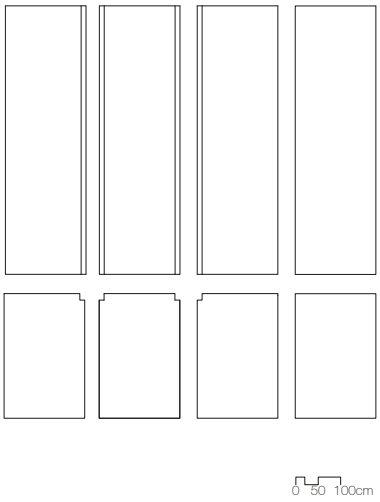
For the design and construction of a five-story building, with five homes per floor, the prefabricated structural frames are installed with the same criteria of orientation used for the construction of a two-story building. The conformation of fillings and gaps in the façades generates structural and aesthetic conditions that, from the architectural designs, respond to different conditions of the context. Access to the housing units is made through the common circulations, located at the back façade, where the stairs and elevators are also located.

The transversal location of the frames on five floors generates architectural typologies similar to those used in two-story buildings. The service units (also made up of a kitchen, a laundry area and a bathroom in the typical dwelling) must be located in the same point on each of the floors of the building to ensure the efficient operation of the electrical, plumbing and voice- and data-network installations. The precast-concrete frames should consider – from their industrial production – the perforations in the slabs for the passage of the technical ducts indicated in the architectural designs. It is not advisable to perforate the structural elements during the construction process. Therefore, having the support structure and the location of the technical facilities defined, the rest of the floor of the dwelling is free and permits different distributions of the social area and bedrooms. In this type of building, the openings in the front and back façades naturally illuminate and ventilate each of the interior spaces.

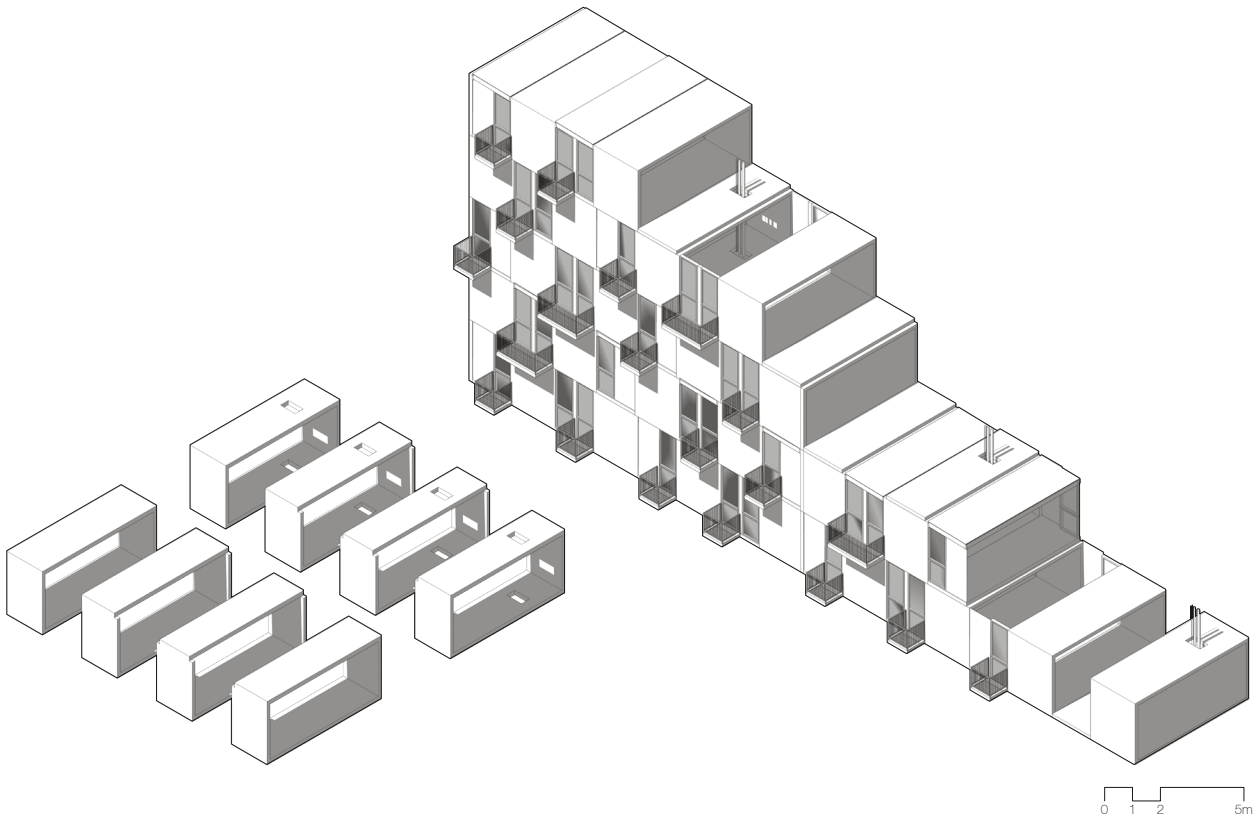
The unions between the structural frames located in each of the floors is preferably specified by geometric assemblies, which are reinforced with metal pins or rods that join the frames in different heights. The union with the metal rods can be reinforced with a grouting in the perforations of the frames to stiffen their movements. The dimensions of these metal rods are calculated according to the number of stories of the building, the conditions of the terrain and the zones of seismic risk. At the same level, the frames do not require an additional union, since the assemblies between them in different heights stiffens the structural system.

Indicators	
Type of structure	Spatial cells
Type of prefabrication	Open
Number of housing units (on average, per building)	25
Height of the buildings (in number of stories)	5
Number of types of precast elements	4
Structural spatial cells	2.08 per dwelling
Frontage (in linear meters)	8.40
Depth (in linear meters)	5.80
Living Room - Dining Room (in square meters)	19.20
Bedrooms (in square meters)	17.85
Kitchen (in square meters)	3.80
Bathroom (in square meters)	4.80
Laundry Area (in square meters)	2.20
Area constructed per home (in square meters)	47.85

Table 45
Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)



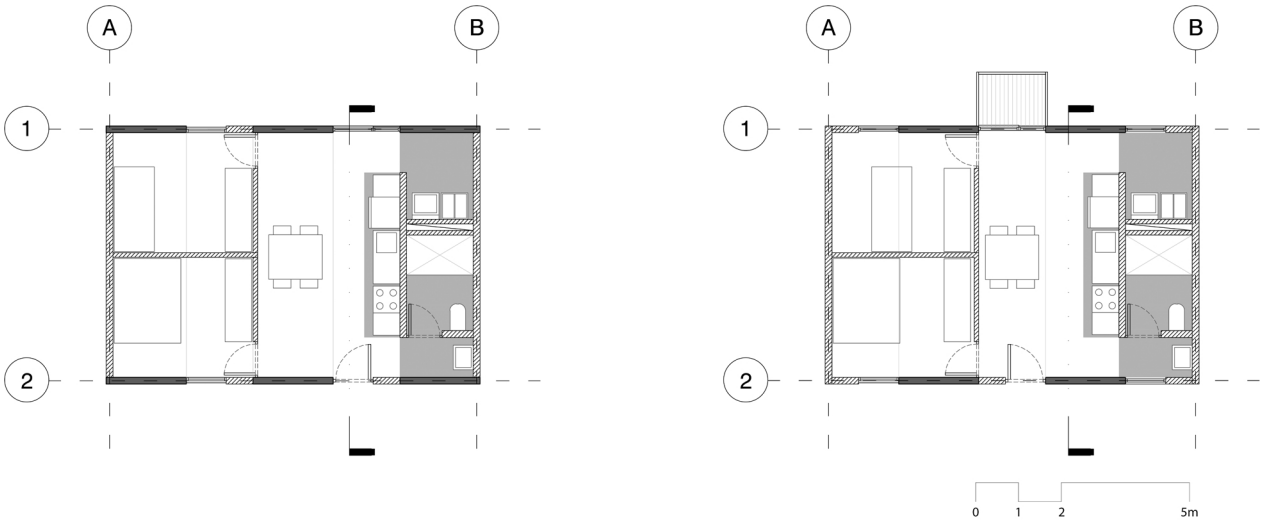
Graphic 259
Components: floor plans and façade



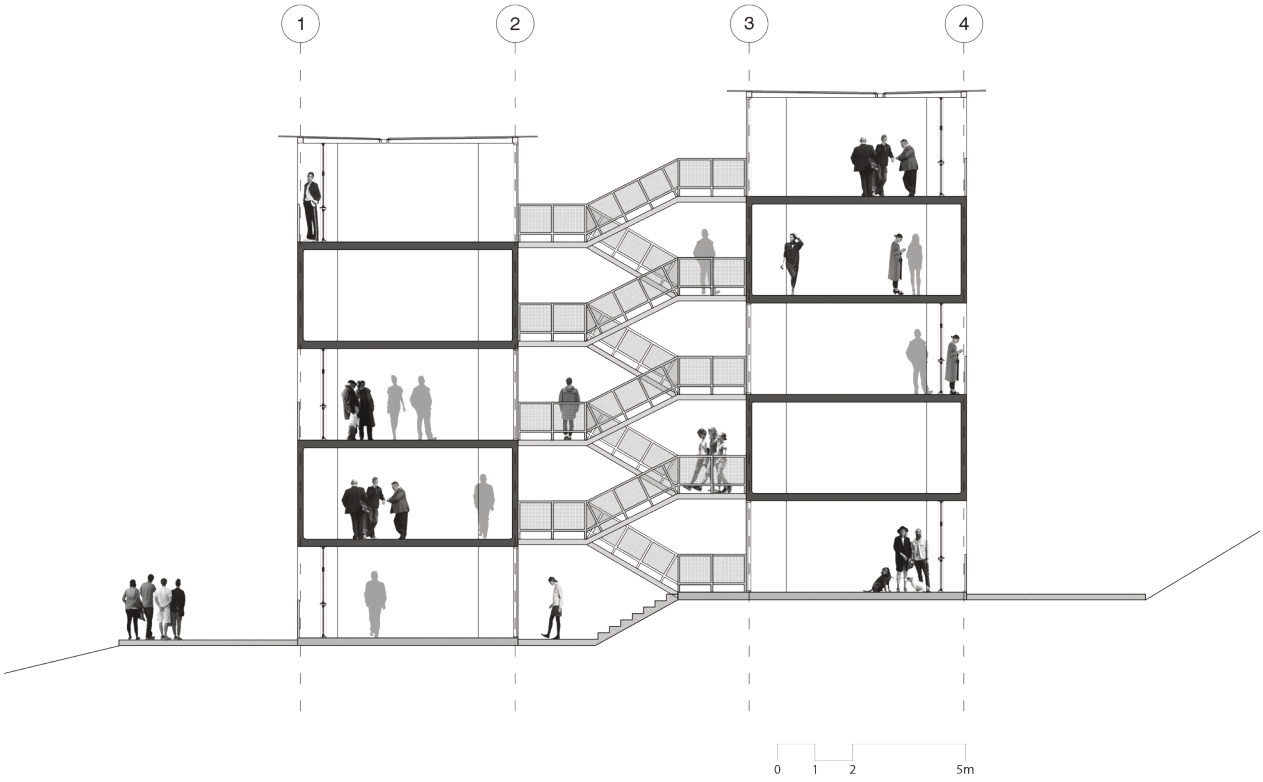
Graphic 260
Constructive process



Graphic 261
General floor plans



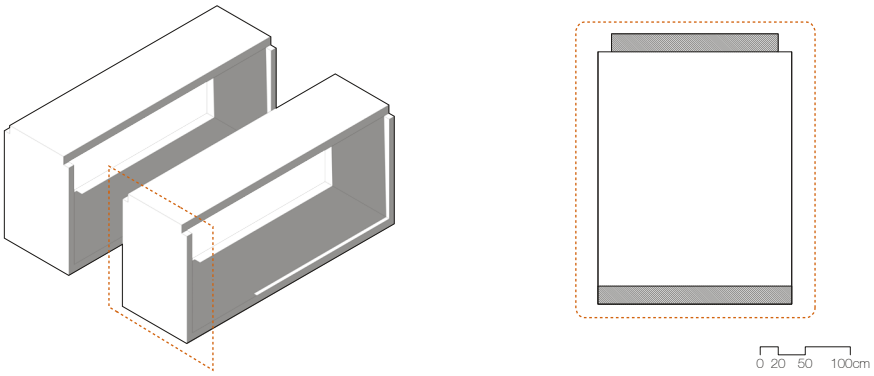
Graphic 262
Typologies of housing: ground level and upper level



Graphic 263
Sections



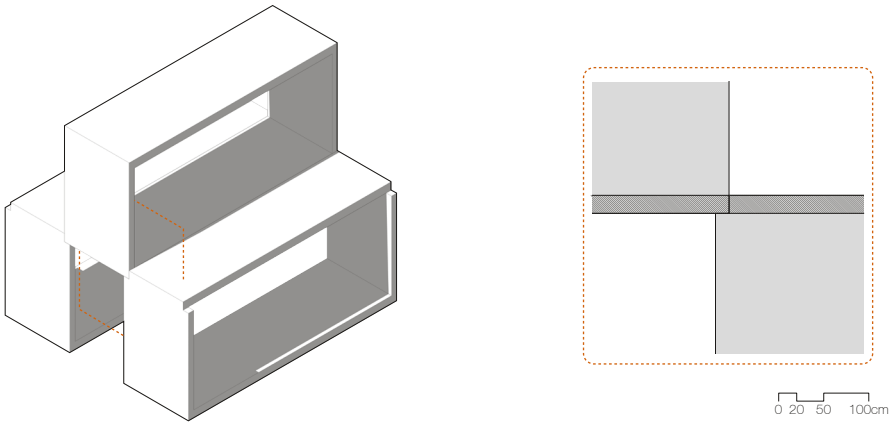
Graphic 264
Façades



Graphic 265
Constructive details



Graphic 266
Constructive process: installation of prefabricated structural elements



Graphic 267
Constructive details



Graphic 268
Constructive process: installation of non-structural elements (walls and façades)



Graphic 269 The technical system, the architectural language and the public space



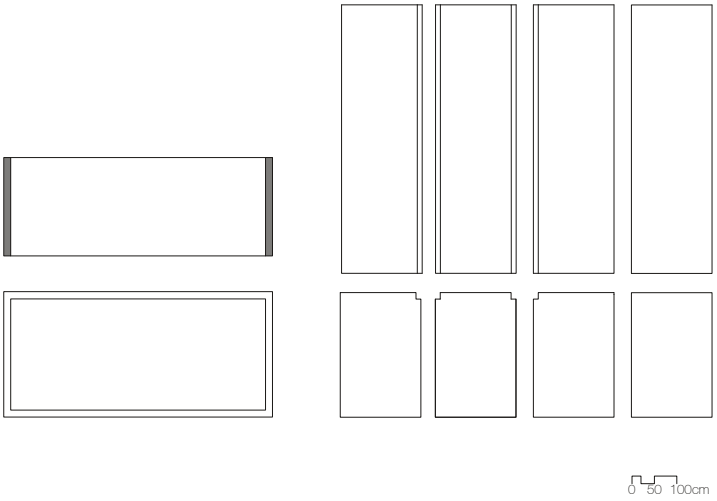
8.3.3. Social Housing C. Mixed grouping: lineal and transversal industrialized frames

In this urban grouping, concrete structural frames are arranged in a linear and transversal manner, which permits configuring a diverse set of living typologies. In this building, the same structural principle is continued; it consists of two lower frames supporting another frame located on the upper floor. The free spaces between the frames can be occupied by non-structural walls or windows. In this typology, that includes the linear and transverse layout of the frames, two- and five-story buildings are also proposed; an average of 2.5 precast-concrete structural frames are used per dwelling. The free spaces between the frames generate the openings that are subsequently used as accesses or windows. Each grouping of frames has the dimensions of the linear and transversal systems. The 5.80m width remains constant; depths vary between 1.80m and 2.00m according to the type of architectural and spatial configuration sought. The two walls and the two slabs of each frame have a thickness between 15cm and 20cm, according to the structural calculations for each building and between them they are joined preferably (among other options), by metallic rods in height or with post-tensioning cables when the frames are joined horizontally. The kitchen, laundry and bathroom units are located on one side of the dwelling to permit the development of different typologies on the same floor.

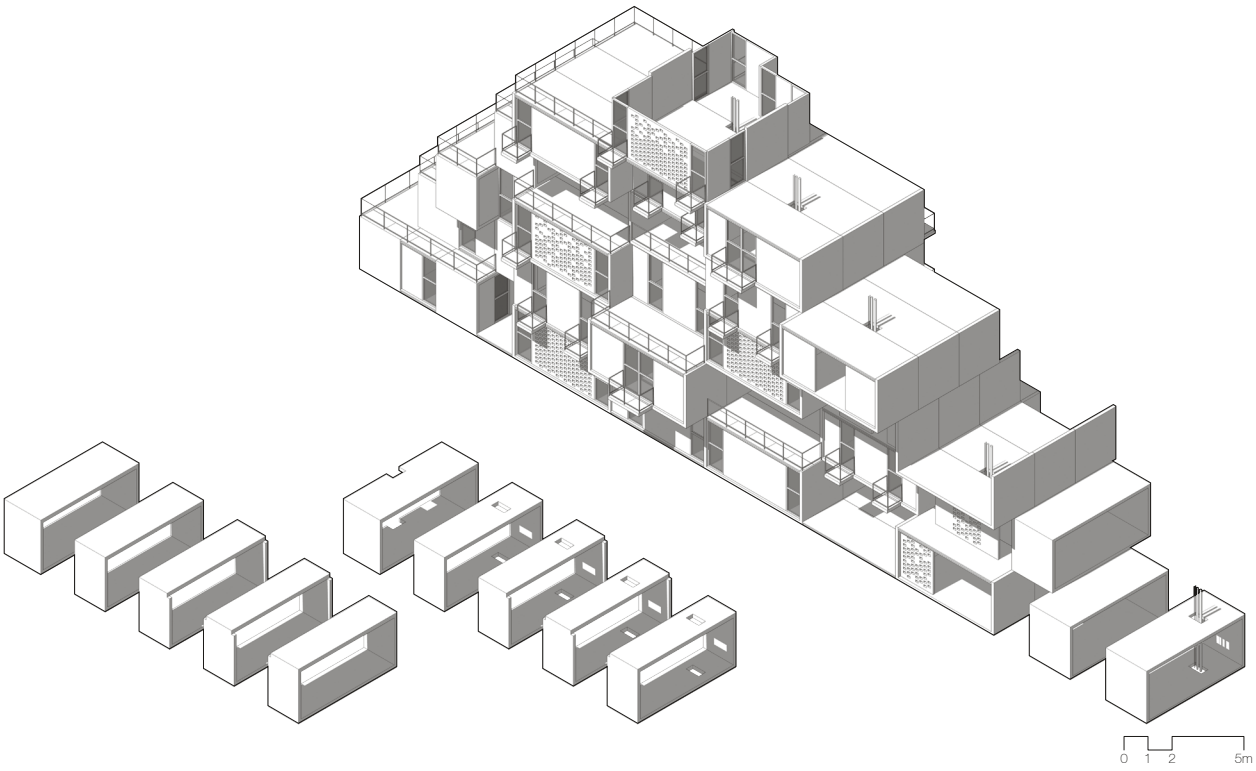
This also permits the electrical, hydrosanitary and voice- and data-network installations to be located continuously between the different levels of the building, so that the construction is more efficient and the floors free (as a space resulting from the arrangement of the structural elements and the service units), can receive different types of housing, according to the characteristics of its occupants. The façades are formed by the structural elements and by the non-structural elements arranged in different ways according to the architectural designs, a condition that increases the variants in the language of the system, generates other spaces of the roofs of the houses and that responds to environmental, cultural, technical and social conditions. The combination of linear and transversal frames in the same building generates – besides the increase of the typological variety – other possibilities in its language from conditions of individuality, adaptability to different contexts and incrementality in its occupation process.

Indicators	
Type of structure	Spatial cells
Type of prefabrication	Open
Number of housing units (on average, per building)	25
Height of the buildings (in number of stories)	5
Number of types of precast elements	5
Structural spatial cells	2.05 per dwelling
Frontage (in linear meters)	5.80 / 8.40
Depth (in linear meters)	8.00 / 5.80
Living Room - Dining Room (in square meters)	15.60 / 19.20
Bedrooms (in square meters)	18.80 / 17.85
Kitchen (in square meters)	3.80 / 3.80
Bathroom (in square meters)	4.80 / 4.80
Laundry Area (in square meters)	2.20 / 2.20
Area constructed per home (in square meters)	45.20 / 47.85

Table 46
Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)



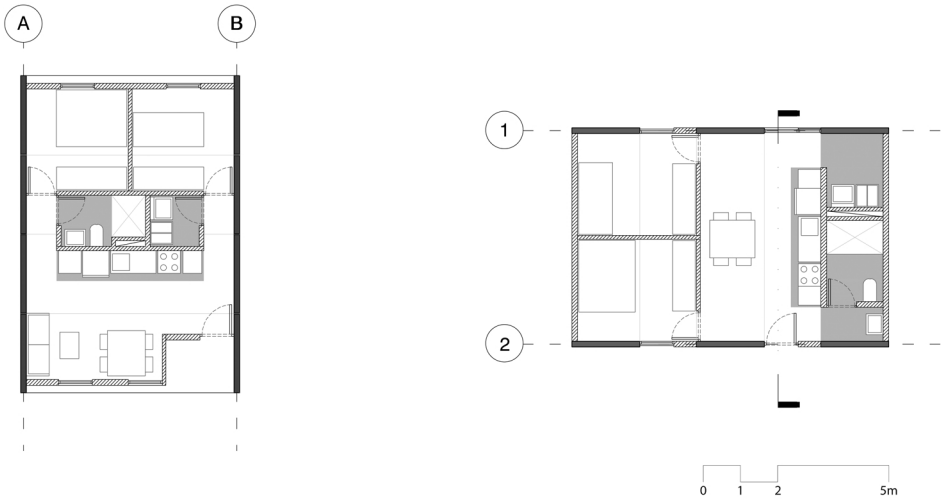
Graphic 270
Components: floor plans and façade



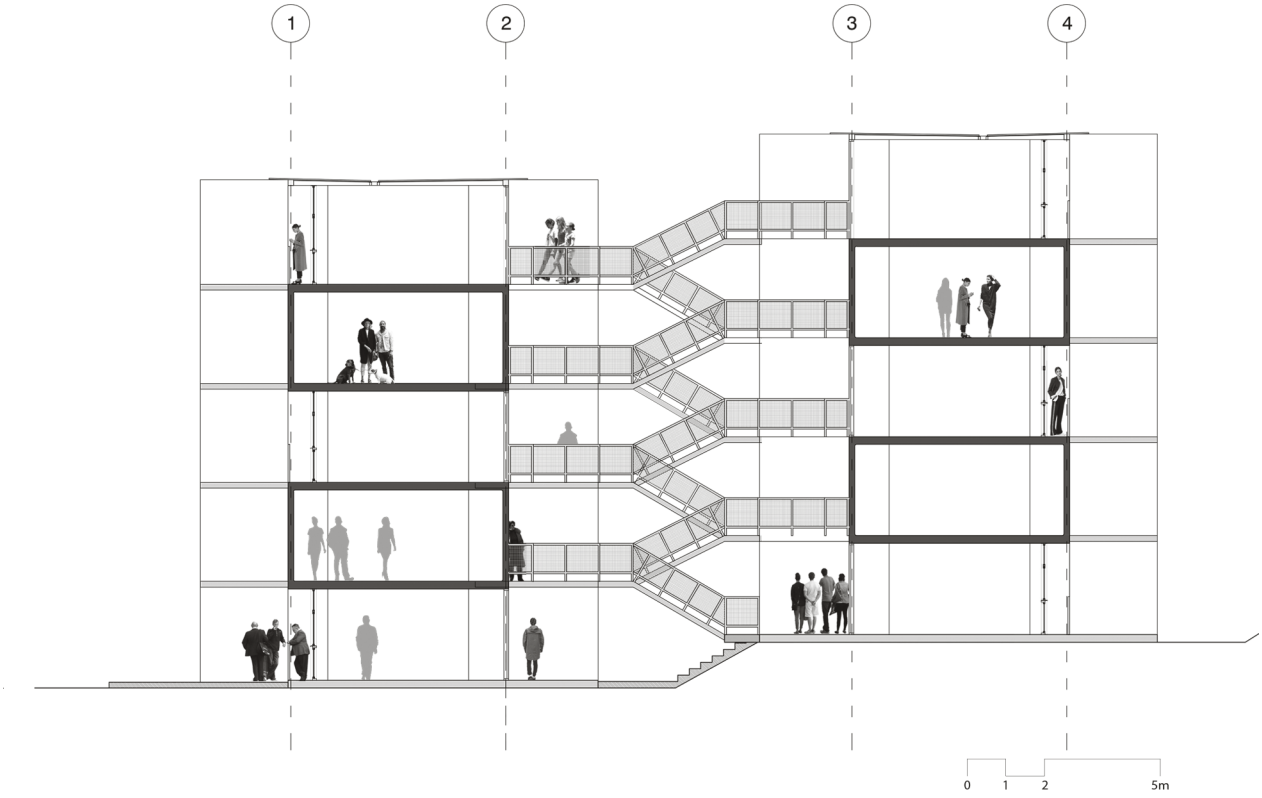
Graphic 271
Constructive process



Graphic 272
General floor plans



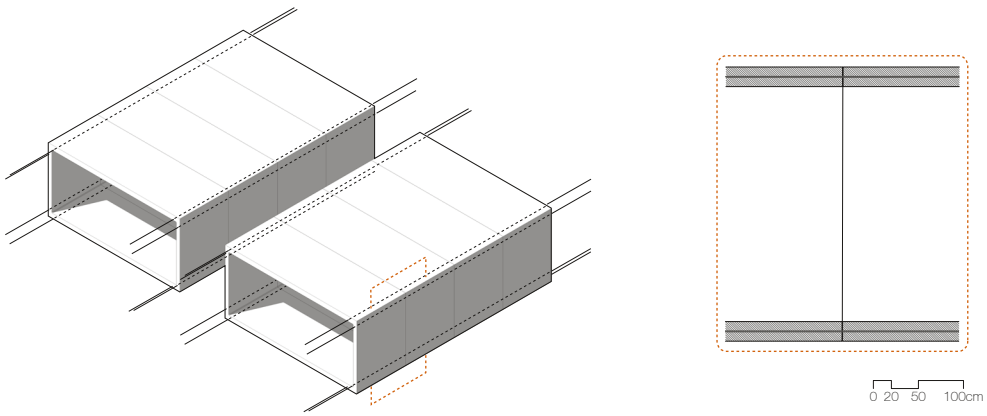
Graphic 273
Typologies of housing



Graphic 274
Sections



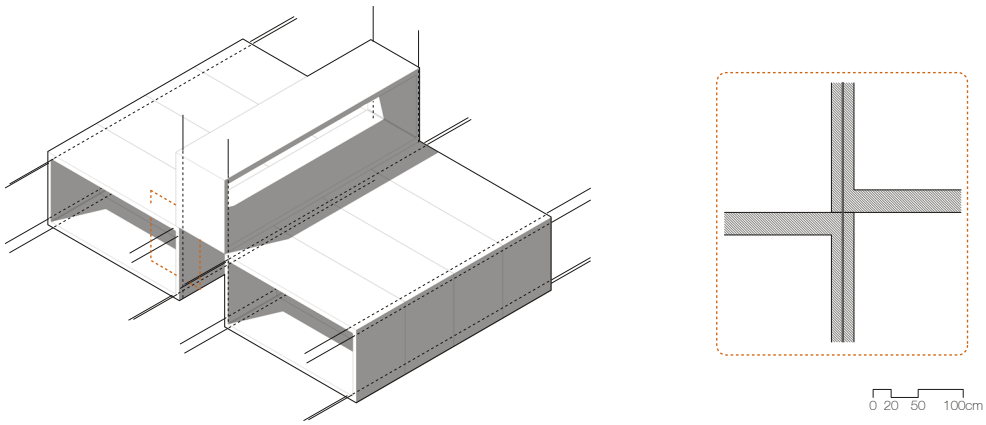
Graphic 275
Façades



Graphic 276
Constructive details



Graphic 277
Constructive process: installation of prefabricated structural elements



Graphic 278
Constructive details



Graphic 279
Constructive process: installation of non-structural elements (walls and façades)



Graphic 280 The technical system, the architectural language and the public space



8.4. Prototypes

In April 2015, two prototypes of social housing were constructed in precast concrete in an alternate campus of Universidad Pontificia Bolivariana in the municipality of Marinilla, 45km east of Medellín. The support structure of a third housing module, located on the second level of the type of transversal frames was also constructed, in accordance with the theoretical principles proposed in the development of this investigation.

8.4.1. Prototype A

The first of the prototypes corresponds to the dwelling of the central courtyard (patio). Its front is 5.80m long and its length is 10.00m, including 2.00 linear meters of patio between the social zone and the bedrooms. The front and back façades were constructed with non-structural elements and, therefore, the openings were defined from the architectural design. The total constructed area is 46.4 m². The structural support was constructed with four precast-concrete frames with the following dimensions: 5.80m long on the front, 2.00m length and 2.70m high. The walls were prefabricated with a thickness of 15cm, and the floor and ceiling slabs, with a thickness of 15cm. The structural frames form the side walls, the floor and the roof of the house. The façades were constructed with concrete blocks measuring 10cm x 15cm x 30cm, dimensionally coordinated with the walls and the precast structural elements. The interior walls were constructed with concrete blocks measuring 10cm x 20cm x 40cm, with the same criteria of dimensional coordination as the façades. The terrain had a replacement of 60cm of land for stone material and grit, to improve its support features and in accordance with the geotechnical study made before construction.

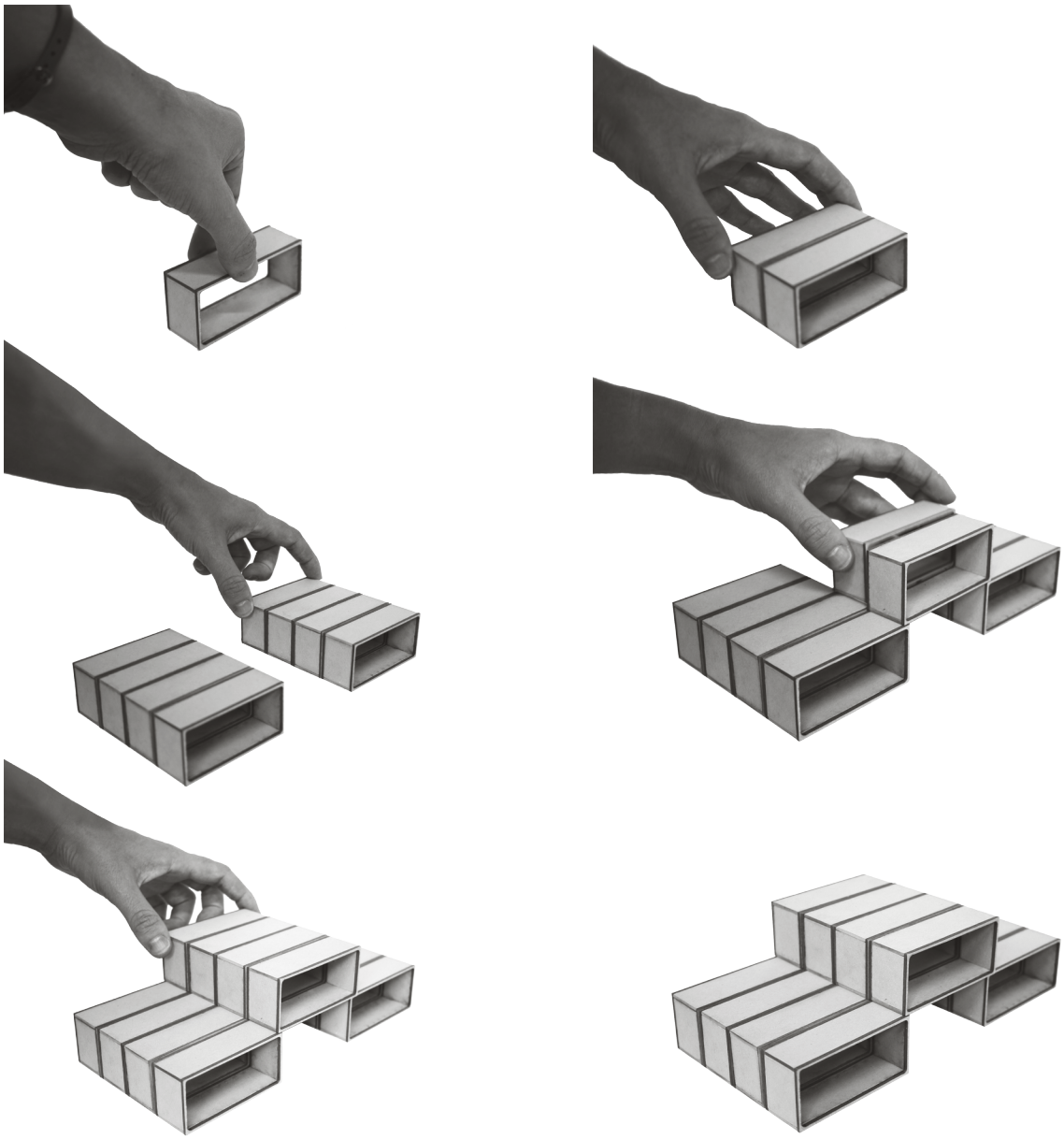
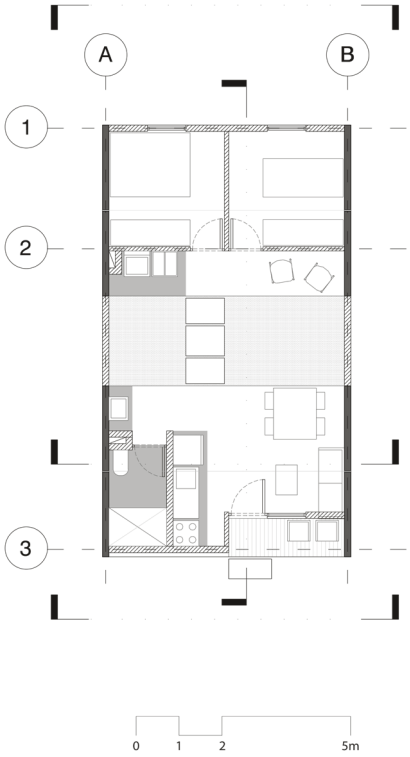
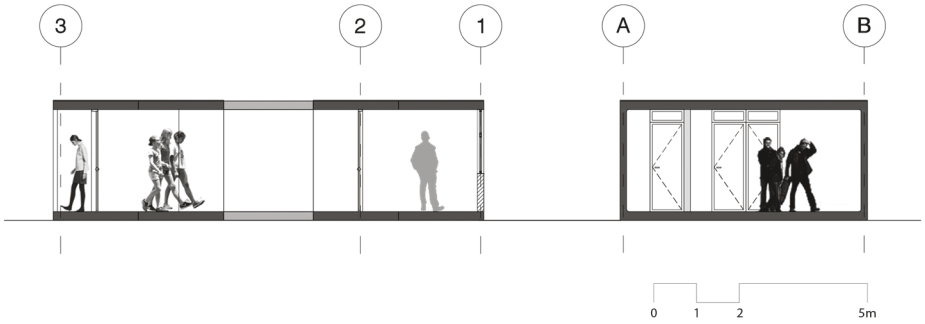


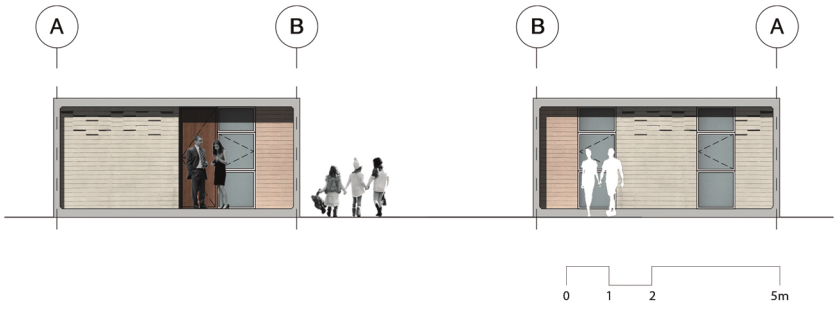
Figure 49
Prototype A. Grouping system model.



Graphic 281
Architectural floor plans



Graphic 282
Sections



Graphic 283
Façades

8.4.2. Prototype B

The second prototype is a two-family house. The façades were constructed on the lower floor; on the upper floor, only the support structure was left in sight. Its front is 8.40m long and its length is 5.80m. The constructed area is 48.72 m². The support structure for the two prototypes was built with five precast-concrete frames with the following dimensions: 1.80m long on the front, 5.80m in length and 2.70m high. According to their configuration, the structural frames form a part of the façades, the floor and the roof. The floor slabs between the prefabricated modules were constructed with in-situ cast concrete, having a resistance of 28 MPa.

The façades were constructed with concrete blocks measuring 10cm x 15cm x 30cm, dimensionally coordinated with the windows and the precast structural elements. Because of its configuration, in the prototype of the first level, the four façades have different openings, a situation that can be achieved with this typology when it is built individually. In a group of dwellings, the units located on the corner can open three of its four façades. This terrain is the same as the one on which Prototype A was built, which had a replacement of 60cm of land for stone material and grit to improve its support features.

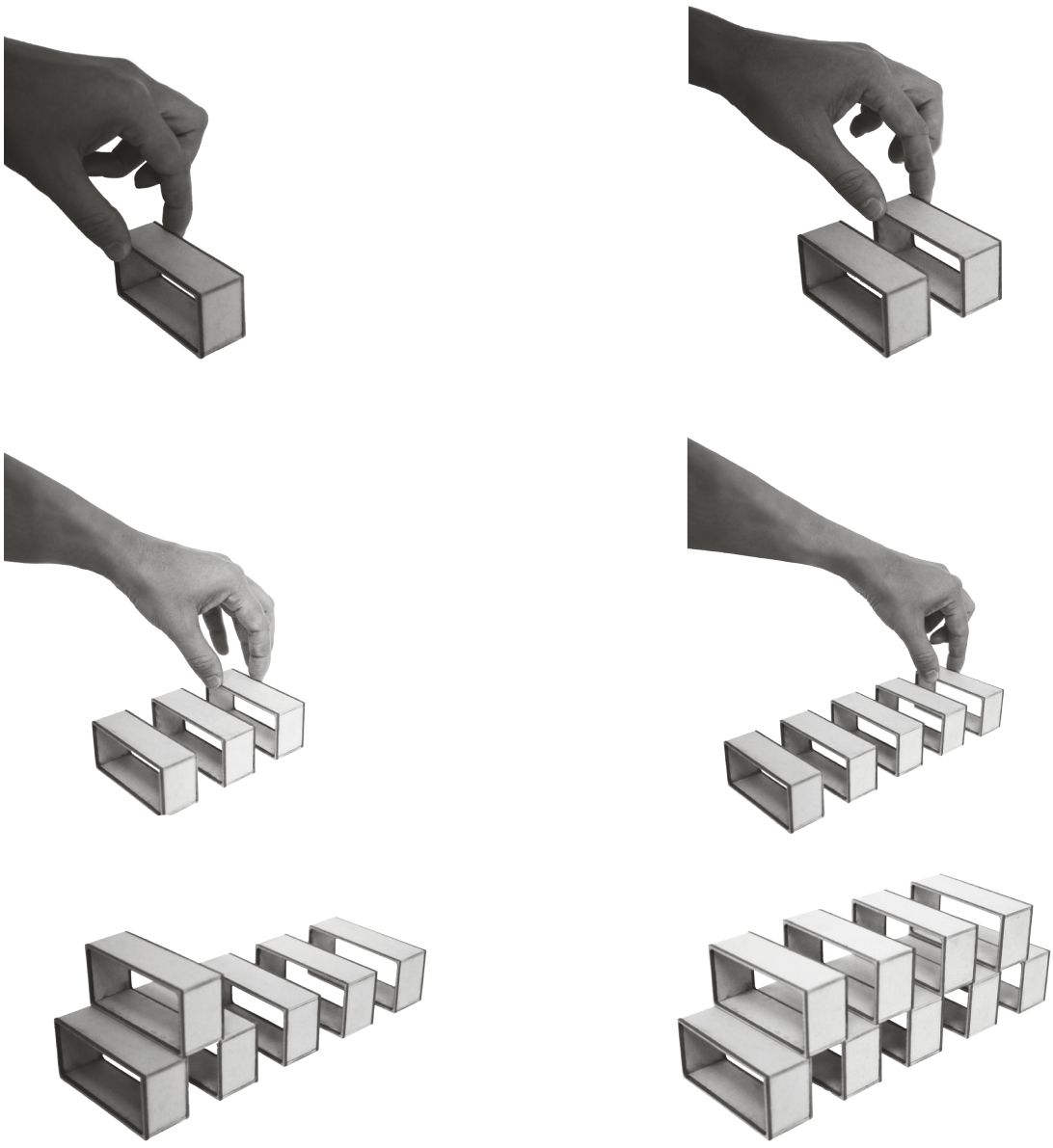
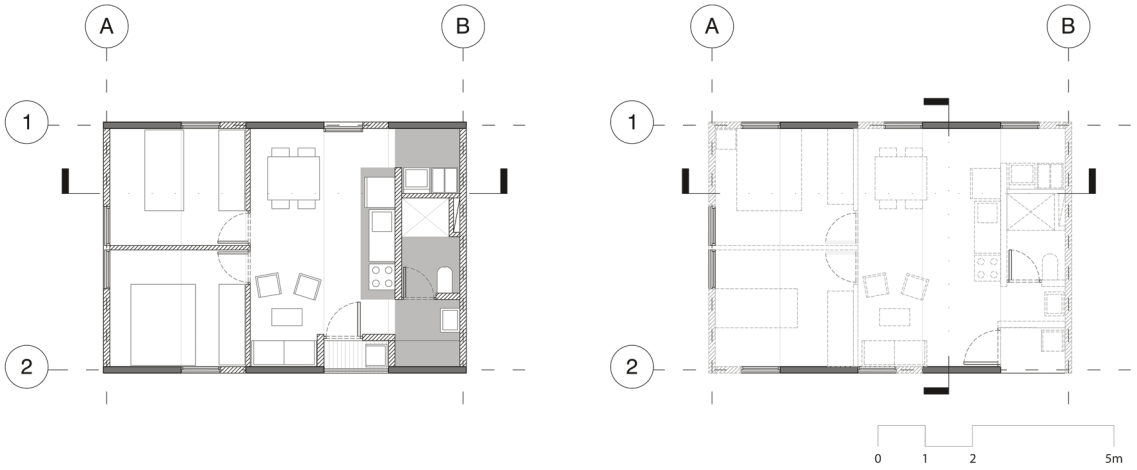
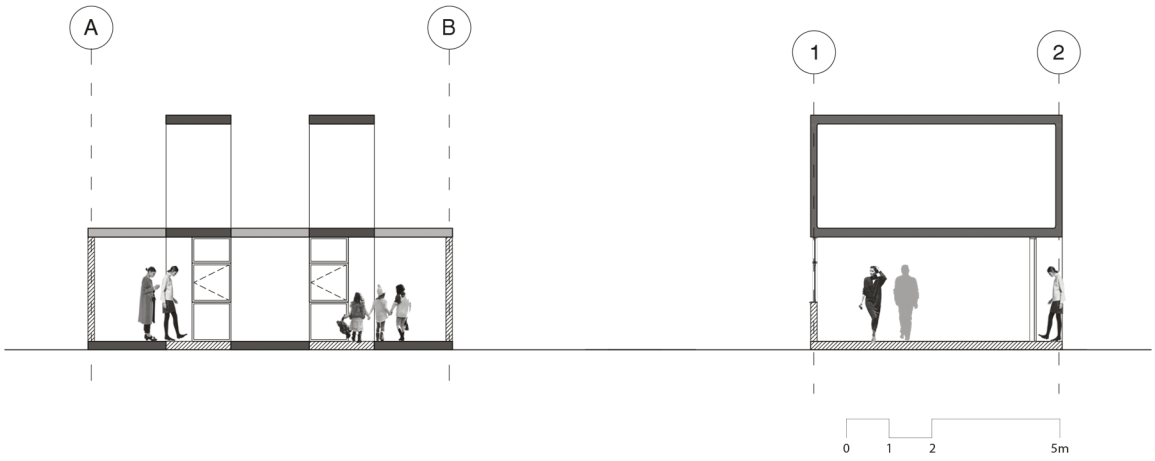


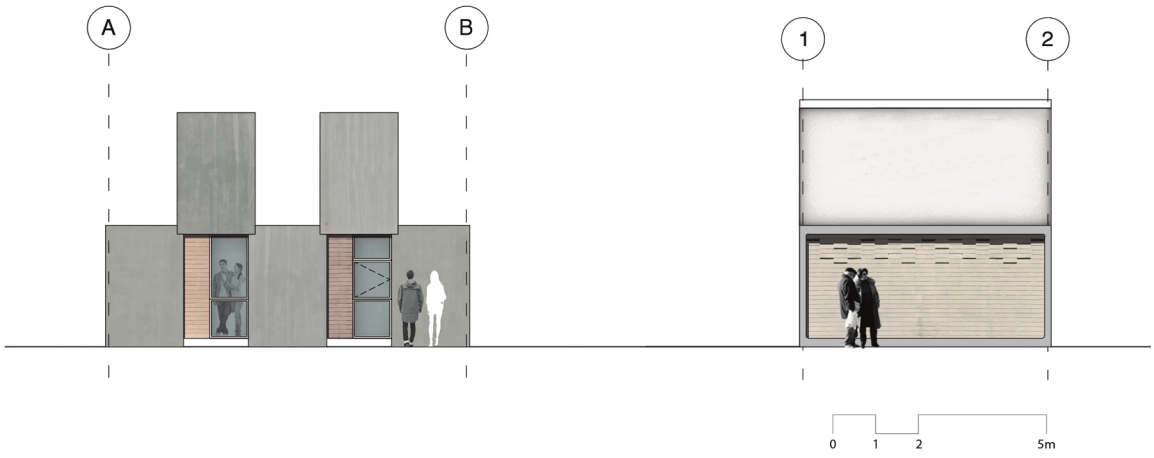
Figure 50
Prototype B. Grouping system model.



Graphic 284
Architectural floor plans: ground level and upper level



Graphic 285
Sections



Graphic 286
Façades

8.4.3. Formwork

An expandable metal formwork was designed to receive the concrete castings of the structural frameworks. The design was done with Engineer Antonio José Cano in the city of Medellín, during December of 2014 and January of 2015. It was manufactured by *Industria Leguz,* in the municipality of Itagüí during February and March 2015. This formwork permitted the production of the precast-concrete frames with different dimensions. The thicknesses of the walls and slabs could reach up to 20cm per section. The front of the structural frames could have a dimension of up to 6.00m long; the depth could reach 2.60m and the height could be up to 2.80m.



Figure 51
The manufacturing process of the formwork was done in the Industria Leguz workshops; Itagüí, Antioquia, February and March 2015

8.4.4. Structural reinforcements

The specifications of the structural reinforcements are variable according to the height of the building and the load-bearing capacity of the terrain. In the construction of the prototypes, two bi-dimensional meshes were designed for each one of the components of the structural frame.

For the floor-type frames, which play the role of being the foundations of the building, the design of the structural reinforcements was done in the following manner:

- In the floor slab, at its bottom, a first bi-dimensional structural reinforcement mesh was designed, measuring 3/8" in diameter. At the top, a 1/2" bi-dimensional mesh was designed.
- In the roof slab, at its bottom, a first bi-dimensional structural reinforcement mesh was designed, measuring 1/2" in diameter. At the top, a 3/8" mesh was designed.
- For the walls of the structural frames, a double bi-dimensional mesh with 1/2"-diameter metallic reinforcements was installed.
- Each mesh was installed 2.5cm from the surface and a grid measuring 10cm x 10cm.

In the air frames, which are those that have no contact with the terrain, the only difference in the structural reinforcement regarding the floor-type frames is that the double structural mesh of the floor slab has a 1/2" grid of reinforcement rods at the bottom and a 3/8" grid at the top. The amount of reinforcement steel in the structural frames was 90 kilograms per cubic meter of concrete.



Figure 52
Assembly process of the reinforcement meshes for the structural frames. *Comité de Prefabricados de Antioquia.* April 2015.

8.4.5. Production of precast structural frames

The production of the structural frames was done in the municipality of Bello, Antioquia, by the *Comité de Prefabricados* of the Colombian Chamber of Construction (*Cámara Colombiana de la Construcción,* CAMACOL). It was coordinated by the Architectural Technical Experimentation and Studies Laboratory (*Laboratorio de Estudios y Experimentación Técnica en Arquitectura,* LEET) and by the Architectural and Urbanism Laboratory (*Laboratorio de Arquitectura y Urbanismo,* LAUR), at *Universidad Pontificia Bolivariana* (UPB) in Medellín. The design of the concrete mixture for the prefabrication of the frames obtained resistances of 14 MPa in the first eight hours after casting. At 28 days, the concrete mixture reached a resistance to compression of 54 MPa.

Components	kg/m³	Weight (%)	Price (%)
Type III Cement or similar	1200.00	50.00	87.50
Sand 0 - 5 mm	570.00	23.75	1.77
Coarse aggregate 5 - 10 mm	470.00	19.58	1.50
Additives	10.00	0.42	9.18
Dry fly ash	0.00	0.00	0.00
Water	150.00	6.25	0.05
Concrete totals	2400.00	100.00	100.00

Table 47
Design of the K-type mixture for the construction of precast concrete structural elements. Housing Construction Cost Index (ICCV), Colombia, February 2015. Prices provided by Proyectar architectural budget firm, located in Medellín, Colombia. Engineers Juan Carlos Gómez and Nathalie Rúa, December 2016. The design of the mixture was conducted with the advice of Engineer Cipriano Londoño, Medellín, Colombia. Manufacture of the specimens conducted in the *Comité de Prefabricados de Antioquia.* Evaluations of the mixture for compressive resistance conducted in the *Comité de Prefabricados de Antioquia.*

Two structural frames were manufactured each day. The production of the elements required five days for the castings and five additional days to wait for the increase in their structural resistance and to transport them to the place where the prototypes would be built.



Figure 53
Casting process of the structural frames

In the construction of the frames, it was necessary to specify some construction details for the processes of casting, demolding, manipulating the elements in the plant, transporting and installing them on site. The edges of the frames were designed with a one-centimeter bevel, to preserve their geometry and prevent pinching or deterioration in the transport and installation processes. On the surfaces of the walls, where the frames would be joined together, neoprene was installed to seal possible filtrations of water between the frames. Some cylindrical metal elements, located on the lateral walls of the frames, permitted being turned over 90° after the casting process of the elements at the plant, which was done with the frames in a horizontal position. To install the precast elements on site, on the upper slabs of the frames, a metallic connector was installed during the casting process, so that cranes could take them and install them. In the joint of the horizontal (plate) and vertical (wall) elements, a 5cm bevel had to be constructed to allow the passage of the metallic reinforcements in charge of the stiffening of the structural elements.

8.4.6. Transport

Two structural frames could be transported simultaneously in each trip from the production plant to the municipality of Marinilla. Four trips were needed, with a cargo vehicle measuring 12.20m in the length of its platform and one trip with a cargo vehicle measuring 6.00m in the length of its platform, to take the nine elements to the site. The weight registered from each structural frame was 14.6 tons. The average travel time was one hour and fifteen minutes (1' 15") in each transport.



Figure 54
The transport process of the structural frames from the production plant to the site of installation

8.4.7. Assembly

In the assembly of the precast-concrete structural frames, a crane with a capacity of 60 tons was used. For the first prototype, the installation time of the four structural frames that made it up was 75 minutes. On average, each frame was installed in a time of 18 minutes and 45 seconds. In the second prototype, the five elements were installed in a period of 80 minutes. The average installation time for each frame was 16 minutes. In the two prototypes, the façades, interior walls, windows, doors, electrical installations and sanitary equipment were installed in the following four days by a team of four operators.







Figure 55, Figure 56, Figure 57
Installation process of the structural frames in the two prototypes

8.4.8. Dwellings

8.4.8.1. Social Housing A. Linear industrialized frames

This first prototype used four self-bearing precast-concrete industrialized frames in the first story. In the interior space, the services were grouped on one side of the house, complementing the free plant that serves as the space for the social area and that was oriented toward the access façade. A central courtyard separated the social area from the bedrooms and permitted the natural illumination and ventilation of both spaces, generating average temperatures of 15°C during the day.[69] This area can be subsequently transformed by the inhabitants of the home, who can extend its social area or build a third bedroom, which would be illuminated from the courtyard.





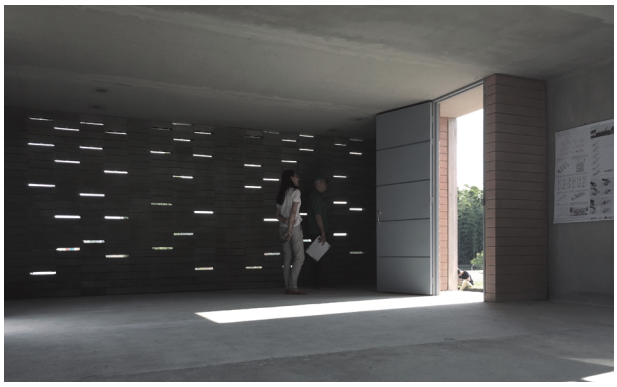


Figure 58, Figure 59, Figure 60
The prototype with linear structural frames and a central courtyard

8.4.8.2. Social Housing B. Transversal industrialized frames

The second prototype used five self-bearing precast-concrete industrialized frames in the two stories. The first floor was finished, but the interior walls were not constructed to leave the space enabled for exhibitions that were made on the system and for visitors to have more space to go through it; the second floor had the structure exposed to explain the installation of the system in height. Concrete-block non-structural walls and floor-to-ceiling windows served to complement the façades and conform the language of the building. In the interior, a free plant permitted appreciating the proportions of the interior space and the modifications that it could have from the architectural designs or from the transformation processes by the inhabitants of the houses. In this case, services were





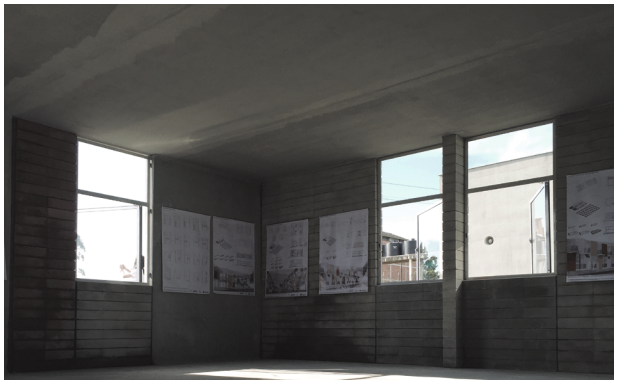


Figure 61, Figure 62, Figure 63
The two-story prototype with transversal structural frames

69 Measurement made by *PVG Arquitectos*. Alexánder González Castaño, Architect. May 2015, November 2015, May 2016

located on a concrete-block wall that left spaces for the filtration of air and light. On the other end, two bedrooms were located, and between these spaces there was a social area that was naturally illuminated and ventilated by floor-to-ceiling windows toward the main façade and that then permitted having average temperatures of 15ºC in the interior space of the façade.[70] In this case, the area for interior growth was not conceived, which can be projected from the architectural designs by increasing one concrete self-bearing frame per dwelling.

8.5. Results

The construction of these prototypes gave the following results in quantitative and qualitative terms, compared to the systems that have been traditionally used for the construction of social housing in Antioquia.

8.5.1. In quantitative terms

8.5.1.1. Products

Two prototypes of housing were built. One had one floor and the other, two floors, which left the support structure exposed on the upper floor.

8.5.1.1.1. Area for the Type A housing prototype

The constructed area of the typology of frames, arranged linearly with open façades, was 46.40 m²; with a courtyard area of 11.60 m², which can be used as an area for future growth.

8.5.1.1.2. Area for the Type B housing prototype

The constructed area of the typology of frames, arranged transversally with semi-open façades, was 48.72 m². These areas can be modified according to the dimensions of the self-bearing structural frames or with the number of the frames in the conformation of each dwelling, which defined dimensionally coordinated modular growths with all the elements that are part of the project.

8.5.1.2. Resources

According to the budgets made by the firm *Proyectar,* in 2015 and in 2016, with the data obtained from the construction of these prototypes,[71] the total costs were scales to a set of 10 houses on two floors and a five-story building with 25 dwellings. Each one considered the linear arrangement of the frames with open façades and the transversal arrangement with semi-open façades.

8.5.1.2.1. Costs and construction time for the two storey Type A housing prototype

In the linear system of open façades, in a two-story, 10-dwelling building, 20 precast-concrete structural frames were required, an average of two frames per dwelling.

The scaling of the total costs showed a 9% savings compared to the costs of VIP built with in-situ cast-concrete structures and concrete-block or brick masonry.

The installation time of the four structural frames, for the construction of the linear prototype of open façades, was 75 minutes, an average of 18 minutes and 45 seconds.

The electrical and hydrosanitary installations, façade walls, dividing walls, windows, doors and the kitchen and bathroom furnishings of this prototype were installed in four days by a group of four operators.

The time foreseen and calculated for the construction of a two-story, 10-dwelling project in the system of linear frames with open façades is four weeks, 25% of the time used for the construction of the same project with conventional systems.

8.5.1.2.2. Costs and construction time for the five storey Type A housing prototype

In a five-story, 25-dwelling building, 52 self-bearing concrete structural frames were required, an average of 2.08 frames per home.

The scaling of the total costs showed an 11% savings compared to the costs of cast concrete structures or built with structural masonry.

The installation time of the four structural frames, for the construction of the linear prototype of open façades, was 75 minutes, an average of 18 minutes and 45 seconds.

The electrical and hydrosanitary installations, façade walls, dividing walls, windows, doors and the kitchen and bathroom furnishings of this prototype were installed in four days by a group of four operators.

The time foreseen and calculated for the construction of a two-story, 10-dwelling project in the system of linear frames with open façades is four weeks, 25% of the time used for the construction of the same project with conventional systems. In a five-story, 25-dwelling building with the system of self-bearing structural frames with open façades, the construction time would be eight weeks, 20% of the time conventionally used for the construction of buildings with the systems used in the local context.

8.5.1.2.3. Costs and construction time for the two storey Type B housing prototype

In the transversal grouping of structural frames, that left the facades semi-open in a two storey, 10-dwelling building, 25 frames are needed, an average of 2.5 units per dwelling. The total costs showed an 8% savings compared to the costs of *VIP* built with *in-situ* cast-concrete structures and concrete-block or brick masonry. The installation time of the five structural frames, for the construction of the two prototypes with transversal frames and semi-open facades, was 80 minutes, an average of 16 minutes each. The electrical and hydro sanitary installations, facade walls, interior walls and windows of this prototype were installed in four days by a group of four operators. The time foreseen and calculated for the construction of this two storey, 10-dwelling project, in the system of linear frames with open facades, is four weeks, 25% of the time used for the construction of the same project with conventional systems.

70 Measurement made by *PVG Arquitectos*. Alexánder González Castaño, Architect. May 2015, November 2015, May 2016

71 Budgets made by the firm Proyectar, by Engineer Juan Carlos Gómez Ángel in the city of Medellín. The initial calculations were made in February 2015. In May 2015, the budgets were adjusted, once the construction of the prototypes was completed. In December 2016, cost and time calculations were carried out again, with updated prices.

Indicators	Traditional System		Longitudinal Frames		Transversal Frames	
Heights (in stories)	2	5	2	5	2	5
Dwellings	10	25	10	25	10	25
Constructed area	45.00	45.00	45.20	45.20	47.85	47.85
Interior area	42.00	42.00	42.90	42.90	44.53	44.53
Costs (on SMMLV)	60.00	57.00	54.60	50.73	55.20	54.00
Time (in weeks)	16.00	40.00	4.00	8.00	4.00	8.00

Table 48
Comparison of costs and time in the construction of the dwellings' typologies.

8.5.1.2.4. Costs and construction time for the five storey Type B housing prototype

In a five-story, 25-dwelling building with frames arranged transversally on semi-open façades, 63 units were required, an average of 2.52 frames per home. The total costs showed a 10% savings compared to the costs of cast-concrete structures or built with structural masonry. The installation time of the five structural frames, for the construction of the two prototypes with transversal frames and semi-open façades, was 80 minutes, an average of 16 minutes each. The electrical and hydrosanitary installations, façade walls, interior walls and windows of this prototype were installed in four days by a group of four operators. The time foreseen and calculated for the construction of this two-story, 10-dwelling project in the system of linear frames with open façades is four weeks, 25% of the time used for the construction of the same project with conventional systems. For a five-story, 25-dwelling building with the system of self-bearing structural frames with open façades, the construction time would be eight weeks, 20% of the time conventionally used in the construction of housing buildings in concrete castings and masonry.

8.5.2. In qualitative terms

8.5.2.1. Objective criteria

8.5.2.1.1. Modularity

A single type of structural frame was used for the construction of each prototype, which permitted its industrialized production with a single mold or formwork. In the linear grouping of frames with open façades, a module measuring 5.80m in front, 2.00m deep and 2.70m high was used. In the transversal grouping, the frames had dimensions equal to 1.80m on the side, 5.80m deep and 2.70m high. The non-structural elements – such as concrete blocks and windows – that were part of the system were dimensionally coordinated with the precast concrete frames to reduce waste, cuts and reprocesses on site.

8.5.2.1.2. Replicability

With the same geometry and with dimensions corresponding to the same structural modules, the frames were replicated industrially; the quality of their finishes and the surfaces in concrete were controlled and were the elements that defined the spatial order in the architectural project to configure two different typologies of housing. The technical quality of the structural elements was controlled in the production plants.

8.5.2.1.3. Transportability

The transport of the structural elements conditioned its size and weight. Thus, it was necessary to carry out an evaluation of the characteristics of the roads to determine the feasibility of each project. A frame-production system, with mobile plants in the lots where projects are built, is an option that should be considered when transport is not possible. In this case, two frames were transported in each trip, with the dimensions and maximum weights established in regulations, which allowed the structural elements to arrive at the urban lots, which must have adequate conditions to unload the elements and for the entrance of the assembly equipment.

8.5.2.1.4. Adaptability

The frames were located in a previously leveled, improved lot with a depth of 60cm, where a replacement was made with coarse and fine materials, with a 98% confinement proctor, according to the structural designs and soil studies. As for the adaptability of the technology to the conditions of the regional context, the industrialized processes that used skilled labor were combined with conventional labor for the construction with non-structural elements. Therefore, conventional labor processes can be adapted to the industrialization and assembly processes.

8.5.2.1.5. Accessibility

The designs and proportions defined permitted accessibility to the urban space and the houses, and the circulation of people with different mobility capabilities.

8.5.2.2. Subjective criteria

8.5.2.2.1. Simplicity

The system of foundations uniformly distributes the loads and permits evaluating terrains that – through an improvement with stone materials – can be suitable to support buildings up to 10 stories tall. This condition permits using lots that have been rejected for the construction of housing buildings, due to their characteristics and those of the foundation systems of traditional systems. In the one- and two-story prototypes, the structural frames were joined by simple support. In the longitudinal structural frames with open façades, the horizontal union between the frames did not need an additional element and the connection was solved by the friction between the frames. Between the joints, neoprene sealants were used to ensure their tightness. In the transversal structural frames, assemblies were constructed to allow joining the lower elements without needing of additional elements to rigidize their union.

8.5.2.2.2. Flexibility

The rationality and precision of the industrialized frame is complemented with non-structural elements that have materials and forms that give the house different room options, and a language in accordance with the environmental, cultural, social and economic context. The location of the structural elements, in the perimeters of the living space, generates free plants, which allows considering different typological variations according to the needs of each family group. The architectural conditions of one and the other typology were selected from a series of already designed possibilities, which allowed using the free plants to generate the interior spaces with spatial and environmental quality.

8.5.2.2.3. Comfort

Average interior temperatures, measured in each one of the prototypes, were 15ºC. The non-structural elements, localized for the definition of the language of the prototypes, were arranged there as a possibility that permits considering different materials, textures, finishes and architectural configurations. In addition to solving technical and economic aspects, the construction of new housing should solve aspects related to the quality of life, well-being and social development.

8.5.2.2.4. Beauty

The interior free plants are constructed with non-structural elements, according to the environmental, cultural, social and economic characteristics of the setting. The condition of beauty is associated with the recognition of the context and its conditions. Architecture is a technical and social response that aims to improve the quality of life of its inhabitants.

8.5.2.2.5. Transformability

The interior free plants were constructed with non-structural elements that can be modified according to the needs and habits of the families. In the one-story prototype, with linear frames and open façades, an interior courtyard permits the controlled growth of the housing. In housing with other typologies, the location of the structural elements and the modification of interior spaces will permit usage according to the living conditions of each family.

Through efficient processes, with a reasonable management of available resources, partial industrialization of the dwelling in precast-concrete reduces the housing deficit, decreases construction time and costs with high quality technical and spatial solutions that combine industrial processes with activities developed by traditional labor.

In conclusion, it is possible to state that, observing appropriate restrictions, the industrialization of social housing with precast-concrete elements is a feasible alternative to reduce the housing deficit in Colombia and the Department of Antioquia.



Figure 64
The prototypes constructed, in the alternate campus of Universidad Pontificia Bolivariana. Marinilla, Antioquia.



Summary

Industrialized, individualized and transformable social housing

The construction of housing prototypes in precast concrete on a natural scale provided the following results in quantitative and qualitative terms, compared to the systems that have traditionally been used for the construction of social housing in Antioquia.

In quantitative terms

Products

Two housing prototypes were built. One was one-story tall with a system of linear frames (Housing Type A). The other was two-stories tall and had transversal frames (Housing Type B), which exposed the support structure on the upper floor.

Housing Type A: The constructed area of this typology, with open façades, was 46.40 m², with a patio area of 11.60 m²; which can be used as an area of future growth.

Housing Type B: The constructed area of this, with semi-open façades, was 48.72 m². These areas can be modified according to the dimensions of the structural frames or with their quantity in the conformation of each dwelling, which defines a modular growth that is dimensionally coordinated with all the elements that are part of the project.

Resources

According to estimates made by the firm *Proyectar,* with the data obtained from the construction of these prototypes, the total costs were scaled to a set of 10 dwellings on two floors, and to a building with 25 dwellings on five floors. Each of them considered the linear arrangement of frames with open façades and the transversal arrangement with semi-open façades.

Construction costs and time of the two-story Housing Type A:

In the linear system of open façades, in a two-story, 10-dwelling building, 20 structural frames in precast concrete are required; an average of two frames per dwelling. The scaling of the total costs showed 9% in savings in relation to the Priority Social Interest Housing (VIP) constructed with in-situ cast concrete structures and in concrete block or brick masonry. The installation time of the four structural frames for the construction of the open-façade linear prototype was 75 minutes, an average of 18 minutes and 45 seconds per frame. The electrical and hydrosanitary installations, façade walls, dividing walls, windows, doors and the kitchen and bathroom furnishings of this prototype were installed in four days by a group of four operators. The foreseen, calculated time for the construction of a ten-dwelling, two-story project in the system of open-façade with linear frames is four weeks, 25% of the time used for the construction of the same project with conventional systems.

Construction costs and time of the five-story Housing Type A:

In a five-story, 25-dwelling building, 52 concrete load-bearing structural frames are required, an average of 2.08 frames per dwelling. The scaling of the total costs indicated that the total costs are reduced by up to 11%, compared to the costs of structures cast in concrete or constructed with structural masonry. In a five-story, 25-dwelling building with load-bearing, open-façade structural frames, the construction time would be eight weeks; 20% of the time used for the construction of buildings with traditionally used systems in the local context.

Construction costs and time of the two-story Housing Type B:

In the transversal grouping of structural frames that leave semi-open façades in a two-story, 10-dwelling building, 25 frames are needed; an average of 2.5 units per dwelling. The total costs showed an 8% in savings in relation to the Priority Social-Interest Housing (VIP) constructed with in-situ cast concrete structures and in concrete block or brick masonry. The installation time of the five structural frames, for the construction of two prototypes, was 80 minutes, an average of 16 minutes each. The electrical and hydrosanitary installations, façade walls, interior walls and the windows of this prototype were installed in four days by a group of four operators. The foreseen, calculated time for the construction of this ten-dwelling, two-story project is also four weeks, 25% of the time used for the construction of the same project with conventional systems.

Construction costs and time of the five-story Housing Type B:

In a five-story, 25-dwelling building with transversally arranged frames, 63 units were required; an average of 2.52 units per dwelling. The total costs are reduced by up to 10% compared to the costs of structures cast in concrete or constructed with structural masonry. For a five-story, 25-dwelling building, the construction time would be eight weeks, 20% of the time used in the construction of housing buildings in cast concrete and masonry. Table 49 shows the comparison of costs and time among the traditional-construction systems and longitudinal- and transversal-frame systems.

In qualitative terms

Objective Criteria

Modularity

A single type of structural frame was used for the construction of each prototype, which allowed producing it industrially with a single mold. In the linear grouping of frames with open façades, a module measuring 5.80m long, 2.00m deep and 2.70m high was used. In the transversal grouping, the frames used had equal dimensions of 1.80m long, 5.80m deep and 2.70m high. The non-structural elements that were part of the system, such as walls in concrete blocks and windows, were dimensionally coordinated with the precast concrete frames to reduce waste, cuts and reprocessing on site.

Replicability

With the same geometry and with dimensions corresponding to the same structural modules, the frames were replicated industrially; the quality of their finishes and surfaces in concrete were controlled, and it was the elements that defined the order of the living space in the architectural project to configure two typologies of housing.

Indicators	Traditional System		Longitudinal Frames		Transversal Frames	
Heights (in stories)	2	5	2	5	2	5
Constructed area	45.00	45.00	45.20	45.20	47.85	47.85
Interior area	42.00	42.00	42.90	42.90	44.53	44.53
Costs (in SMMLV)	60.00	57.00	54.60	50.73	55.20	54.00
Time (in weeks)	16.00	40.00	4.00	8.00	4.00	8.00

Table 49
Comparison of costs in the construction of the prototypes

Transportability

Two frames were transported in each trip to the municipality of Marinilla, located 45km from Medellín. The conditions that had to be met conditioned their sizes and weights, in accordance with the regulations of the Ministry of Transport. Therefore, it was necessary to conduct an evaluation of the characteristics of existing roads, to determine the feasibility of the construction of prototypes on this lot, which was adapted for the unloading of the elements and the entrance of the assembly equipment.

Adaptability

The lot where the prototypes were installed was leveled and improved beforehand. At a depth of 60cm, the natural terrain was replaced with coarse and fine materials, raising the confinement proctor by up to 98%, according to the soil studies and structural designs. The production and assembly processes of the precast structural frames were combined with conventional labor for the construction of the non-structural elements (interior walls and façades).

Accessibility

The proportions of the designs allow accessibility to the urban space and the dwellings, and the circulation of people with different mobility capabilities.

Subjective Criteria

Simplicity

In the one and two-story prototypes, the structural frames are supported directly on the terrain. In height, they are joined by simple supports. The homogeneous transmission of the loads onto the terrain means that each structural element weighs, on average, one ton per square meter (the load-bearing structures or framed systems conventionally weigh between 5 to 10 tons per square meter), which enables land that was originally dismissed for social-housing projects. All the joints among the walls and slabs were made at industrial plants. In the longitudinal, open-façade frames, the joints among the elements did not need an additional element and the connection was solved by friction among the frames.

Among the joints of the frames on the same level, neoprene sealants were used to guarantee the tightness among them and the impermeability of interior spaces. In transversal structural frames, geometry assemblies were constructed, which permitted joining the lower elements without the need for additional elements to stiffen their joint.

Flexibility

The architectural conditions of the two typologies were selected from a series of already designed possibilities, which allowed taking advantage of the free floors to generate interior spaces with spatial and environmental quality. The industrialized structure is complemented with non-structural elements that give the dwelling different room options, and a language in accordance with the environmental, cultural, social and economic context. The location of the structural elements in the perimeter of the living space (walls between dwellings and slabs) generates free floors, which permits considering different typologies according to the needs of each family group.

Comfort

The average indoor temperature, measured in each of the prototypes, was 15ºC. The non-structural elements in interior spaces, and on façades, defined the language of the typologies and were specified as one of the multiple possibilities that the system allows regarding materials, textures, finishes and architectural configurations.

Aesthetics

The interior free floors were constructed with non-structural elements that can be modified according to the needs and habits of the families. The condition of beauty is associated with the recognition of the context and the desires of their inhabitants. Aluminum windows and concrete blocks with different colors were used as the language of the housing typologies, which can be modified according to the geographic context, climate, and designs with the communities or with the availability of materials at each site.

Transformability

In the prototype of Housing Type A (one-story), a patio permits the controlled growth of the housing within the living space. The interior walls are non-structural elements that can be modified in the process of occupying the dwelling. In the prototype of Housing Type B (two-stories), the interior space is a free floor that can be sub-divided according to the conditions, in order to take advantage of the space desired by each family. On the second floor, the support structure that is left exposed allows the construction of interior divisions and façades with non-structural elements, using traditional constructive systems that are adapted to the needs and changes during the occupation process.

With a reasonable management of available resources, concrete prefabrication of the housing structure reduces the housing deficit, decreases construction time and costs with solutions that control technical and spatial quality, and combine industrial processes with activities developed by the traditional labor force.



Perspectives

Two industrial developments are proposed as future projects based on the results of this research.

The first is to increase the efficiency of the precast concrete structural frames by reducing the weights and costs of the elements, generating open U-shaped frames. These frames can be located on the top level to receive the structure of the roof or be installed from the first to the upper floors, which would generate double heights and different spatialities in the dwellings, reducing the amounts of originally specified material and weights.

The second is the development of a modular structural system of self-bearing frames, industrialized with metallic structures and masonry blocks, with the same formal and grouping principles, to build social housing in urban and rural environments with difficult accessibility. These frames function as the support structure of the masonry pieces, which are fitted between the metal profiles to form floors and walls. In this case, the presence of specialized equipment or tools is not necessary in the assembly and mounting processes, since each piece that makes up the system can be installed independently. If each complete frame is to be installed, a crane similar to the one used in the assembly process of the precast-concrete structural frames is necessary.

9.1. Open U-shaped structural frames in precast concrete

This development consists of the industrialization of open structural frames, formed by two load-bearing walls joined to a slab in the lower part, also prefabricated in concrete. The structural precast walls that make up the frame must be rigidized with one or two metallic beams, located in the center or on the ends, for each frame. In the linear configuration of open-façade frames, the same metallic mooring beam between two frames could rigidize the union between them and eliminate the flexion of the wall in its upper part.

9.1.1. In quantitative terms

Eliminating one of the two slabs that configure the U-frame allows the reduction of 35.4% of the volume and weight of a standard closed frame. This condition allows the construction of a greater number of houses if budgets are maintained. It also reduces costs and production and assembly time for the same number of dwellings. According to the structural calculations made, the inner reinforcement steel and the mooring beams between the walls of the frames would increase their weight by about 10%, in accordance to the original amount used in closed frames.

The system preserves the urban and architectural characteristics, and increases efficiency in the transport. By eliminating the upper slab, a total of four frames – measuring up to 6.00m long, 2.60m wide and 2.70m in height – can be transported simultaneously, complying with the maximum dimensions and weights allowed. The structural characteristics are modified by reducing the weight and volume of concrete and by increasing the weight of the metallic elements that serve as structural reinforcement, which could reduce the costs of the system by an additional 7% in residential buildings of one or several stories high.[72]

9.1.2. In qualitative terms

For the development of this precast-concrete open-frame system, the objective and subjective criteria defined in the original system are maintained, defined thus:

9.1.2.1 Objective criteria

The *modularity* and *replicability* of the system maintain the dimensional coordination in the design, the production and the installation of the structural frames.

Efficiency is increased in the *transportability* compared to that of closed frames because the geometry and weight of the open frames allow grouping up to four units in each trip.

The criteria of *adaptability* to different contexts are maintained. The weights of the structural elements are reduced by approximately one third, which permits considering soils with other mechanical characteristics. On site, it is necessary to adapt the topographic profiles to the dimensions of the structural frames.

The criteria of *accessibility* defined for the closed-frame system are maintained, with roads that permit the transport of these elements to the work site. In places with difficult accessibility, the installation of field factories is proposed for the on-site production of the structural frames.

9.1.2.2. Subjective criteria

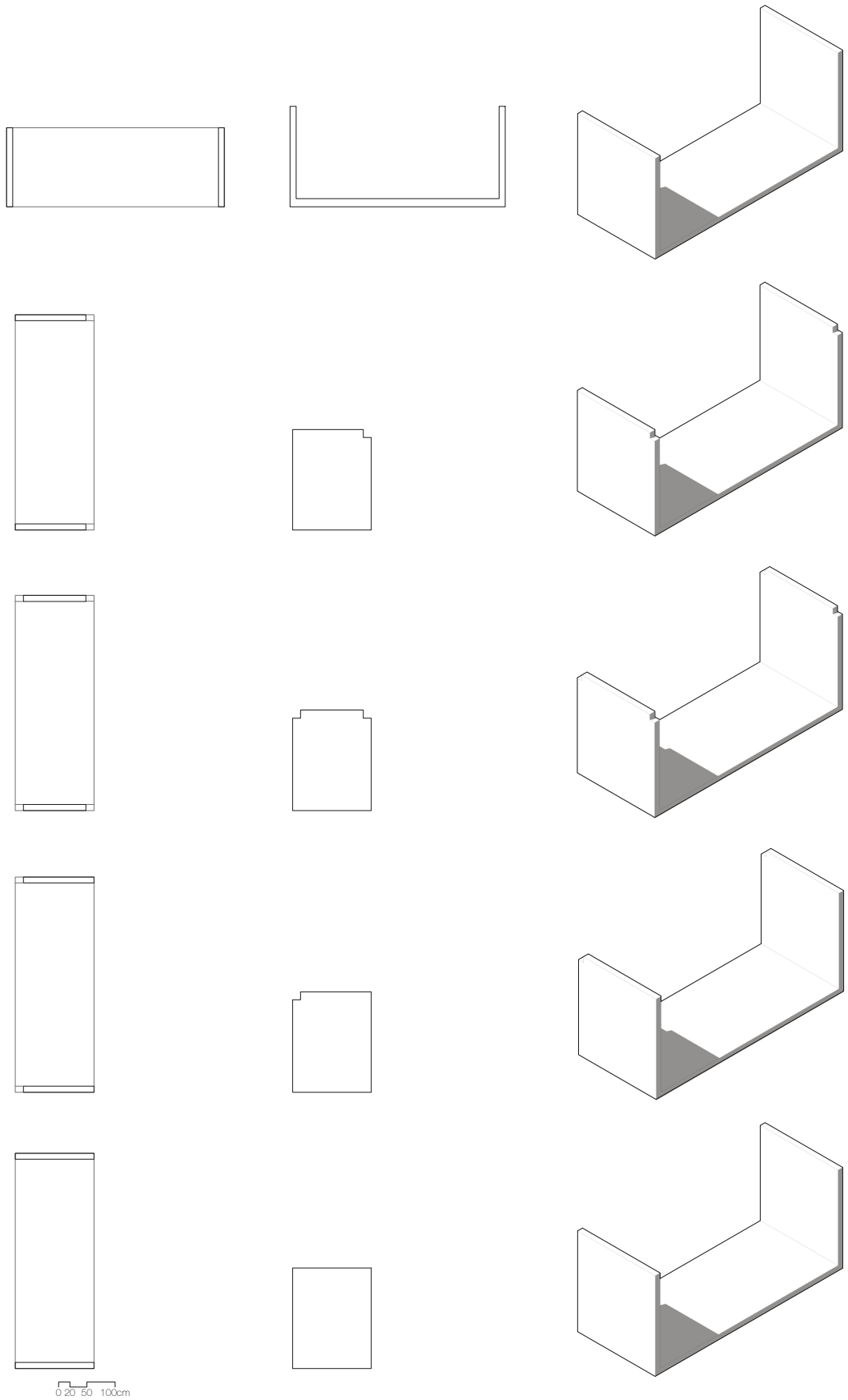
The *simplicity* of the system is given by the number of structural elements that make it up. For a building with linear frames, only one type of element is necessary, which is replicated to form the grouping designed. For a building with transversal frames, it is necessary to use four types of elements: two corner frames (with recesses on one of its sides), a central frame (with recesses on both sides) and a top frame (without recesses on the sides) that receives the roof.

Flexibility increases with respect the original concept, due to the fact that the arrangement of the open or "U" structural frames permits conforming interior spaces at double height. This condition increases the number of housing typologies and the possibilities of using the interior space.

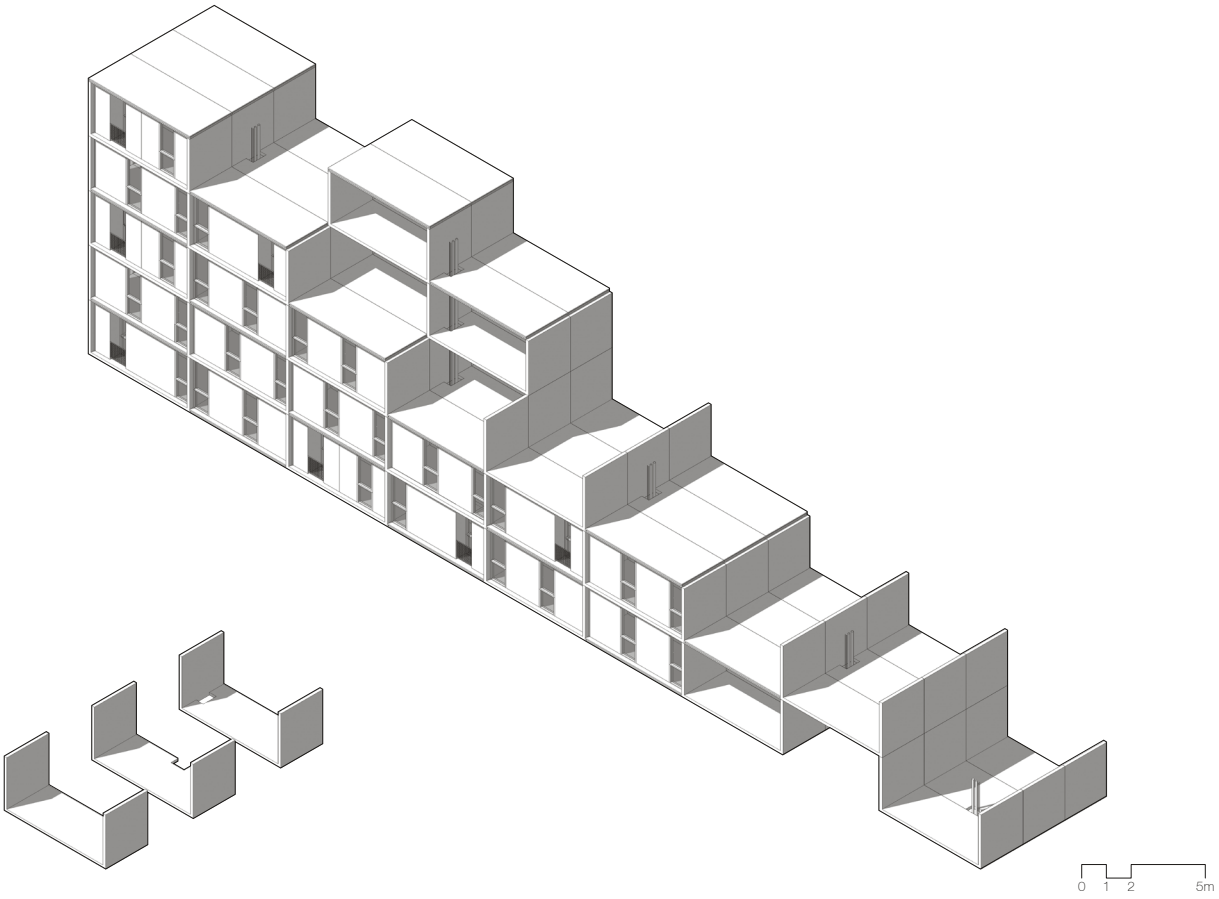
The conditions of comfort of the interior space are maintained in the typical floors. On the top floor, it is necessary to install a complete roof on the open frames, which improves the conditions of temperature of the interior space according to the designs and the technical specifications of the roof.

The conditions of habitability from the use of open or "U" frames permit generating new *aesthetics* using double heights in interior spaces, which increases the possibility of language in the façades of the buildings.

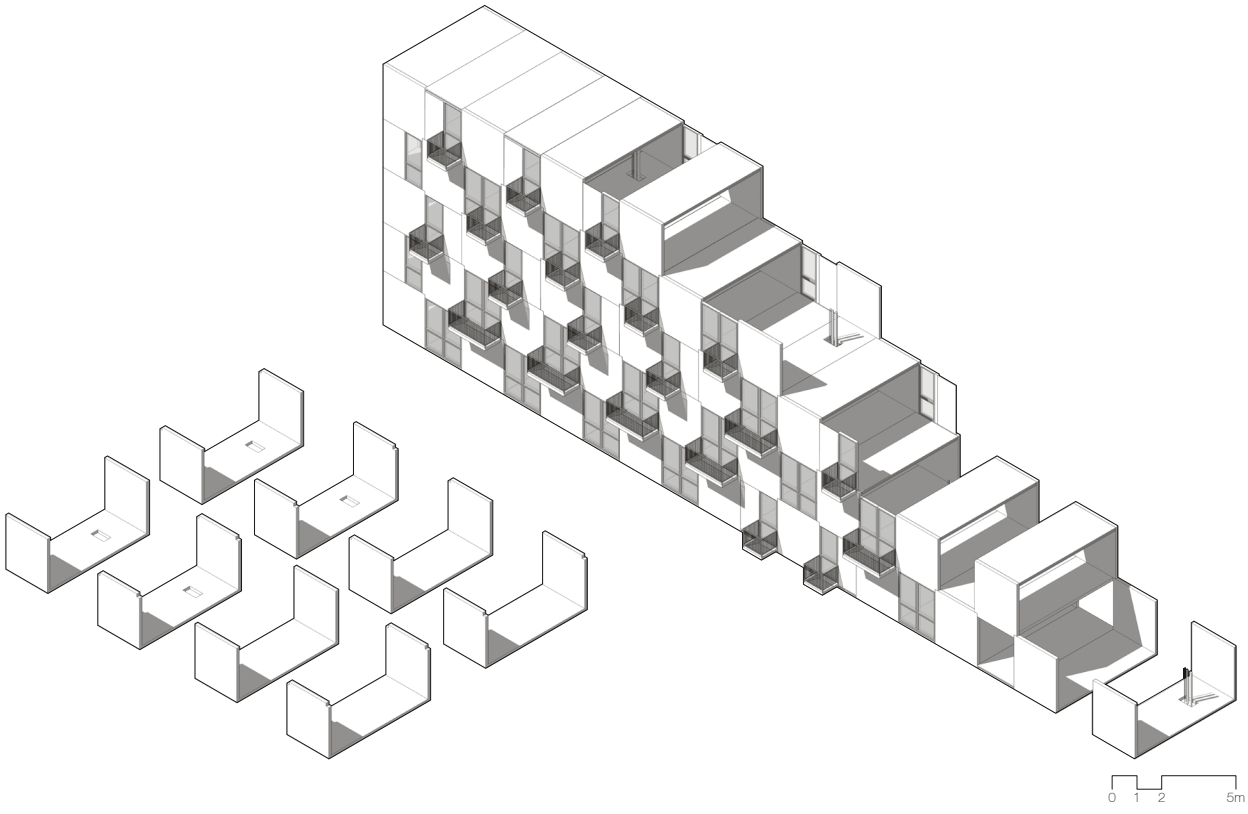
72 Budgets made by the firm Proyectar, by Engineer Juan Carlos Gómez Ángel in the city of Medellín. The initial calculations were made in February 2015. In May 2015, the budgets were adjusted, once the construction of the prototypes was completed. In December 2016, cost and time calculations were carried out again, with updated prices.



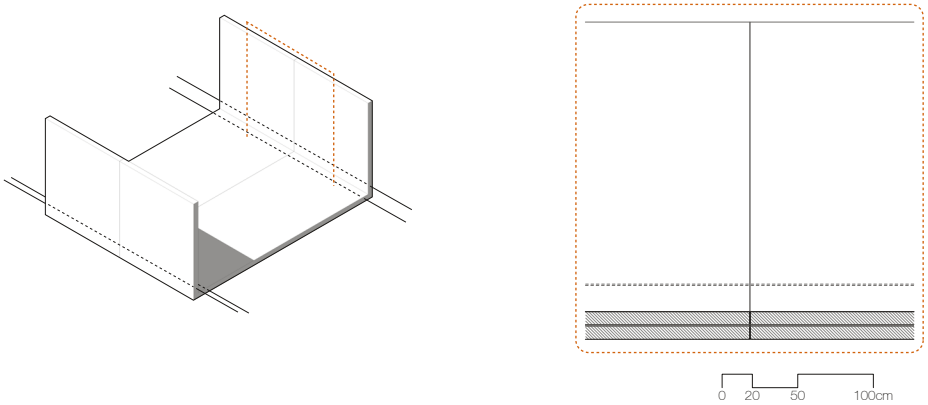
Graphic 287
Components: floor plans, façade and axonometry



Graphic 288
Constructive process with linear and open "U"-shaped precast-concrete structural frames



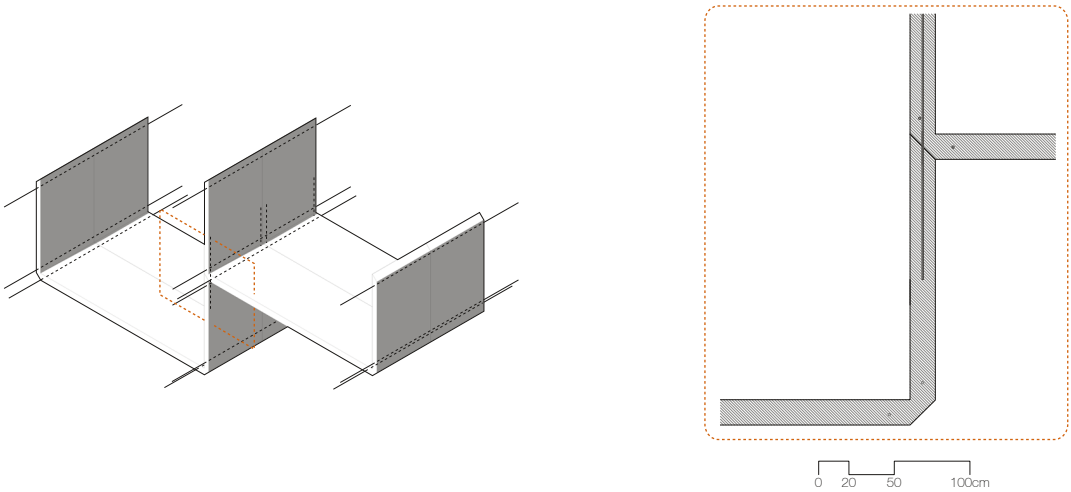
Graphic 289
Constructive process with transversal and open "U"-shaped precast-concrete structural frames



Graphic 290
Constructive details



Graphic 291
Constructive process: installation of prefabricated structural elements



Graphic 292
Constructive details



Graphic 293
Constructive process: installation of non-structural elements (interior walls and façades)



Graphic 294 The technical system, the architectural language and the public space



The *transformability* of the living space increases compared to the system of closed structural frames. In this modality, the housing units can have double or single heights. This implies that in the interior space, typologies can be developed and modified over time according to the preferences of each family, the number of members and their living conditions.

9.2. Structural framework with metal profiles and masonry

The transport, adaptability, accessibility, simplicity, aesthetics and transformation of the system can be adapted to specific social housing projects for rural and urban environments with difficult accessibility. The dimensions of the precast-concrete industrialized frames make not all settings suitable for the construction of a project with these dimensions and characteristics for their assembly.

9.2.1. In quantitative terms

With this system of frames, which combines metallic profiles and masonry in concrete blocks or ceramic brick, the number of houses and the areas required for rural settings could be maintained or increased, while reducing costs construction time and ensuring the feasibility of the system in rural areas, where nearly 50% of the country's housing deficit is located (DANE, n. d.).

9.2.2. In qualitative terms

For this system, objective and subjective criteria for structural, urban and architectural designs, are defined.

9.2.2.1. Objective criteria

The criteria of *modularity* and *replicability* are maintained, since the industrial, standardized production of the frames is made with criteria of dimensional coordination between the metallic profiles and the masonry elements that configure the system.

Transportability increases efficiency, since the metallic profiles and masonry elements can reach the construction site in different means of transport used in urban or rural areas with difficult accessibility.

Adaptability to different types of contexts permits the installation of metallic structural elements and uses the masonry available in the area. The metallic profiles and masonry can then be assembled on site without the need for specialized personnel. For the fixation of the elements to the terrain, the same procedure used in precast-concrete frames, through which the confinement proctor is improved according to the one proposed by the study of the ground, is specified and each one of the frames distributes its load to the terrain. In flat or sloped topographies, the configuration of the building can be adapted to different contexts, since no specialized equipment or labor is needed for installation.

The *accessibility* is proposed through the condition of the roads that communicate the lot with its surroundings, from the designs of collective spaces without stairs and without barriers for displacement, and from the proportion of the interior spaces of the homes.

9.2.2.2. Subjective criteria

The *simplicity* of the system is given by the number of elements that make it up and by the unions between them. The main structure is formed by metallic, 15 x 15 square centimeter sections for columns and beams, with calibers defined according to the structural design. These elements are joined by screws, without the need for welding equipment or specialized techniques. A set of 1"-diameter metallic rods are attached to the bolted or welded lower side beams, with factory-made perforations. The separation between these rods is proportional to the cells of the masonry elements, which are fixed one on top of the other through a concrete casting – known as grouting – inside the cells, which stiffens the joint. The lateral walls end up being confined with the installation of the upper beams. The floor of each frame is formed by 2" x 2" inverted T-section metallic profiles, which receive the masonry elements that form the mezzanine slab, and are subsequently rigidized with metallic rods and a concrete casting. The union between the metallic frames is also made with bolts, with the same grouping systems proposed for the linear and transversal open and semi-open façades.

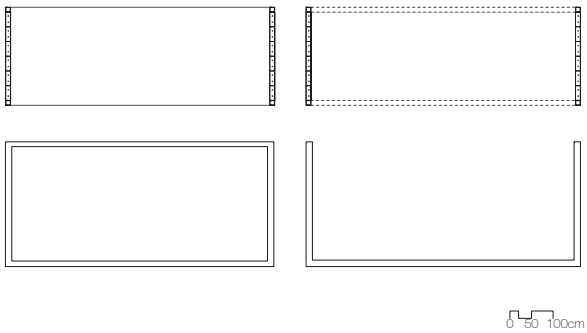
By being conceived with the same geometries and proportions, the system's *flexibility* is maintained, since the structural elements are located in the perimeter of the frames; the interior spaces maintain their free floors to propose different architectural designs or the most suitable forms of occupation to the environmental, cultural and social context.

Through its structural configuration, the opening systems of the frames, their orientation and materiality define the criteria for the *comfort* of interior space. These frames can have open and semi-open façades, which permit controlling solar incursion and the natural ventilation in the interior of the space.

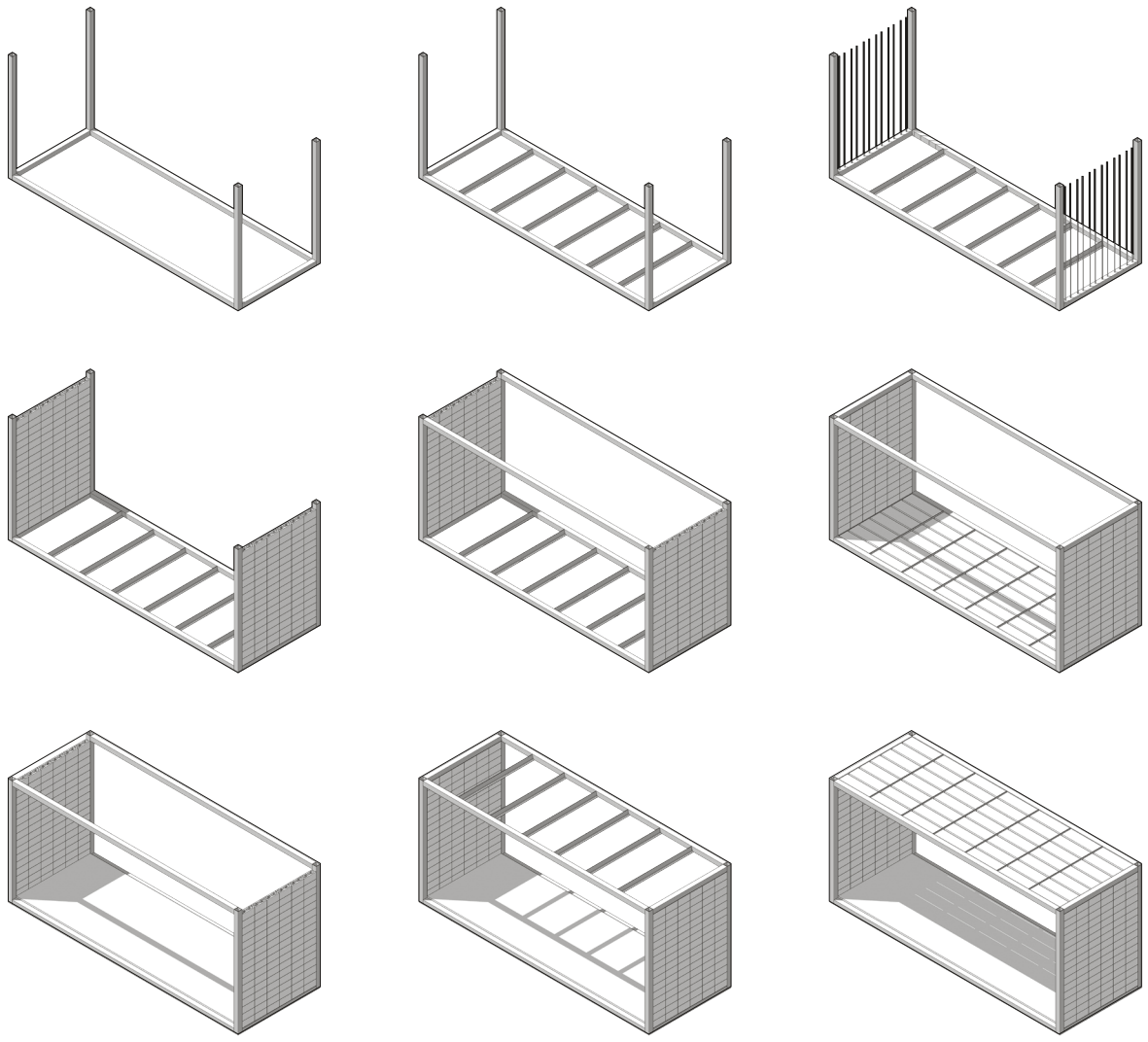
The placement of the non-structural elements permits the generation of different responses on the façade and in the interior space, according to the environmental conditions of the site and the *aesthetic* criteria in the composition of these buildings. The correct orientation of the buildings allows proposing criteria of well-being in the use of urban and interior spaces.

The *transformability* of the living space and the language of the project, as in the system of precast-concrete frames, are made once the users of the houses have occupied them. The modification of non-structural elements, the extension of the useful areas and the variation to the uses of the interior spaces can be made according to the configuration of the system's non-structural elements.

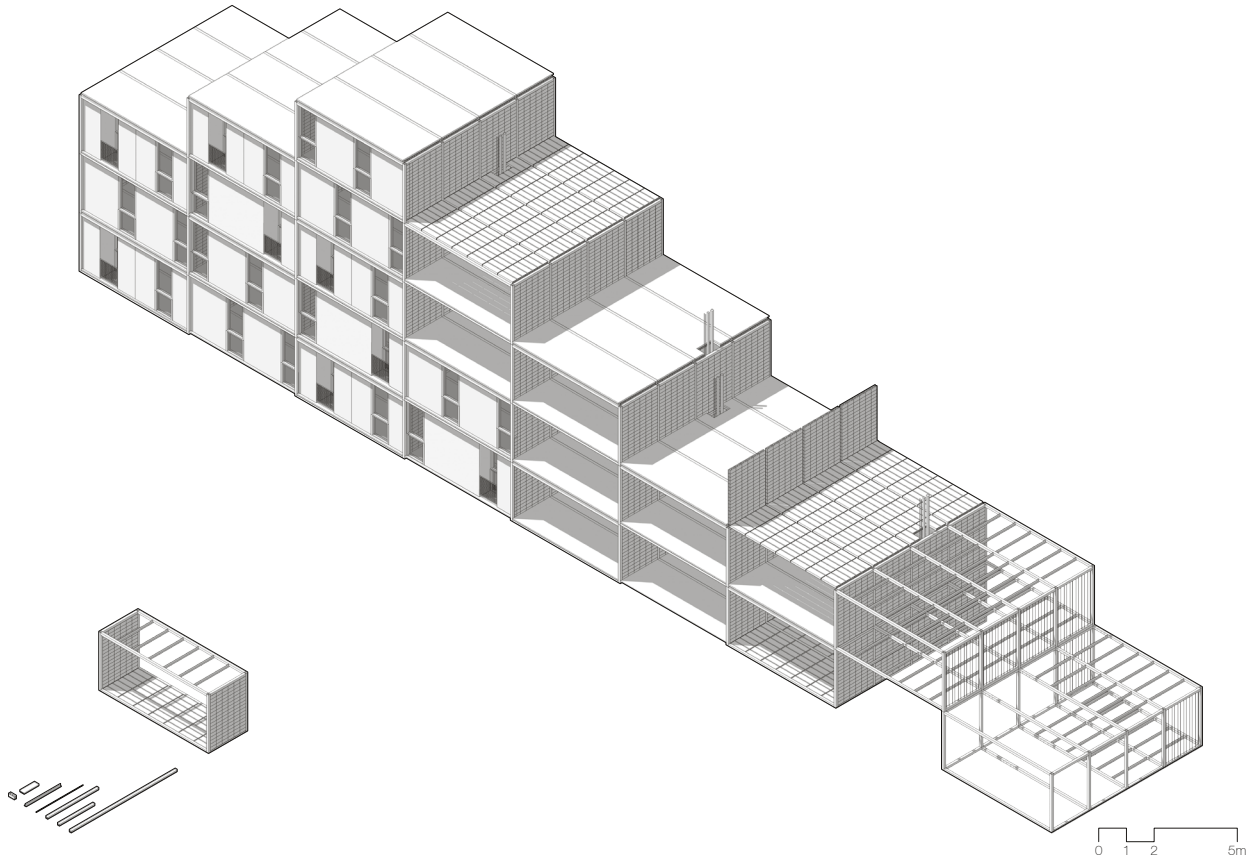
This proposal combines structural, spatial and language conditions that preserve the characteristics of the industrialized precast-concrete frames, allowing them to increase their adaptability to different contexts due to the proportions of the elements that make them up, the forms of installation and the tools necessary to join their components. Housing in rural settings, with a housing deficit as great as the deficit in urban settings, can be conceived from industrialized, modular and sustainable systems that permit the simultaneous use of traditional and industrialized materials.



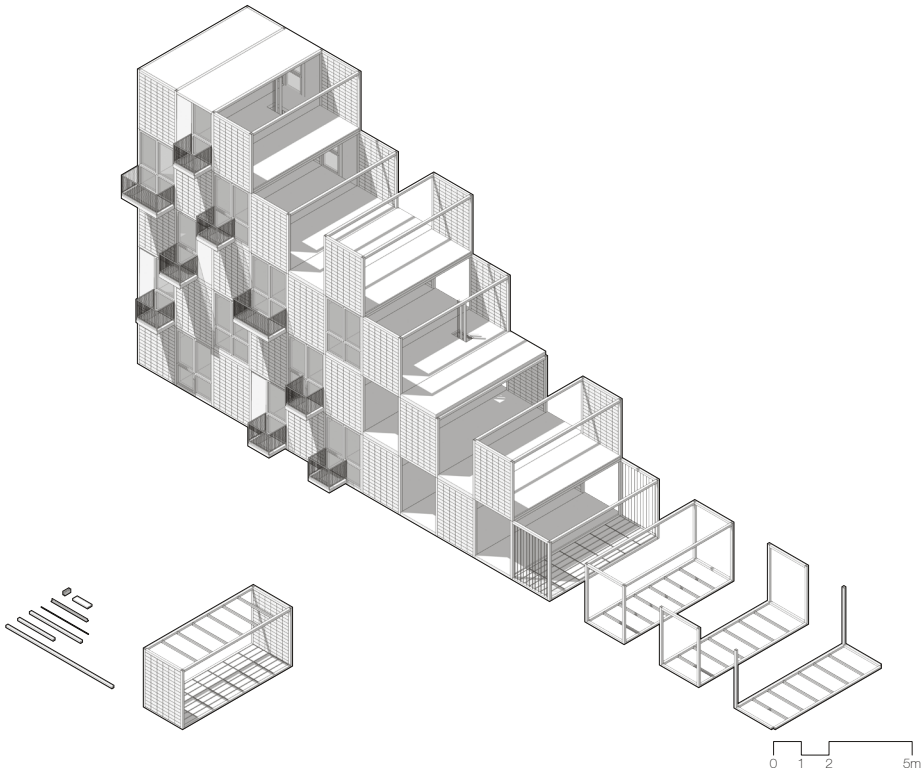
Graphic 295
Components: floor plans and façade



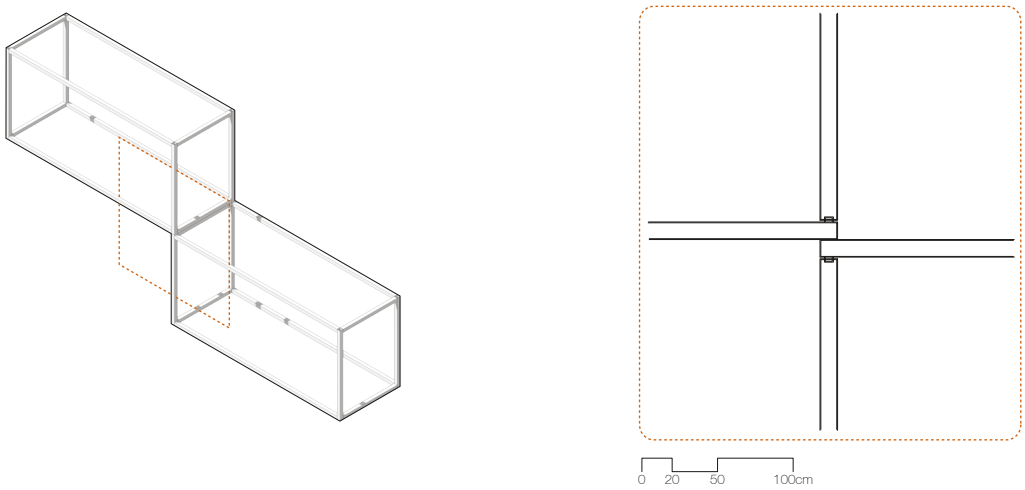
Graphic 296
Constructive process of a metallic structural frame with elements in masonry



Graphic 297
Constructive process: linear metallic structural frames and masonry



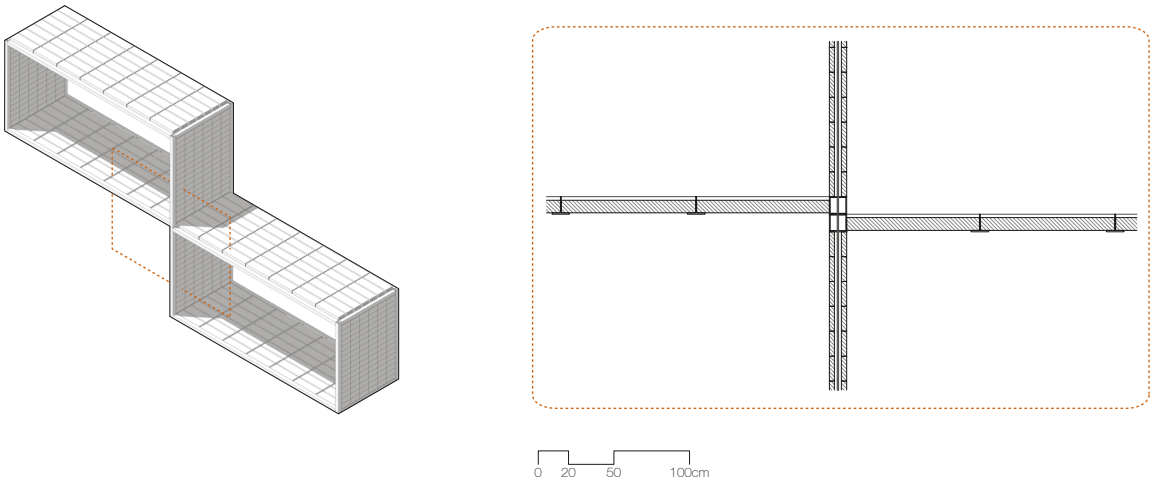
Graphic 298
Constructive process: transversal metallic structural frames and masonry



Graphic 299
Constructive details



Graphic 300
Constructive process: installation of metallic structural frames



Graphic 301
Constructive details



Graphic 302
Constructive process: installation of masonry between the metallic structural frames



Graphic 303 The technical system, the architectural language and the public space



Summary

Future developments

From the results of this research, two industrial developments are proposed as future projects. The first is to reduce the weights and costs of structural elements through open frames that eliminate one of their two slabs, generating a "U" shape. The second is the development of a modular structural system of industrialized frames with metallic structures and masonry blocks for the construction of social housing in rural settings.

U-shaped open structural frames in precast concrete

This development is based on the industrialization of open structural frames, formed by two load-bearing walls and a floor slab in the lower or upper part, retaining the same structural principles of the system. The structural walls that form the frames must be stiffened with a metal beam at the center, or with two metal beams located at their ends to stiffen the joint between them and eliminate wall bending at the top.

Eliminating one of the two slabs to form the U-shaped frame allows the reduction of up to 35.4% of the volume and weight of a closed structural frame. This condition reduces costs and production and assembly time. According to the structural calculations made, the inner reinforcing steel would increase by 10% compared to the original quantity used in closed prefabricated frames.

The system preserves urban and architectural characteristics and increases efficiency in the transport. By eliminating the upper slab, a total of four frames measuring up to 6.00m in length, 2.60m wide and heights of up to 4.50m, it can be transported simultaneously, complying with the maximum dimensions and weights permitted. The structural characteristics are modified by reducing the weight and volume of concrete, and by increasing the weight of the metallic elements that serve as structural reinforcement. The development of the U-shaped, industrialized, precast concrete frames, consisting of a floor slab, two structural walls and one or two transversal metal elements that stiffen them, can reduce the system's costs by an additional 7%.[73]

Structural framework with metal profiles and masonry

Industrialized frames in precast concrete cannot be transported and installed in all settings, even in urban areas. This system can be adapted to social housing projects for urban settings that are difficult to access, or even for rural settings. The components of the precast-concrete frames can be replaced by structural metal profiles and cement or clay blocks in the walls and slabs, joined by assemblies, weldings or metal pins that guarantee structural continuity. This system can consider closed structural frames (with two slabs and two walls), or open, U-shaped frames, with two walls and a slab.

In quantitative terms

With this system, costs and construction time can be reduced, thus ensuring the feasibility in rural territories, where almost 50% of the country's housing deficit is located.[74]

In qualitative terms

This system meets the objective and subjective criteria for structural, urban and architectural designs.

Objective criteria

The criteria of modularity and replicability are maintained in relation to precast-concrete frames, since the industrial production is standardized and is done with criteria of dimensional coordination between the metallic profiles and the masonry elements.

Transportability increases its efficiency, since the metallic profiles and the masonry elements can arrive at the construction site in different means of transport used in rural territories.

Adaptability to different contexts permits the installation of metallic structural elements, and uses masonry elements available in the area. The assembly of metallic profiles and masonry can be finished on site without the need for specialized personnel or hoisting equipment. For the fixation of the elements to the terrain, the same procedure used in precast-concrete frames is specified; this improves the confinement proctor according to the information obtained in the soil study. These frames, which use lighter elements, uniformly distribute their load onto the terrain. In flat or sloped topographies, the building configuration can be adapted to different contexts.

The accessibility of the system is proposed through the design of collective spaces without displacement barriers, and from the proportion of the interior spaces of the dwellings, which must allow the mobility of the disabled.

Subjective criteria

The simplicity of the system is given by the number of elements that make it up, and by the joints among them. The main structure is made up of metal profiles in sections measuring 15cm x 15cm for the columns and beams, with calibres defined according to the structural design. These elements are joined at the industrial plant or on site through metal screws or pins, without the need for specialized welding equipment or techniques. A set of 1" diameter metal rods is used to install the masonry elements that make up the structural diaphragms. These rods are joined to the lower lateral beams through screws or weldings, with perforations that come ready from the factory. The separation between these rods is proportional to the cells of the masonry elements, which are reinforced by a casting of concrete. The lateral walls are confined with the installation of the upper beams. The floor of each frame is formed by metallic profiles

73 Budgets made by the firm *Proyectar,* by Engineer Juan Carlos Gómez Ángel in the city of Medellín. The initial calculations were made in February 2015; in May 2015, the budgets were adjusted, once the construction of the prototypes was completed. In December 2016, cost and time calculations were made again, with updated prices.

74 National Administrative Department of Statistics of Colombia (*Departamento Administrativo Nacional de Estadística,* DANE). Accessed January 15, 2017; available at www.dane.gov.co

with inverted T-sections, measuring 2" x 2", which receive the masonry elements that come to form the floor slab, which is then stiffened with metal rods and a casting of concrete on the surface. The joints among the metal frames are also made with metallic bolts, screws or pins, with the same grouping systems proposed for the system of precast concrete frames.

Being conceived with the same geometries and proportions, the flexibility of the system is maintained, since the structural elements are located in the perimeter of the frames and the interior spaces maintain their free floors to propose different architectural designs and manners of occupation, according to environmental, cultural and social settings.

From their structural configuration, the opening systems of the frames, their orientation and their materiality define the criteria of comfort in interior spaces. These frames can have open and semi-open façades, which allow controlling solar incursion and natural ventilation. The location of the non-structural elements generates different responses on the façade and in the interior space, according to the environmental conditions of the site. The correct orientation of the buildings, the strategies of the façade to control solar incursion and permit cross ventilation, define criteria of wellbeing in the use of urban and interior spaces.

The transformation of living spaces and language, like in the system of precast-concrete structural frames, is done by the users once they have occupied the dwellings. The modification of areas, variation in the uses of interior spaces and changes in the language of the project, can be made according to the disposition and materiality of non-structural elements.

This proposal combines structural, spatial and language conditions that preserve the characteristics of industrialized precast concrete frames. The metallic and masonry elements that make it up permit increasing its adaptability to different contexts, due to their proportions, the forms of installation and the tools necessary to join them. In rural settings, with a housing deficit as big as the deficit in urban settings, social housing can also be conceived through industrialized modular structural frames made up of metal profiles and masonry elements.



Bibliography

Aerocivil. (n. d.). *Aerocivil.* Downloaded from http://www.aerocivil.gov.co.

Aguilera, R. (n. d.). Construction Systems Used in Popular Mass Housing. Chapter VIII: The Projects. Ciudad Bachué. Research done for the Center for Studies in Construction and Urban and Regional Development (*Centro de Estudios de la Construcción y el Desarrollo Urbano y Regional,* Cenac). *Escala* (the Latin American Magazine of Architecture, Art and Engineering). *13*(104), pp. 23-26.

Alcaldía de Bogotá. (n. d.) *Ministerio de Transporte* (Ministry of Transport). Downloaded from http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=36620#0.

Alonso, P. and Palmarola, H. (2012). The Soviet KPD System in Cuba and Chile, 1963-1973. In Y. Delemontey (Ed.), *Understanding and Conserving Industrialised and Prefabricated Architecture* (pp. 299-307). Laussane: *Presses polytechniques et universitaires romandes.*

Alonso, P. and Palmarola, H. (2014). Twenty-Eight Systems (Veintiocho Sistemas) (1931-1981). In Monolith Controversies. Text from the Chile Pavilion in the 14th International Exposition of Architecture "*La Biennale di Venezia*". Ostfildern, Germany: Hatje Cantz Verlag.

Amateur Athletic Foundation of Los Angeles. (2003). *The Games (Die Spiele): The Official Report of the Organizing Committee for the Games of the XXth Olympiad Munich.* Volume 2. Munich: ProSport GmbH & Co.KG.

American Concrete. (2008) *Ultra High Performance Concretes.* In *Institute. Concrete International.* Downloaded from www.concrete.org.

Andrade, S. (2005). Dictionary of Economics (*Diccionario de Economía*). Mexico City: *Ediciones Andrade.*

Arango, S. (1989). History of Architecture in Colombia (*Historia de la Arquitectura en Colombia*). Bogotá: Universidad Nacional de Colombia.

Araújo, R. (1997). Precast Concrete and Construction in Height (*Hormigón prefabricado y construcción en altura*). *Tectónica: Monografías de Arquitectura, Tecnología and Construcción*, (5), pp. 6-7.

Aravena, A. and Iacobelli, A. (2012) What's the Point? (*¿Cuál es el Punto?*) and Structural Lessons (*Lecciones estructurales*) The Milan House. In *Elemental, Incremental Housing and Participatory Design Manual (Elemental, manual de vivienda incremental y diseño participativo)* (pp. 14-493). Ostfildern, Germany: Hatje Cantz Verlag.

Bergdoll, B. and Christensen, P. (2008). *Home Delivery: Fabricating the Modern Dwelling.* New York: Museum of Modern Art.

Böttger, D. (1974). *Montagebau.* Berlin: VEB *Verlag für Bauwesen.*

Bravo, I. (1997). Official Protected Housing (*Viviendas de Protección Oficial*) in Alcobendas. In *Tectónica: Monografías de Arquitectura, Tecnología and Construcción*, (5), p. 28.

Cabrera, J. (2011). A manual mechanized system: "the Sandino System" (*Un sistema mecanizado manual: "el Sistema Sandino"*). Downloaded from http://civilgeeks.com/2011/09/08/un-sistema-semimecanizado-manual-el-sistema-sandino.

Cabrera, L. (2015). Housing and Concrete: Evolution of popular housing in Bogotá (*Vivienda y concreto: evolución de la vivienda popular en Bogotá*). Downloaded from https://proyectodecada.wordpress.com/2015/05/10/vivienda-y-concreto-evolucion-de-la-vivienda-popular-en-bogota.

Cárdenas, D. and Peláez, L. (2010). *Manual de acabados en concreto arquitectónico.* Medellín: Cementos Argos.

Chiavenato, I. (2004). Introduction to the General Theory of Administration (*Introducción a la teoría general de la Administración*). Madrid: McGraw-Hill Interamericana de España.

Comisión Sismorresistente, Comisión Asesora Permanente para el Régimen de Construcciones Sismorresistentes (Permanent Advisory Committee for the Earthquake–Resistant Construction System) and *Minambiente, Ministerio de Ambiente, y Desarrollo Sostenible* (Ministry of the Environment and Territorial Development). (2010). *The Colombian Earthquake–Resistant Construction Regulations, NSR-10. (Reglamento Colombiano de Construcción Sismo-Resistente NSR-10).* Bogotá: The Office of the Commission Secretary: The Colombian Association of Seismic Engineering, AIS (*Secretaría de la Comisión: Asociación Colombiana de Ingeniería Sísmica,* AIS). March 2010, p. 11.

Condo Madness. (n. d.). *Khrushchyovka, K-7 system.* Downloaded from http://www.condomadness.info/China-Khrushchyovka.html.

Corona. (2009). Pro Habitat Award. For Decent Housing for Colombia. Professional Summons 2008-2009. Panels Generated through Banana Agroindustry Waste. Bogotá: Editorial J.L. Impresores.

CTA, *Centro de Ciencia y Tecnología de Antioquia.* (2013). Participatory Sub-Regional Road Plans (*Planes Viales Subregionales Participativos*). Medellín.

DANE, *Departamento Administrativo Nacional de Estadística* (National Administrative Department of Statistics of Colombia). (1993) *General Census 1993: Housing Deficit.* Downloaded from http://www.dane.gov.co/index.php/estadisticas-sociales/deficit-de-vivienda.

DANE, *Departamento Administrativo Nacional de Estadística* (National Administrative Department of Statistics of Colombia). (2005). *Colombia: General Census 2005. Housing Deficit by Departments (Déficit de Vivienda por Departamentos).* Downloaded from http://www.dane.gov.co/index.php/estadisticas-sociales/deficit-de-vivienda.

DANE, *Departamento Administrativo Nacional de Estadística* (National Administrative Department of Statistics of Colombia). (2015). *Technical Newsletter (Boletín Técnico).* Downloaded from http://www.dane.gov.co/files/investigaciones/condiciones_vida/pobreza/Antioquia_Pobreza_2014.pdf.

DANE, *Departamento Administrativo Nacional de Estadística* (National Administrative Department of Statistics of Colombia). (n. d.). Home. . Downloaded from http://www.dane.gov.co.

Del Col, J. (2007). *Spanish-Latin Dictionary.* Bahía Blanca, Argentina: Instituto Superior Juan XXIII.

Digm. (2015). Panel I – 510, . Downloaded from http://digm.ru/tipovoy-zhiloy-dom-serii-1-510.html.

Dimitrijevic, R. (1994). *Researches of the column - slab joint in the IMS skeleton system*, 1(XXI). Belgrade: IMS Institute Proceedings.

Dimitrijevic, R. and Gavrilovic, B. (2000). *Precast prestressed concrete skeleton in contemporary building – IMS System.* Belgrade: IMS Institute.

DNP, *Departamento Nacional de Planeación* (National Planning Department of Colombia). (2005). Colombian II Centennial Vision: 2019 (*Visión Colombia II Centenario*: 2019). In V. Londoño (Ed.) (pp.179-180). Bogotá: Editorial Planeta Colombiana S. A.

DNP, *Departamento Nacional de Planeación* (National Planning Department of Colombia). (2008). National Planning Department of Colombia. *Principal Infrastructure Projects: The Central Railroad System of Colombia.* Bogotá.

Echeverri, A. and Orsini, F. (2010). Informality and Social Planning in Medellín (*Informalidad and Urbanismo Social en Medellín*). In M. Hermelín, A. Echeverri and J. Giraldo (Eds.), *Medellín: Environment, Culture, Society. (Medellín: medio ambiente, cultura, sociedad)* (p. 130). Medellín: Fondo Editorial Universidad EAFIT.

Elías, X. (2009). *Waste destined for the manufacture of dense materials: Cements. (Residuos destinados a la elaboración de materiales densos: los cementos). Recycling Industrial Waste: urban solid wastes and sewage sludge (Reciclaje de Residuos Industriales: residuos sólidos urbanos y lodos de papelera).* Barcelona: Ediciones Díaz de Santos.

Escovar, A. (2006). Milestones and Protagonists: Prefabricated and Prestressed. The Construction of Concrete in Colombia: Appropriation, Expression, Projection. (*Hitos y protagonistas: prefabricados y preesforzados. la construcción del concreto en colombia: apropiación, expresión, proyección*). In B. Arcos and D. Burbano (Eds.) (p. 89). Bogotá: Panamericana Formas e Impresos.

FDB, *Fachvereinigung Deutscher Betonfertigteilbau e.V.* (n. d.). The German Professional Association for the Precast Concrete Construction. Downloaded from http://www.fdb-typenprogramm.de.

Fédération Internationale du Béton (FIB). (2011). *Affordable Housing. Prefabrication for affordable housing.* Ostfildern: Document Competence Center Siegmar Kästl.

Fernández, A. (2009). *Steidle + Partner: Viviendas Múnich.* A+T Architecture Publishers. Downloaded from http://aplust.net/permalink.php?atajo=steidle__partner_housing_munich&idioma=es.

Fernández, A., Mozas, J. and Arpa, J. (2011). Density Is Home. A+T Architecture Publishers. Vitoria-Gasteiz.

Forero, F. (2008). From the Dom-Inó structure to Ciudad Bachué: Reflections on progressive and informal housing. *Dearquitectura* (03), p. 128.

Forero, S. (2011). Recent Trend of Housing Construction in Colombia (*Tendencia reciente de la construcción de vivienda en Colombia*). In Colombian Chamber of Construction (*CAMACOL*), *Economic Report (Informe económico Cámara Colombiana de la Construcción Camacol* (pp. 6-7). Bogotá: Camacol.

Fox, M. (1997). *At home in Habitat.* Toronto Star.

Freire, E. et al. (2009) Design. In *Housing Deficit Methodology (Metodología déficit de vivienda).* Bogotá: DANE e Imprenta Nacional.

Funes, J. (1994). *Cost Accounting (Contabilidad de costos).* Cochabamba: Educación and Cultura.

García-Huidobro, F., Torres, D. and Tugas, N. (2008). *¡El tiempo construye! (Time Builds!).* Barcelona, Spain: Editorial Gustavo Gili.

García, J. and Gutiérrez, L. (2008). *Costs Accounting (Contabilidad de costos).* México City: McGraw-Hill Interamericana.

Gobernación de Antioquia. (2006). *Transport, Recreation and Commerce: Explanatory Notes (Transporte, recreación y comercio: notas explicativas).* Downloaded from https://www.antioquia.gov.co/antioquia-v1/organismos/planeacion/anuario2006/transporte/notas.doc.

Gobernación de Antioquia. (n. d.a). *Geografía de Antioquia.* Downloaded from http://antioquia.gov.co/index.php/registrar/9790-geografia.

Gobernación de Antioquia. (n. d.b). *Road Map of the Department of Antioquia (Mapa vial del Departamento de Antioquia).* Downloaded from http://www.antioquia.gov.co/antioquia-v1/PDF/web.pdf.

Gómez-Jáuregui, V. (2009). Habidite: Industrialized modular housing (*Habidite: viviendas modulares industrializadas*). *Construction Reports (Informes de la Construcción)*, 61(513), 33-46.

González, D. (2009). Half a Century of Social Housing in Cuba. (*Medio siglo de vivienda social en Cuba*). *Revista INVI.* 24(67), 69-92.

Graf, F. and Delemontey, Y. (2012). *Understanding and Conserving Industrialised and Prefabricated Architecture.* Lausanne: *Presses Polytechniques et Universitaires Romandes.*

Gropius, W. (1973). Sociological Foundations for Minimum Housing for the Worker Population in Cities (*Fundamentos sociológicos de la vivienda mínima para la población obrera en Ciudades*). In C. Aymonino, *Rational Housing Minutes of the CIAM Congresses 1929-1930. (La vivienda racional. Actas de los congresos CIAM 1929-1930)* (pp. 120-121). Barcelona: Gustavo Gili.

Groys, B. (2014). Panel Buildings: Stations on the Way to Utopia (*Edificios de paneles: estaciones camino a la utopía*). In P. Alonso and H. Palmarola (Eds.), *Monolith Controversies. The Chile Pavilion in the 14th International Exposition of Architecture "La Biennale di Venezia"* (p. 40). Ostfildern: Editorial Hatje Cantz.

Habitat 67. (n. d.). *Complexe de la cité du havre. "354 cubes of a magnificent grey-beige build up one on the other to form 146 residences"*. Downloaded from http://www.habitat67.com.

Harlander, T. (1999). *Wohnen und Stadtentwicklung in der Bundesrepublik, 2. Kapitel: 1960 bis 1973: "Modernisierung" der Stadstruktur–Flächensanierung und Großsiedlungsbau.* In I. Flagge (Ed.), *Geschichte des Wohnens, Bd. 5, Von 1945 bis heute*. Stuttgart: Wüstenrot Stiftung.

Herzog, T. (1998). *Construction Systems by Angelo Mangiarotti. D*as Beispiel GmbH Verlag. Lehrstuhl für Entwerfen und Baukonstruktion II. Darmstadt: *Technische Universität Munich.*

Herzog, T. (2010). *Projektbeschreibung / Spezielle Konstruktionen und Produkte.* In: O. von Miller Forum and T. Herzog (Ed.), *Hirmer Verlag GmbH* (pp. 10-32). Munich.

Hess Group. (n. d.). *Cellular Concrete.* Downloaded from http://www.hessgroup.com/es/hess-aac-systems/hormigon-celular.

Hoyos, C. (2010). Landscape management in the Aburrá Valley: Toward the conservation of nature in the city (*Gestión del paisaje en el Valle de Aburrá: hacia la conservación de la naturaleza en la ciudad*). In M. Hermelín, A. Echeverri and J. Giraldo (Eds.), *Medellín: Environment, Culture, Society (Medellín: medio ambiente, cultura, sociedad)* (p. 94). Medellín: Fondo Editorial Universidad EAFIT.

IDEAM, Instituto de Hidrología, Meterología and Estudios Ambientales (The Colombian Institute of Hydrology, Meteorology and Environmental Studies). (n. d.) *The Atmosphere, Weather and Climate (La atmósfera, el tiempo and el clima).* Downloaded from https://documentacion.ideam.gov.co/openbiblio/Bvirtual/publicaciones/publicaciones2.html.

IGAC, *Instituto Geográfico Agustín Codazzi.* (n. d.). Maps of Colombia (*Mapas de Colombia*). Downloaded from http://www.igac.gov.co/igac.

Instrucción Española del Hormigón Estructural, EHE (The Spanish Institute of Structural Concrete). (n. d.). *Instrucción Española del Hormigón Estructural.* Downloaded from http://www.fomento.gob.es/MFOM/LANG_CASTELLANO/ORGANOS_COLEGIADOS/MASORGANOS/CPH/instrucciones/EHE_es.

Inter-American Development Bank, IADB. (2014). *IADB Study: Latin America and the Caribbean Face a Growing Housing Deficit.* Downloaded from http://www.iadb.org/es/noticias/comunicados-de-prensa/2012-05-14/deficit-de-vivienda-en-america-latina-y-el-caribe,9978.html.

Jovanovic, J., Grbic, J. and Petrovic, D. (2004). *Prefabricated Construction in Former Yugoslavia: Visual and Aesthetics Features and Technology of Prefabrication.* Belgrado.

Koontz, H. and Heinz, W. (2004). *Administration: A global perspective (Administración: Una Perspectiva Global).* Madrid: McGraw-Hill Interamericana de España.

Krippner, R. (2001). Building with Systems. – Learningfrom the 1960's? *Detail (Elemente + Systeme).* (4), pp. 606-607.

Krippner, R. (2005). *Holzleichtbeton–Eigenschaften und Einsatzmöglichkeiten.* In *Detail, Baustoff Beton.* Munich: *Institut für internationale Architektur-Dokumentation GmbH & Co. KG.*

Kulterman, U. (1965). *Neues Bauen in der Welt.* Tübingen: Wasmuth Verlag.

Land, P. (2008). The Experimental Housing Project of Lima: Background and ideas (*El Proyecto Experimental de Vivienda,* PREVI) *de Lima: antecedentes e ideas.* In F. García-Huidobro, D. Torres and N. Tugas, *¡El Tiempo Construye! (Time Builds!)*, (pp. 10-11). Barcelona: Editorial Gustavo Gili.

Le Corbusier. (1976). Toward a New Architecture: Guiding Principles (*Hacia una nueva arquitectura; principios directrices*). In U. Conrads, *Programs and Manifestos of XX Century Architecture (Programas and Manifiestos de la Arquitectura del Siglo XX), (p. 96).* Barcelona: Lumen.

Li, V. (2012). Bendable Concrete (Engineered Cement Concrete). Current Concrete Nano-Technologies. In P. Petricone (Ed.), *Concrete Ideas. Material to Shape a City* (p. 24). Londres: Thames & Hudson Editions.

Loaiza, E. (2016). The Camacol International Construction, Architecture and Design Fair. Conference by Eduardo Loaiza, Manager of the Colombian Chamber of Construction (*Cámara Colombiana de la Construcción,* CAMACOL). Evolution of Housing Construction in Colombia.

Lucas, P., Salas, J. and Barrionuevo, R. (2012). Forty years of PREVI-LIMA: Some teachings for the industrialization of low-cost housing in Latin America (*Cuarenta años del PREVI-LIMA: Algunas enseñanzas para la industrialización de la vivienda de bajo costo en Latinoamérica). Informes de la Construcción,* 64(525), 56-59.

Mañà, F., González, J., Cuchí, A., Zamora, J. and Roca, L. (2001). The Techniques of Industrialized Construction (*Las técnicas de la construcción industrializadas*). In *Alternatives to the conventional construction of homes* (*Alternativas a la construcción convencional de vivienda*), (p. 78). Barcelona: Institut de Tecnología de la Construcción de Catalunya ITeC.

Mankiw, G. (2004). *Economy (Economía).* Madrid: McGraw-Hill Interamericana de España.

Martinsviertel, K. (n. d.). 1969-1977. Information obtained at www.j-schuermannarchitekten.de. Downloaded from http://www.j-schuermannarchitekten.de/index.php?id=38.

Maya, T. (2008). *Residential áreas and urban development in Bogotá (Áreas residenciales and desarrollo urbano en Bogotá). Masters in Art History and Architecture.* Bogotá: Universidad Nacional de Colombia.

Medina, L. (1986). *Construction Systems used in Cuba (Sistemas Constructivos Utilizados en Cuba).* Havana, Cuba: Editorial ENPES.

Mintransporte, Ministerio de Transporte (Ministry of Transport). (n. d.a). Maximum widths of vehicles. (*Ancho máximo de los vehículos*). Downloaded from https:/www.mintransporte.gov.co/loader.php?lServicio=FAQ&lFuncion=viewPreguntas&id=74.

Mintransporte, Ministerio de Transporte (Ministry of Transport). (n. d.b). Rail Transport and Rail Networks. Downloaded from https://www.mintransporte.gov.co/loader.php?lServicio=FAQ&lFuncion=viewPreguntas&id=68#a485.

Minvivienda, Ministerio de Vivienda, Ciudad y Territorio (Ministry of Housing). (2014) Ministry of Housing, City and Territory for the Seventh World Urban Forum. Chapter 1: Toward an Integral Policy (*Hacia una Política Integral*). In: Colombia: 100 Years of Housing Policies (*Colombia, 100 años de Políticas Habitacionales*). *Panamericana Formas e Impresos S.A.* Bogotá, 2014. p. 26.

Minvivienda, Ministerio de Vivienda, Ciudad y Territorio (Ministry of Housing). (n. d.a). Programs: 100,000 free homes. Downloaded from http://www.minvivienda.gov.co/Ministerio/Paginas/Objetivos%20y%20Funciones.aspx.

Minvivienda, Ministerio de Vivienda, Ciudad y Territorio (Ministry of Housing). (n. d.b). Regarding the Ministry: Mission and Vision. Downloaded from http://www.minvivienda.gov.co/Ministerio/Paginas/Mision%20y%20Vision.aspx.

Morton, J. (1994). *From Southgate to Hallwood Park: 25 Years in the Life of a Community*. Liverpool: Merseyside Improved Homes.

Musso, F. (2016). *Vom Systembau zum Bauen mit System.* Munich: Verlag Ludwig.

Nilson, A. (1987) *Design of Prestressed Concrete.* New Jersey: John Wiley & Sons.

Oliveira Da Silva, R. (2002). *Theories of Administration (Teorías de la Administración).* Mexico City: International Thomson Editores, S. A. de C. V.

Ostornol, S. and Cardozo, O. (n. d.). *Estudio de dimensiones de barcazas que navegan por el Río Magdalena, Colombia. Escuela de Arquitectura y Diseño – Magíster Náutico y Marítimo.* Valparaíso: Pontificia Universidad Católica. Downloaded from http://wiki.ead.pucv.cl/images/1/17/Tarea_2_Estudio_parametrico_barcazas_rio_magdalena_Oscar_Cardozo.pdf.

Panelové domy. (n. d.). G-57 constructive system. Downloaded from http://panelovedomy.ekowatt.cz/g-57.html.

Pawlitschko, R. (2011). Discussion: A Second Look – *Genter Strasse* Housing Development in Munich. In *Detail: Zeitschrift für Architektur. Institut für Internationale Architektur-Dokumentation GmbH & Co.* Munich. Downloaded from http://www.detail-online.com/inspiration/discussion-a-second-look--genter-strasse-housing-development-in-munich-108900.html.

Petricone, P. (2012) (Ed.). *Graphic Concrete: peri photo engraving. In: Concrete Ideas. Material to Shape a City.* Londres: Thames & Hudson Editions.

Petrovic, G. (2000). Basic IMS System Elements. In: *IMS Building Technology*, (pp. 4-8). Beograd: Institut IMS RD.

Portland Cement Association. (n. d.). Portland Cement Association. Downloaded from http://www.cement.org/bridges/br_uhpc.asp.

Prochiner, F., Walczyk, R. and Hartmann, D. (2001). Innovative Plug-In Connections–the Key Technology for Prefabricated Housing. *Skelettsystem aus Fertigteilen. Institut für Internationale Architektur-Dokumentation GmbH*, Munich. In *Detail*, (4), 706.

RAE. (n. d.a). *Diccionario de la lengua Española*. Downloaded from http://lema.rae.es/drae/?val=eficiencia.

RAE. (n. d.b). *Diccionario de la lengua Española*. Downloaded from http://lema.rae.es/drae/?val=eficacia.

RAE. (n. d.c). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=7CUEdL2.

RAE. (n. d.d). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=B7MbcqN|B7QOlcz|B7RFb89.

RAE. (n. d.e). *Diccionario de la lengua Española*. Downloaded from http://lema.rae.es/drae/?val=tiempo.

RAE. (n. d.f). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=6nVpk8P|6nXVL1Z.

RAE. (n. d.g). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=PVTcmPD.

RAE. (n. d.h). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=W2p5Bt6.

RAE. (n. d.i). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=aMgmTGw.

RAE. (n. d.j). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=0hMBUwM.

RAE. (n. d.k). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=0K1XBn0.

RAE. (n. d.l). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=XvgYMXu.

RAE. (n. d.m). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=I5lQtvP.

RAE. (n. d.n). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=AGa3Pig.

RAE. (n. d.o). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=5Jw7ezp.

RAE. (n. d.p). *Diccionario de la lengua Española*. Downloaded from http://dle.rae.es/?id=aJbn4er.

Ramírez, D. (2000). *Topics of Study, selected from the text of Managerial Accounting (Temas de Estudio Seleccionados del texto de Contabilidad Administrativa).* México City: McGraw-Hill.

Regás, F. and Bolaños, J. (2007). *Piedra Moldeada: GRC y Hormigón Arquitectónico.* Barcelona: Encuadernaciones Mármol.

Rivas, M., Ganzer, J. and Cosme, M. (n. d.). Current and Future Applications of Carbon Nano-tubes (*Presentes y futuras aplicaciones de los nano-tubos de carbón*). In *Informe de Vigilancia Tecnológica*, (11). Madrid: Ediciones Fundación Madrid para el Conocimiento.

Robbins, S. and Coulter, M. (2005). *Administration.* Boston: Pearson Education.

Saldarriaga, A and Carrascal, R. (2006). The Concept of Social Housing as a Response to the Housing Problem: Training and Evolution in the XX Century (*El Concepto de la Vivienda Social como respuesta al problema de vivienda: formación and evolución en el siglo XX*). In *Social Housing in Colombia (Vivienda Social en Colombia). The Corona Pro Habitat Award.* Bogotá: Pre-printing and Printing: Editorial Bochica.

Saldarriaga, A. (2009). Settlement, Cultura and Ways of Living (*Poblamiento, Cultura and Formas de Habitación*). In *Past Presents: Housing in Colombia (Pasados Presentes: La Vivienda en Colombia).* Bogotá: OP Gráficas.

Salvadori, M. and Heller, R. (1978). *Structures for Architects (Estructuras para Arquitectos).* Buenos Aires: Editorial CP 67.

Sambricio, C. (2012). *The City and Housing in Latin America 1930-1960 (Ciudad y vivienda en américa latina* 1930-1960). Madrid: Lampreave Ediciones.

Samuelson, P. and Nordhaus, W. (2002). *Economy (Economía).* Madrid: McGraw Hill Interamericana de España.

Schätzke, C. and Schneider, H. (2005) *Textil Concrete (Textilbeton).* In *Detail, Concrete (Baustoff Beton).* Munich: I*nstitut für internationale Architektur-Dokumentation GmbH & Co. KG.*

Schätzke, C. and Schneider, H. (2006). Concrete with Textile Reinforcement (*Hormigón con Refuerzo Textil*). In M. Peck (Ed.), *Hormigón (Diseño, Construcción, Ejemplos)*, (pp.32-37). München: Detail Praxis. *Institut für internationale Architektur-Dokumentation GmbH & Co, KG.*

Segre, R. (2005). *Three decades of reflections on Latin American Habitat (Tres décadas de reflexiones sobre el Hábitat Latinoamericano).* Bogotá: Universidad Nacional de Colombia.

Staib, G., Dörrhöfer, A. and Rosenthal, M. (2008a) *Teil B: Grundlagen. In: Elemente + Systeme: Modulares Bauen (Entwurf, Konstruktion, neue Technologien).* München: Detail Ediciones. *Institut für Internationale Architektur-Dokumentation GmbH & Co. KG.*

Staib, G., Dörrhöfer, A. and Rosenthal, M. (2008b) Teil C: Tragwerke. *Raumzellensysteme. Raumzellen aus Beton. In: Elemente + Systeme: Modulares Bauen (Entwurf, Konstruktion, neue Technologien).* München: Detail Ediciones. *Institut für Internationale Architektur-Dokumentation GmbH & Co. KG.*

Staib, G., Dörrhöfer, A. and Rosenthal, M. (2008c). Teil C: Tragwerke. *Gebaute Beispiele im Detail. Wohn- und Geschäftsgebäude in Rathenow.* In: *Elemente + Systeme: Modulares Bauen (Entwurf, Konstruktion, neue Technologien).* Munich: Detail Ediciones. *Institut für Internationale Architektur-Dokumentation GmbH & Co. KG.*

Stanton, W., Etzel, M. and Bruce, W. (1999). *Marketing Dictionary (Diccionario de Marketing).* Madrid: Cultural S. A.

Stepan, K. and Winkler, T. (2010). *Tragwerksplanung* (Structural Planning). In O. von Miller and T. Herzog (Eds.), *Hirmer Verlag GmbH* (pp. 38-40). Munich.

Téllez, G. (1980). Architecture and urbanism in the current `time (*La arquitectura y el urbanismo de la época actual*). In *Handbook of Colombian History, Volume III* (p. 377). Bogotá: Instituto Colombiano de Cultura.

The United Nations Economic Commission for Latin America and the Caribbean (ECLAC). (2010). Panorama social 2010. Downloaded from http://www.eclac.org/prensa/noticias/comunicados/8/41798/graficoCOMUNICADO_PANORAMASOCIAL2010_FINAL.pdf.

Tillmann, M. (2011). J*oints for the Precast Concrete Elements (Knotenverbindungen für Betonfertigteile).* Bonn: German Professional Association for the Precast Concrete Construction (*Fachvereinigung Deutscher Betonfertigteilbau FDB e.V.*).

TU Delft. (n. d.). Stories of Science. Self-healing of Concrete by Bacterial Mineral Precipitation. Downloaded from http://www.citg.tudelft.nl/en/research/projects/self-healing-concrete.

Vargas, H. (2010). "History of Prefabrication in Concrete in Colombia: Notes to record learning" (*"Historia de la Prefabricación en Concreto en Colombia: notas para registrar un aprendizaje"*). Memorials of the conference *Reunión del Concreto.* Cartagena de Indias, Colombia.

Villanueva, P. and Macía, C. (2000). *Villanueva.* Seville: *Tanais Ediciones S. A.*

VIVA, *Empresa de Vivienda de Antioquia* (The Housing Company of Antioquia). (2014). Housing and Habitat Laboratory. Medellín: *Gobernación de Antioquia.*

VIVA, *Empresa de Vivienda de Antioquia* (The Housing Company of Antioquia). (2015). Population Projection 2013 (*Proyección Poblacional 2013*). Medellín: Library of Housing in Antioquia (*Biblioteca de la Vivienda de Antioquia*). Mesa Editores – Taller Estándar.

Wachsmann, K. (1959). *Fügen und Verbinden. Wendepunkt im Bauen (Point of Inflection in Construction).* Wiesbaden: Otto Krausskopf Verlag GmbH.

West, M. (n. d.). *The Centre for Architectural Structures and Technology CAST.* Manitoba: Faculty of Architecture, University of Manitoba. Downloaded from http://umanitoba.ca/cast_building/index.html.

Wikiwand. (n. d.). WBS 70. Downloaded from http://www.wikiwand.com/de/WBS_70.

World Bank. (n. d.). International Bank for Reconstruction and Development / World Bank. Report on World Development 2009: A New Economic Geography. Downloaded from http://siteresources.worldbank.org/INTWDR2009/Resources/WDR_OVERVIEW_ES_Web.pdf.

Zamora, J. *et al.* (2004). What is Dimensional Coordination? *(¿Qué es la Coordinación Dimensional?). Proyectar la Arquitectura desde la Coordinación Dimensional.* Barcelona: Instituto de Tecnología de la Construcción de Cataluña (ITeC).

Laws

Law 1444 of 2011.

Law 1753 of 2015. Social-Interest Housing and Priority Social-Interest Housing (*Vivienda de Interés Social y Vivienda de Interés Prioritario*). Downloaded from http://www.secretariasenado.gov.co/senado/basedoc/ley_1753_2015_pr001.html.

Law 3 of 1991

Law 388 of 1997

Law 388 of 1997

Law 46 of 1980

Law 546 of 1999

Law 795 of 2003

Law 9 of 1989

Interviews

E. Loaiza. (2010, December 12). Manager of the Antioquia Regional Office of the Colombian Chamber of Construction (CAMACOL). Interview by Alejandro Restrepo Montoya [Video recording]. Files from the Dissertation Concrete Home. *Universidad Pontificia Bolivariana,* Medellín.

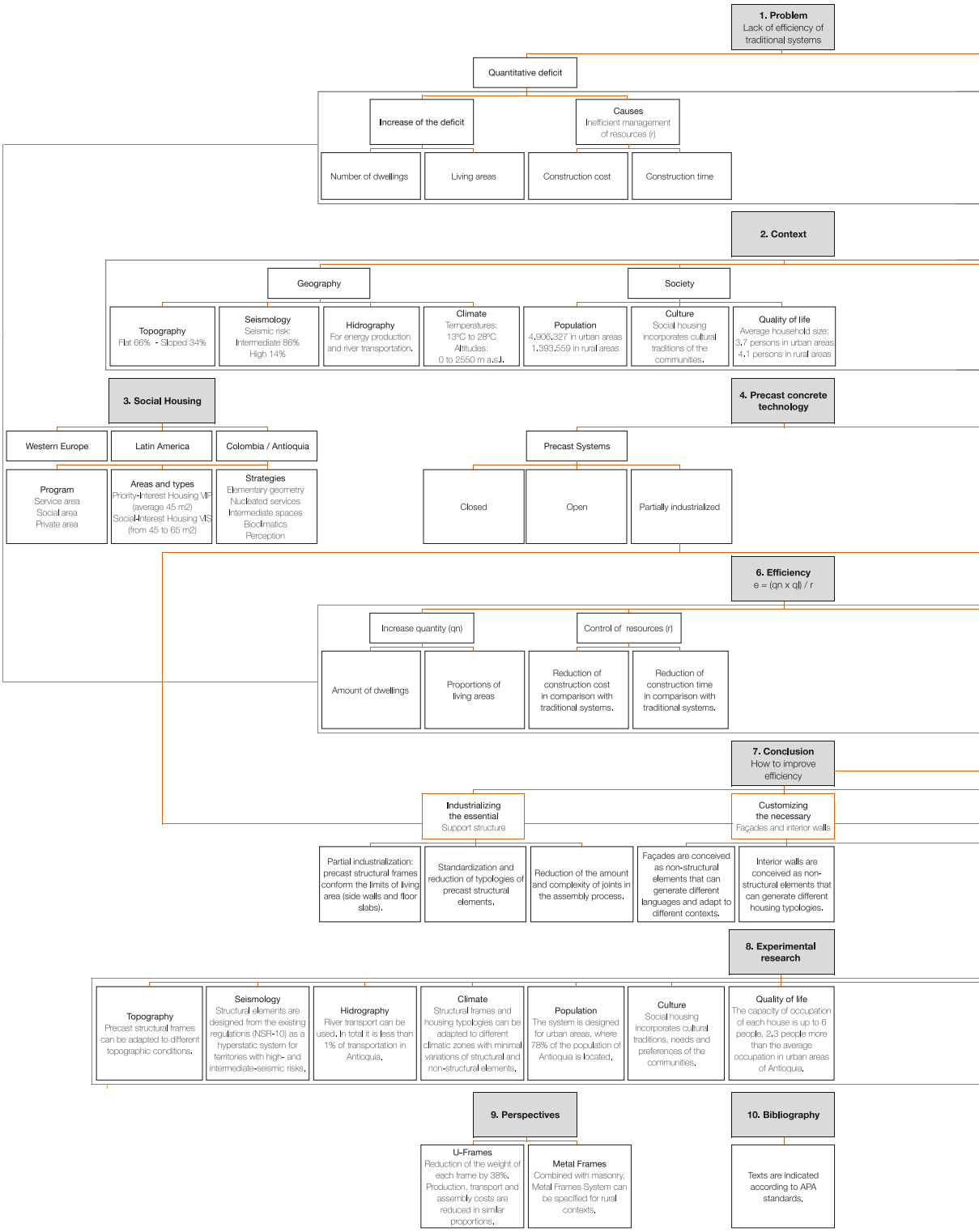
E. Loaiza. (2016, January 20). Manager of the Antioquia Regional Office of the Colombian Chamber of Construction (Camacol). Interview by Alejandro Restrepo Montoya [Video recording]. Files from the Dissertation Concrete Home. *Universidad Pontificia Bolivariana,* Medellín.

I. Asuad. (2016, June). Housing Manager of the Family Compensation Fund (COMFAMA). Medellín.

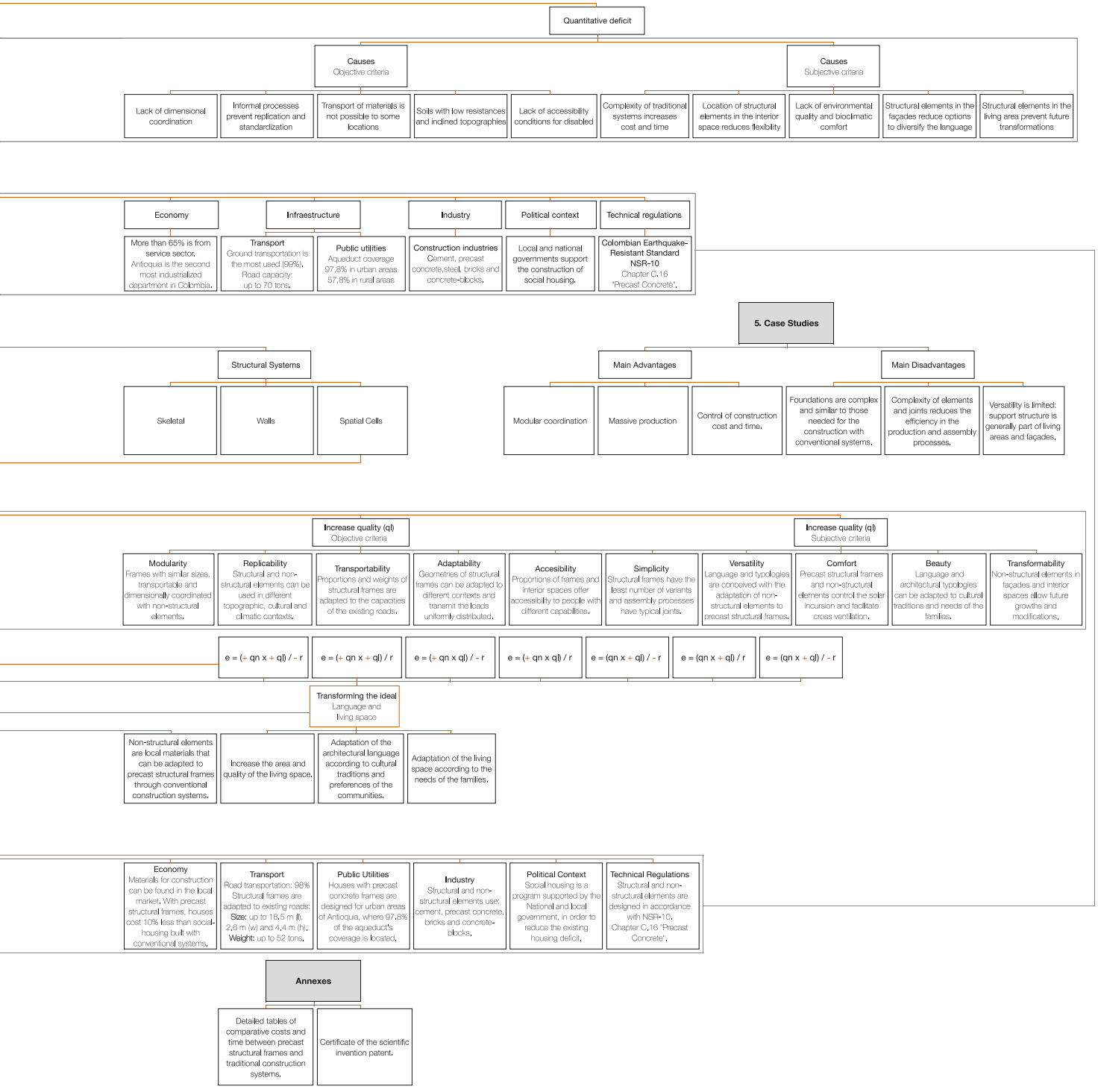
J. Schürmann (2014, July 4). Architect. Cologne, Germany.

Annexes

Annex 1 Conceptual structure



Concrete Home From the approach of the problem to the urban, architectural and technical proposal / Conceptual organization of the research process


Quantitative deficit
Causes
Objective criteria
Causes
Subjective criteria
Lack of dimensional coordination
Informal processes prevent replication and standardization
Transport of materials is not possible to some locations
Soils with low resistances and inclined topographies
Lack of accessibility conditions for disabled
Complexity of traditional systems increases cost and time
Location of structural elements in the interior space reduces flexibility
Lack of environmental quality and bioclimatic comfort
Structural elements in the façades reduce options to diversify the language
Structural elements in the living area prevent future transformations
Economy
Infraestructure
Industry
Political context
Technical regulations
More than 65% is from service sector. Antioquia is the second most industrialized department in Colombia.
Transport
Ground transportation is the most used (99%). Road capacity: up to 70 tons.
Public utilities
Aqueduct coverage 97,8% in urban areas 57,8% in rural areas
Construction industries
Cement, precast concrete,steel, bricks and concrete-blocks.
Local and national governments support the construction of social housing.
Colombian Earthquake-Resistant Standard NSR-10
Chapter C.16 "Precast Concrete".
5. Case Studies
Structural Systems
Main Advantages
Main Disadvantages
Skeletal
Walls
Spatial Cells
Modular coordination
Massive production
Control of construction cost and time.
Foundations are complex and similar to those needed for the construction with conventional systems.
Complexity of elements and joints reduces the efficiency in the production and assembly processes.
Versatility is limited: support structure is generally part of living areas and façades.
Increase quality (ql)
Objective criteria
Increase quality (ql)
Subjective criteria
Modularity
Frames with similar sizes, transportable and dimensionally coordinated with non-structural elements.
Replicability
Structural and non-structural elements can be used in different topographic, cultural and climatic contexts.
Transportability
Proportions and weights of structural frames are adapted to the capacities of the existing roads.
Adaptability
Geometries of structural frames can be adapted to different contexts and transmit the loads uniformly distributed.
Accesibility
Proportions of frames and interior spaces offer accessibility to people with different capabilities.
Simplicity
Structural frames have the least number of variants and assembly processes have typical joints.
Versatility
Language and typologies are conceived with the adaptation of non-structural elements to precast structural frames.
Comfort
Precast structural frames and non-structural elements control the solar incursion and facilitate cross ventilation.
Beauty
Language and architectural typologies can be adapted to cultural traditions and needs of the families.
Transformability
Non-structural elements in façades and interior spaces allow future growths and modifications.
e = (+ qn x + ql) / - r
e = (+ qn x + ql) / r
e = (+ qn x ql) / - r
e = (+ qn x ql) / r
e = (qn x + ql) / - r
e = (qn x + ql) / r
e = (qn x + ql) / - r
Transforming the ideal
Language and living space
Non-structural elements are local materials that can be adapted to precast structural frames through conventional construction systems.
Increase the area and quality of the living space.
Adaptation of the architectural language according to cultural traditions and preferences of the communities.
Adaptation of the living space according to the needs of the families.
Economy
Materials for construction can be found in the local market. With precast structural frames, houses cost 10% less than social-housing built with conventional systems.
Transport
Road transportation: 98%
Structural frames are adapted to existing roads:
Size: up to 18.5 m (l), 2,6 m (w) and 4.4 m (h).
Weight: up to 52 tons.
Public Utilities
Houses with precast concrete frames are designed for urban areas of Antioquia, where 97.8% of the aqueduct's coverage is located.
Industry
Structural and non-structural elements use: cement, precast concrete, bricks and concrete-blocks.
Political Context
Social housing is a program supported by the National and local government, in order to reduce the existing housing deficit.
Technical Regulations
Structural and non-structural elements are designed in accordance with NSR-10. Chapter C.16 "Precast Concrete".
Annexes
Detailed tables of comparative costs and time between precast structural frames and traditional construction systems.
Certificate of the scientific invention patent.

Annex 2 Time and costs

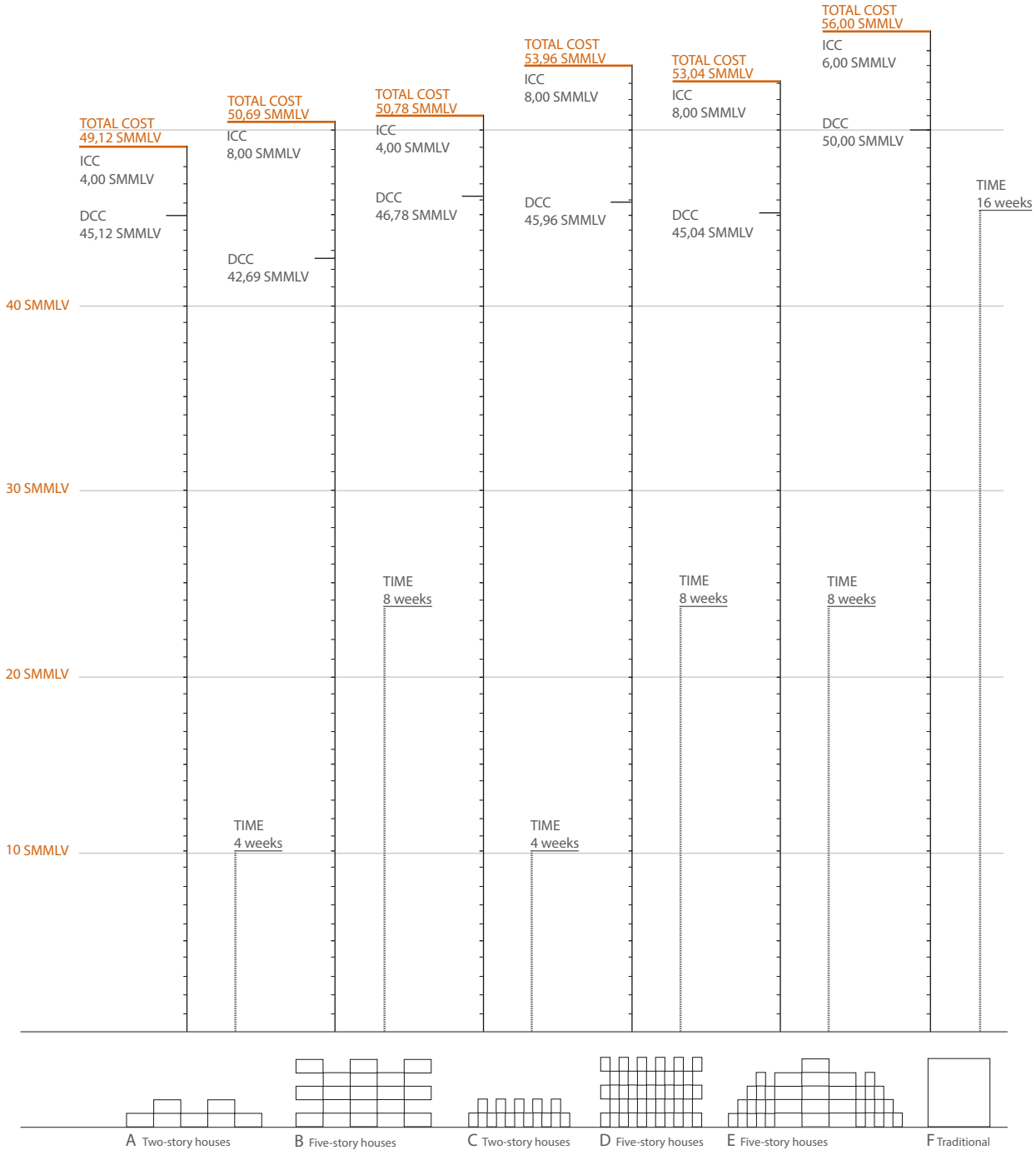
Social Housing A. Linear Industrialized Frames. Two-story houses					
Number of homes					10
Number of floors per project					2
Number of types of precast elements					1
Structural frames per dwelling					2
Frontage (in linear meters per dwelling)					5,8
Depht (in linear meters per dwelling)					8
Length of each frame (including the 0.15 m width of the walls)					5,8
Depth of each frame					2
Thickness of the walls					0,15
Thickness of the slabs					0,2
Height of each ring (including the 0.2 m thickness of the slabs)					2,8
Steel reinforcement per m3 (in kilograms)					110
Interior area of each home					42,35
Area with façade walls and dividing walls in each home					45,2
Value of each transport of the elements					$ 2.700.000
Minimum Monthly Wages (SMMLV) in Colombia in 2018					$ 781.242
Components					
Preliminary	€	599,29	$	2.097.528,00	0,60%
Movement of land	€	5.251,28	$	18.379.478,00	5,21%
Precast-concrete frames, reinforcements and joints	€	34.369,73	$	120.294.050,00	34,13%
Structural and non-structural masonry	€	10.337,55	$	36.181.425,00	10,27%
Floors, plaster, veneres, washing and paint	€	5.671,12	$	19.848.932,00	5,63%
Metalic and Wood carpentry	€	6.166,21	$	21.581.730,00	6,12%
Bathroom and kitchen devices	€	2.186,66	$	7.653.294,00	2,17%
Internal plumbing and gas installations	€	4.793,40	$	16.776.894,00	4,76%
Internal electric installations	€	6.943,00	$	24.300.500,00	6,89%
Rooves	€	5.730,83	$	20.057.891,00	5,69%
Transport of precast elements (20 units)	€	7.714,29	$	27.000.000,00	7,66%
Installation of precast elements (20 units)	€	4.200,00	$	14.700.000,00	4,17%
Nomenclature	€	45,54	$	159.396,00	0,05%
Urban planning and exteriors	€	6.696,36	$	23.437.260,00	6,65%
Total value of 10 homes	**€**	**100.705,25**	**$**	**352.468.378,00**	**100,00%**
Social Housing A. Linear Industrialized Frames. Two-story houses					
Direct construction cost of each house	€	10.070,53	$	35.246.837,80	
Value per m2 constructed with urban planning	€	222,80	$	779.797,30	
Direct construction cost in SMMLV with urban planning				45,12	
Construction time (weeks)				4,00	
Indirect construction cost of each house	€	892,85	$	3.124.968,00	
Indirect construction cost in SMMLV				4,00	
Traditional construction systems (area of each home: 42 m2)					
Direct construction cost of each house with urban planning	€	11.160,60	$	39.062.100,00	
Value per square meter constructed with urban planning	€	265,73	$	930.050,00	
Direct construction cost in SMMLV with urban planning				50,00	
Construction time (weeks)				16,00	
Indirect construction cost of each house	€	1.339,27	$	4.687.452,00	
Indirect construction cost in SMMLV				6,00	
Differences					
Area				3,2	7,62%
Direct construction cost of each house with urban planning	€	1.090,07	$	3.815.262,20	9,77%
Value per square meter constructed with urban planning	€	42,93	$	150.252,70	16,16%
Direct construction cost in SMMLV with urban planning				4,88	9,77%
Construction time (weeks)				12,00	75,00%
Indirect construction cost of each house	€	446,42	$	1.562.484,00	33,33%
Indirect construction cost in SMMLV				2,00	33,33%

Social Housing A. Linear Industrialized Frames. Five-story houses					
Number of homes					25
Number of floors per project					5
Number of types of precast elements					1
Structural frames per dwelling					2
Frontage (in linear meters per dwelling)					5,8
Depht (in linear meters per dwelling)					8
Length of each frame (including the 0.15 m width of the walls)					5,8
Depth of each frame					2
Thickness of the walls					0,15
Thickness of the slabs					0,2
Height of each ring (including the 0.2 m thickness of the slabs)					2,8
Steel reinforcement per m3 (in kilograms)					120
Interior area of each home					42,35
Area with façade walls and dividing walls in each home					45,2
Value of each transport of the elements					$ 2.700.000
Minimum Monthly Wages (SMMLV) in Colombia in 2018					$ 781.242
Components					
Preliminary	€	599,29	$	2.097.528,00	0,25%
Movement of land	€	7.876,92	$	27.569.217,00	3,31%
Precast-concrete frames, reinforcements and joints	€	90.339,03	$	316.186.597,00	37,93%
Structural and non-structural masonry	€	24.639,68	$	86.238.889,00	10,34%
Floors, plaster, veneres, washing and paint	€	11.520,65	$	40.322.269,00	4,84%
Metalic and Wood carpentry	€	20.264,09	$	70.924.325,00	8,51%
Bathroom and kitchen devices	€	5.466,64	$	19.133.235,00	2,29%
Internal plumbing and gas installations	€	11.983,50	$	41.942.235,00	5,03%
Internal electric installations	€	17.357,50	$	60.751.250,00	7,29%
Rooves	€	5.111,41	$	17.889.927,00	2,15%
Transport of precast elements (50 units)	€	19.285,71	$	67.500.000,00	8,10%
Installation of precast elements (50 units)	€	6.900,00	$	24.150.000,00	2,90%
Nomenclature	€	113,85	$	398.490,00	0,05%
Urban planning and exteriors	€	16.740,90	$	58.593.150,00	7,03%
Total value of 25 homes	**€**	**238.199,17**	**$**	**833.697.112,00**	**100,00%**
Social Housing A. Linear Industrialized Frames. Five-story houses					
Direct construction cost of each house	€	9.527,97	$	33.347.884,48	
Value per m2 constructed with urban planning	€	210,80	$	737.785,05	
Direct construction cost in SMMLV with urban planning				42,69	
Construction time (weeks)				8,00	
Indirect construction cost of each house	€	1.785,70	$	6.249.936,00	
Indirect construction cost in SMMLV				8,00	
Traditional construction systems (area of each home: 42 m2)					
Direct construction cost of each house with urban planning			$	39.062.100,00	
Value per square meter constructed with urban planning			$	930.050,00	
Direct construction cost in SMMLV with urban planning				50,00	
Construction time (weeks)				40,00	
Indirect construction cost of each house	€	2.455,33	$	8.593.662,00	
Indirect construction cost in SMMLV				11,00	
Differences					
Area				3,2	7,62%
Direct construction cost of each house with urban planning			$	5.714.215,52	14,63%
Value per square meter constructed with urban planning			$	192.264,95	20,67%
Direct construction cost in SMMLV with urban planning				7,31	14,63%
Construction time (weeks)				32,00	80,00%
Indirect construction cost of each house	€	669,64	$	2.343.726,00	27,27%
Indirect construction cost in SMMLV				3,00	27,27%

Social Housing B. Transversal Industrialized Frames. Two-story houses					
Number of housing units (average per building)					10
Height of the buildings (number of stories)					2
Number of types of precast elements					4
Structural frames per dwelling					2,5
Frontage (in linear meters per dwelling)					8,4
Depht (in linear meters per dwelling)					5,8
Length of each frame (including the 0.15 m width of the walls)					1,8
Depth of each frame					5,8
Thickness of the walls					0,15
Thickness of the slabs					0,2
Height of each frame (including the 0.2 m thickness of the slabs)					2,8
Steel reinforcement per cubic meter (in kilograms)					110
Interior area of each home (in square meters)					44,55
Area constructed per home (in square meters)					47,85
Value of each transport of the frames					$ 2.700.000
Minimum Monthly Wages (SMMLV) in Colombia in 2018					$ 781.242
Components					
Preliminary	€	668,54	$	2.339.880,00	0,64%
Movement of land	€	2.892,73	$	10.124.558,00	2,77%
Precast-concrete frames, reinforcements and joints	€	37.469,95	$	131.144.824,00	35,88%
Structural and non-structural masonry	€	7.453,67	$	26.087.856,00	7,14%
Floors, plaster, veneres, washing and paint	€	6.343,91	$	22.203.687,00	6,08%
Metalic and Wood carpentry	€	9.057,64	$	31.701.730,00	8,67%
Bathroom and kitchen devices	€	2.186,66	$	7.653.294,00	2,09%
Internal plumbing and gas installations	€	4.793,40	$	16.776.894,00	4,59%
Internal electric installations	€	6.943,00	$	24.300.500,00	6,65%
Rooves	€	6.730,19	$	23.555.676,00	6,45%
Transport of precast elements (25 units)	€	8.485,71	$	29.700.000,00	8,13%
Installation of precast elements (25 units)	€	4.650,00	$	16.275.000,00	4,45%
Nomenclature	€	45,54	$	159.396,00	0,04%
Urban planning and exteriors	€	6.696,36	$	23.437.260,00	6,41%
Total value of 10 homes	**€**	**104.417,30**	**$**	**365.460.555,00**	**100,00%**
Social Housing B. Transversal Industrialized Frames. Two-story houses					
Direct construction cost of each house	€	10.441,73	$	36.546.055,50	
Value per m2 constructed with urban planning	€	218,22	$	763.762,92	
Direct construction cost in SMMLV with urban planning				46,78	
Construction time (weeks)				4,00	
Indirect construction cost of each house	€	892,85	$	3.124.968,00	
Indirect construction cost in SMMLV				4,00	
Traditional construction systems (area of each home: 42 m2)					
Direct construction cost of each house with urban planning			$	39.062.100,00	
Value per square meter constructed with urban planning			$	930.050,00	
Direct construction cost in SMMLV with urban planning				50,00	
Construction time (weeks)				16,00	
Indirect construction cost of each house	€	1.339,27	$	4.687.452,00	
Indirect construction cost in SMMLV				6,00	
Differences					
Area				2,55	6,07%
Direct construction cost of each house with urban planning			$	2.516.044,50	6,44%
Value per square meter constructed with urban planning			$	166.287,08	17,88%
Direct construction cost in SMMLV with urban planning				3,22	6,44%
Construction time (weeks)				12,00	75,00%
Indirect construction cost of each house	€	446,42	$	1.562.484,00	33,33%
Indirect construction cost in SMMLV				2,00	33,33%

Social Housing B. Transversal Industrialized Frames. Five-story houses					
Number of housing units (average per building)					25
Height of the buildings (number of stories)					5
Number of types of precast elements					4
Structural frames per dwelling					2,08
Frontage (in linear meters per dwelling)					8,4
Depht (in linear meters per dwelling)					5,8
Length of each frame (including the 0.15 m width of the walls)					1,8
Depth of each frame					5,8
Thickness of the walls					0,15
Thickness of the slabs					0,2
Height of each frame (including the 0.2 m thickness of the slabs)					2,8
Steel reinforcement per cubic meter (in kilograms)					120
Interior area of each home (in square meters)					44,55
Area constructed per home (in square meters)					47,85
Value of each transport of the frames					$ 2.700.000
Minimum Monthly Wages (SMMLV) in Colombia in 2018					$ 781.242
Components					
Preliminary	€	668,57	$	2.339.980,00	0,26%
Movement of land	€	4.339,10	$	15.186.835,00	1,69%
Precast-concrete frames, reinforcements and joints	€	103.833,49	$	363.417.223,00	40,49%
Structural and non-structural masonry	€	20.539,21	$	71.887.243,00	8,01%
Floors, plaster, veneres, washing and paint	€	12.662,21	$	44.317.732,00	4,94%
Metalic and Wood carpentry	€	23.264,09	$	81.424.325,00	9,07%
Bathroom and kitchen devices	€	5.466,64	$	19.133.235,00	2,13%
Internal plumbing and gas installations	€	11.983,50	$	41.942.235,00	4,67%
Internal electric installations	€	17.357,50	$	60.751.250,00	6,77%
Rooves	€	6.730,19	$	23.555.675,00	2,62%
Transport of prefabricated elements (63 units)	€	24.685,71	$	86.400.000,00	9,63%
Installation of prefabricated elements (63 units)	€	8.070,00	$	28.245.000,00	3,15%
Nomenclature	€	113,85	$	398.490,00	0,04%
Urban planning and exteriors	€	16.740,90	$	58.593.150,00	6,53%
Total value of 25 homes	**€**	**256.454,96**	**$**	**897.592.373,00**	**100,00%**
Social Housing B. Transversal Industrialized Frames. Five-story houses					
Direct construction cost of each house	€	10.258,20	$	35.903.694,92	
Value per m2 constructed with urban planning	€	214,38	$	750.338,45	
Direct construction cost in SMMLV with urban planning				45,96	
Construction time (weeks)				8,00	
Indirect construction cost of each house	€	1.785,70	$	6.249.936,00	
Indirect construction cost in SMMLV				8,00	
Traditional construction systems (area of each home: 42 m2)					
Direct construction cost of each house with urban planning			$	39.062.100,00	
Value per square meter constructed with urban planning			$	930.050,00	
Direct construction cost in SMMLV with urban planning				50,00	
Construction time (weeks)				40,00	
Indirect construction cost of each house	€	2.455,33	$	8.593.662,00	
Indirect construction cost in SMMLV				11,00	
Differences					
Area				5,85	13,93%
Direct construction cost of each house with urban planning			$	3.158.405,08	8,09%
Value per square meter constructed with urban planning			$	179.711,55	19,32%
SMMLV with urban planning				4,04	8,09%
Construction time (weeks)				32,00	80,00%
Indirect construction cost of each house	€	669,64	$	2.343.726,00	27,27%
Indirect construction cost in SMMLV				3,00	27,27%

Social Housing C. Mixed grouping: linear and transversal industrialized frames. Five-story houses					
Number of housing units (average per building)					25
Height of the buildings (number of stories)					5
Number of types of precast elements					5
Structural frames per dwelling					2,08
Frontage (in linear meters per dwelling)					5,8 / 8,4
Depht (in linear meters per dwelling)					8,00 / 5,8
Length of each frame (including the 0.15 m width of the walls)					5,8 / 1,8
Depth of each frame					2,00 / 5,8
Thickness of the walls					0,15
Thickness of the slabs					0,2
Height of each frame (including the 0.2 m thickness of the slabs)					2,8
Steel reinforcement per cubic meter (in kilograms)					120
Interior area of each home (in square meters)					44,55
Area constructed per home (in square meters)					47,85
Value of each transport of the frames					$ 2.700.000
Minimum Monthly Wages (SMMLV) in Colombia in 2018					$ 781.242
Components					
Preliminary	€	748,91	$	2.621.198,00	0,30%
Movement of land	€	8.276,80	$	28.968.803,00	3,29%
Precast-concrete frames, reinforcements and joints	€	91.240,06	$	319.340.195,00	36,30%
Structural and non-structural masonry	€	26.633,06	$	93.215.725,00	10,60%
Floors, plaster, veneres, washing and paint	€	14.122,01	$	49.427.039,00	5,62%
Metalic and Wood carpentry	€	21.972,66	$	76.904.325,00	8,74%
Bathroom and kitchen devices	€	5.466,64	$	19.133.235,00	2,17%
Internal plumbing and gas installations	€	11.983,50	$	41.942.235,00	4,77%
Internal electric installations	€	17.357,50	$	60.751.250,00	6,91%
Rooves	€	7.662,24	$	26.817.840,00	3,05%
Transport of prefabricated elements (63 units)	€	21.600,00	$	75.600.000,00	8,59%
Installation of prefabricated elements (63 units)	€	7.440,00	$	26.040.000,00	2,96%
Nomenclature	€	113,85	$	398.490,00	0,05%
Urban planning and exteriors	€	16.740,90	$	58.593.150,00	6,66%
Total value of 25 homes	**€**	**251.358,14**	**$**	**879.753.485,00**	**100,00%**
Social Housing C. Mixed grouping: linear and transversal industrialized frames. Five-story houses					
Direct construction cost of each house	€	10.054,33	$	35.190.139,40	
Value per m2 constructed with urban planning	€	210,12	$	735.426,11	
SMMLV with urban planning				45,04	
Construction time (weeks)				8,00	
Indirect construction cost of each house	€	1.785,70	$	6.249.936,00	
Indirect construction cost in SMMLV				8,00	
Traditional construction systems (area of each home: 42 m2)					
Direct construction cost of each house with urban planning			$	39.062.100,00	
Value per square meter constructed with urban planning			$	930.050,00	
SMMLV with urban planning				50,00	
Construction time (weeks)				40,00	
Indirect construction cost of each house	€	2.455,33	$	8.593.662,00	
Indirect construction cost in SMMLV				11,00	
Differences					
Area				2,55	6,07%
Direct construction cost of each house with urban planning			$	3.871.960,60	9,91%
Value per square meter constructed with urban planning			$	194.623,89	20,93%
SMMLV with urban planning				4,96	9,91%
Construction time (weeks)				32,00	80,00%
Indirect construction cost of each house	€	669,64	$	2.343.726,00	27,27%
Indirect construction cost in SMMLV				3,00	27,27%



ICC: Indirect Construction Cost
DCC: Direct Construction Cost
SMMLV: Minimum Montly Wages

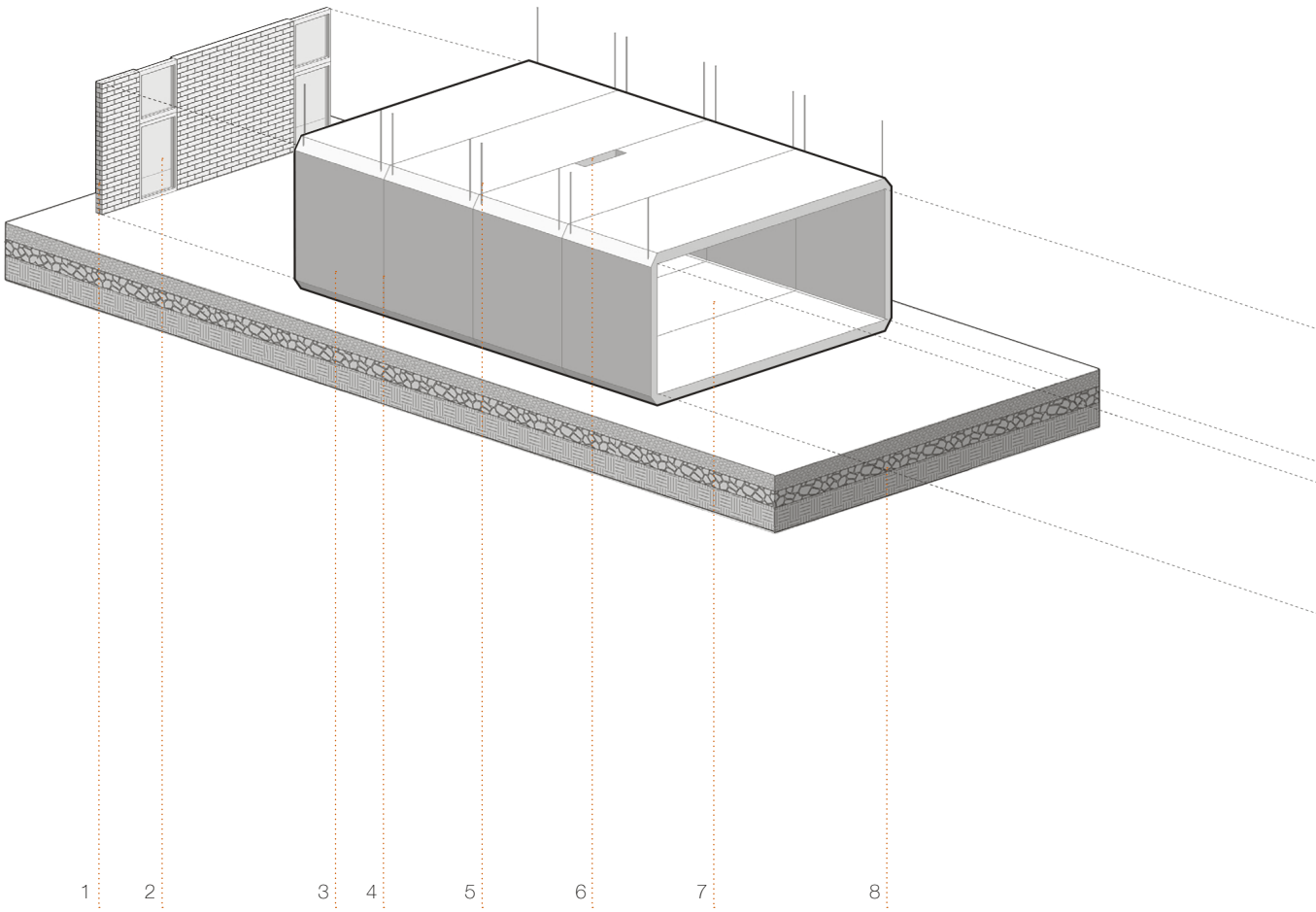
Annex 3 Components of the system

Linear industrialized frames

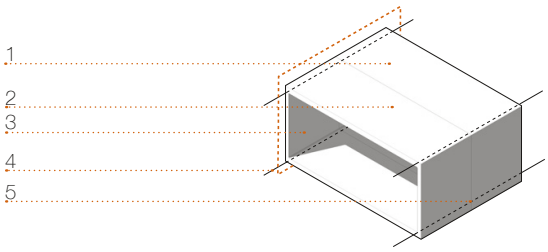
1. Facade: non-structural walls
2. Windows
3. Structural elements: Frames in precast reinforced concrete
4. Joints between structural elements: Neoprene seals or cement mortars
5. Reinforcements in metal bars, according to structural design
6. Space for the location of technical installations
7. Structural floor slab in precast reinforced concrete
8. Improved and Confined soil, according to seismic zone and type of soil
9. Non-structural interior walls in the bedroom area
10. Non-structural interior walls in the service area
11. Technical Installations
12. Kitchen Furniture
13. Non-structural facade walls

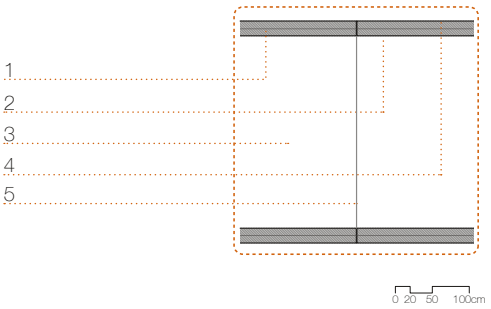
Constructive Details

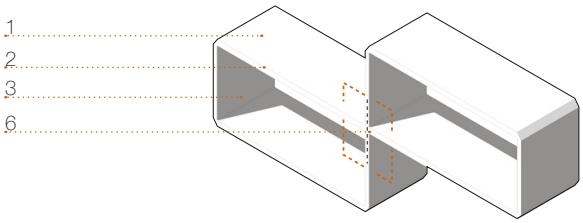
1. Structural frame in precast reinforced concrete
2. Structural slab in precast reinforced concrete
3. Structural wall in precast reinforced concrete
4. Internal post-tensioned metal reinforcements with specifications according to structural design
5. Joint between structural frameworks
6. Union between structural frames by geometric assembly
7. Internal metal reinforcements with specifications according to structural designs

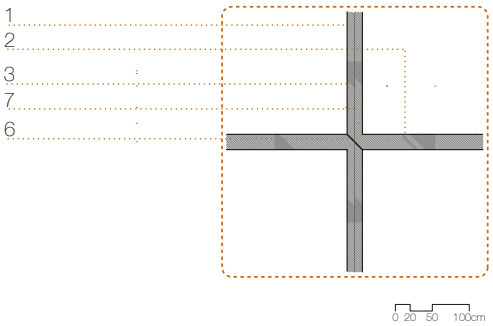


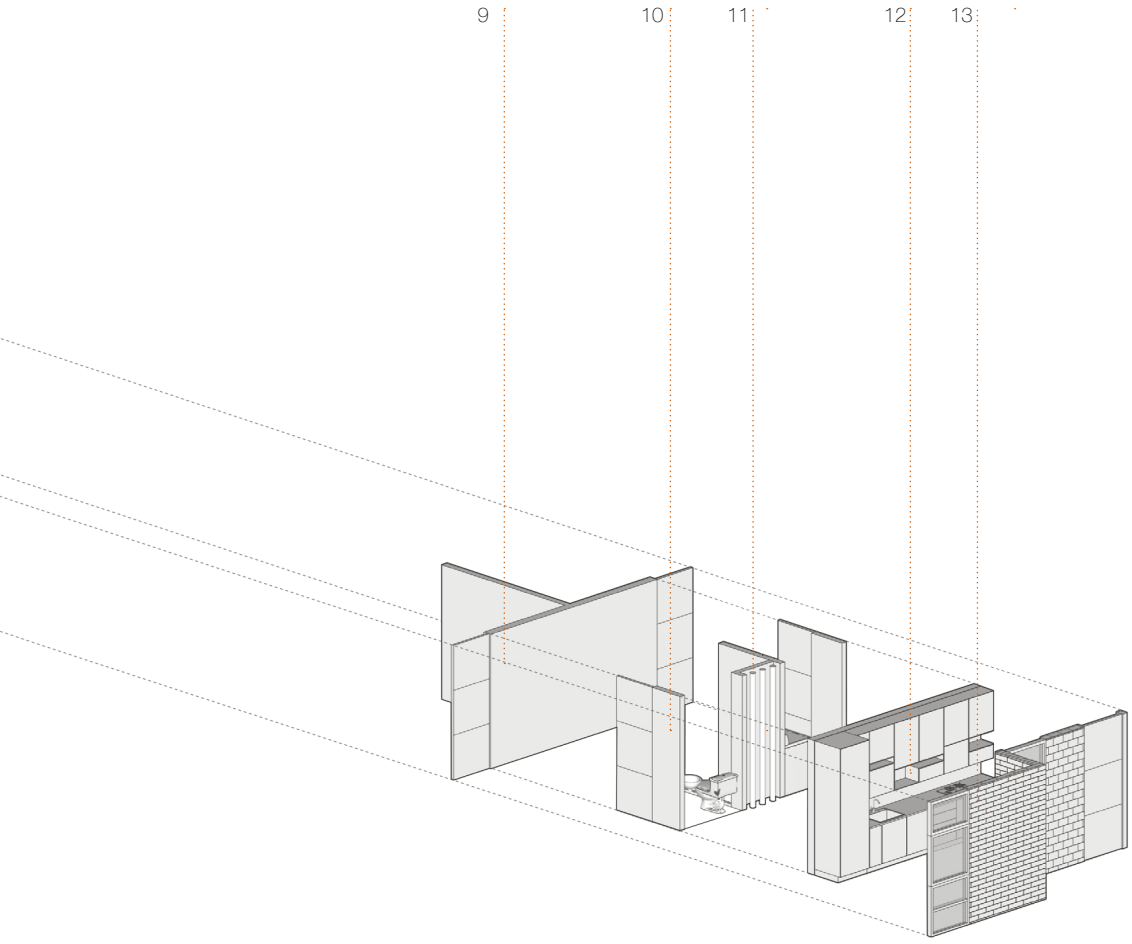
Constructive Details











Linear industrialized frames

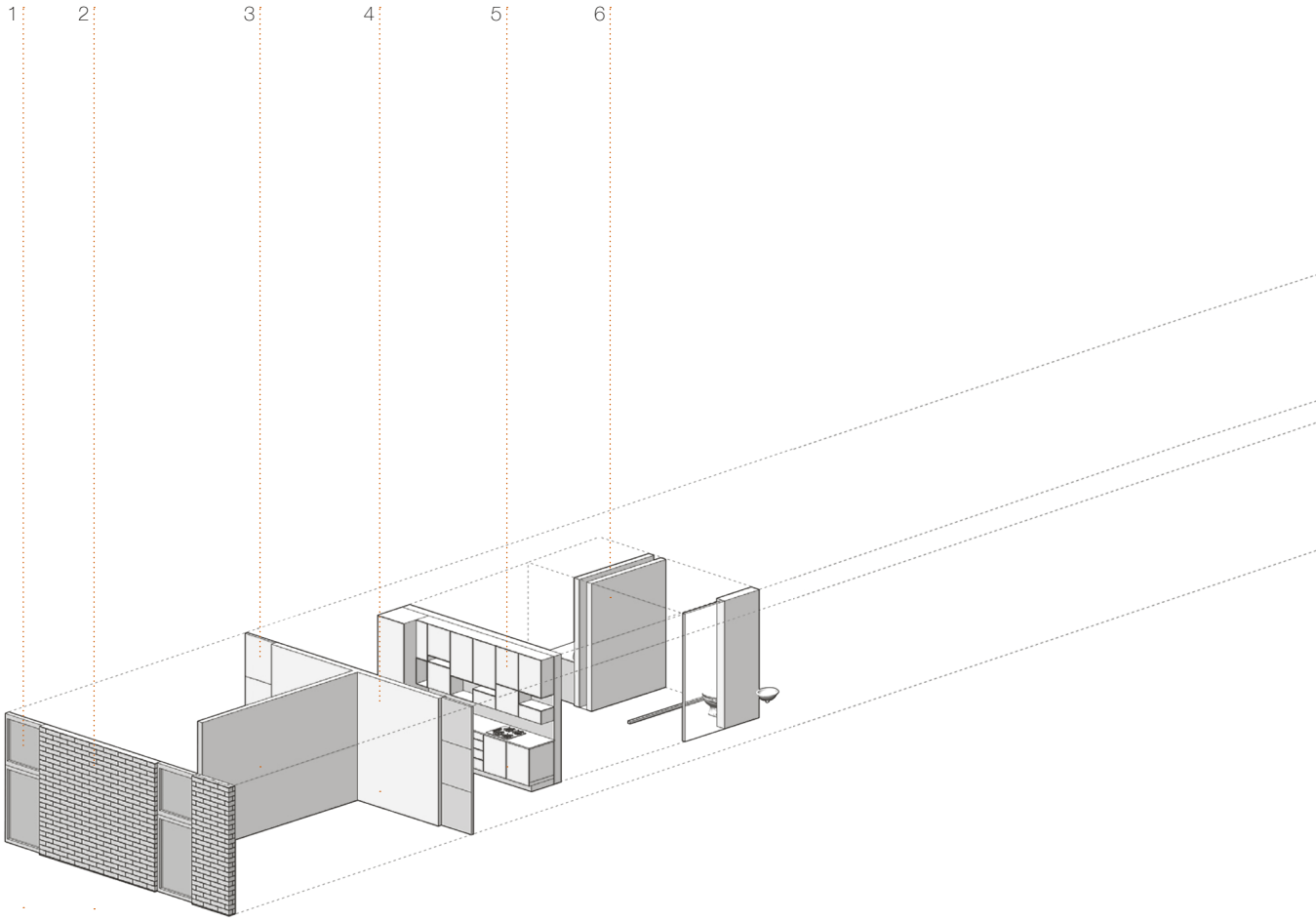
0 1 2 5m

Transversal industrialized frames

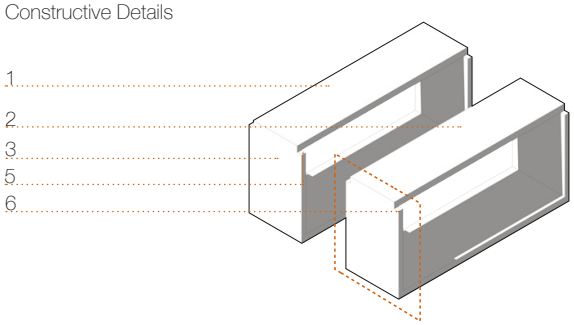
1. Windows
2. Non-structural facade walls
3. Non-structural interior walls in the bedroom area
4. Interior walls
5. Kitchen furniture
6. Technical installations
7 Windows
8. Structural wall in precast reinforced concrete
9. Structural slab in precast reinforced concrete
10. Structural frame in precast reinforced concrete
11. Reinforcements in metal bars, according to structural design
12. Space for the location of technical installations
13. Windows
14. Confined soil, according to seismic zone

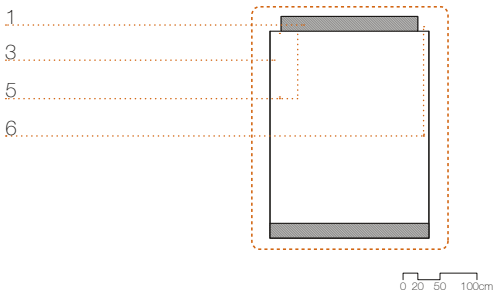
Constructive Details

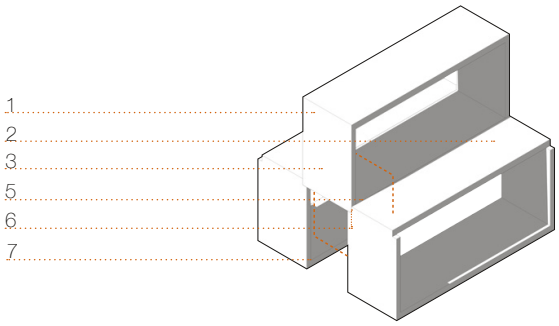
1. Structural frame in precast reinforced concrete
2. Structural slab in precast reinforced concrete
3. Structural wall in precast reinforced concrete
4. Internal post-tensioned metal reinforcements with specifications according to structural design
5. Joint between structural frameworks
6. Union between structural frames by geometric assembly
7. Internal metal reinforcements with specifications according to structural designs

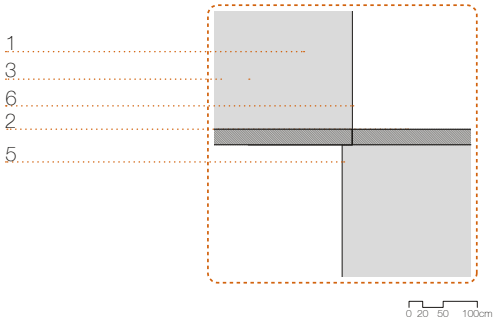


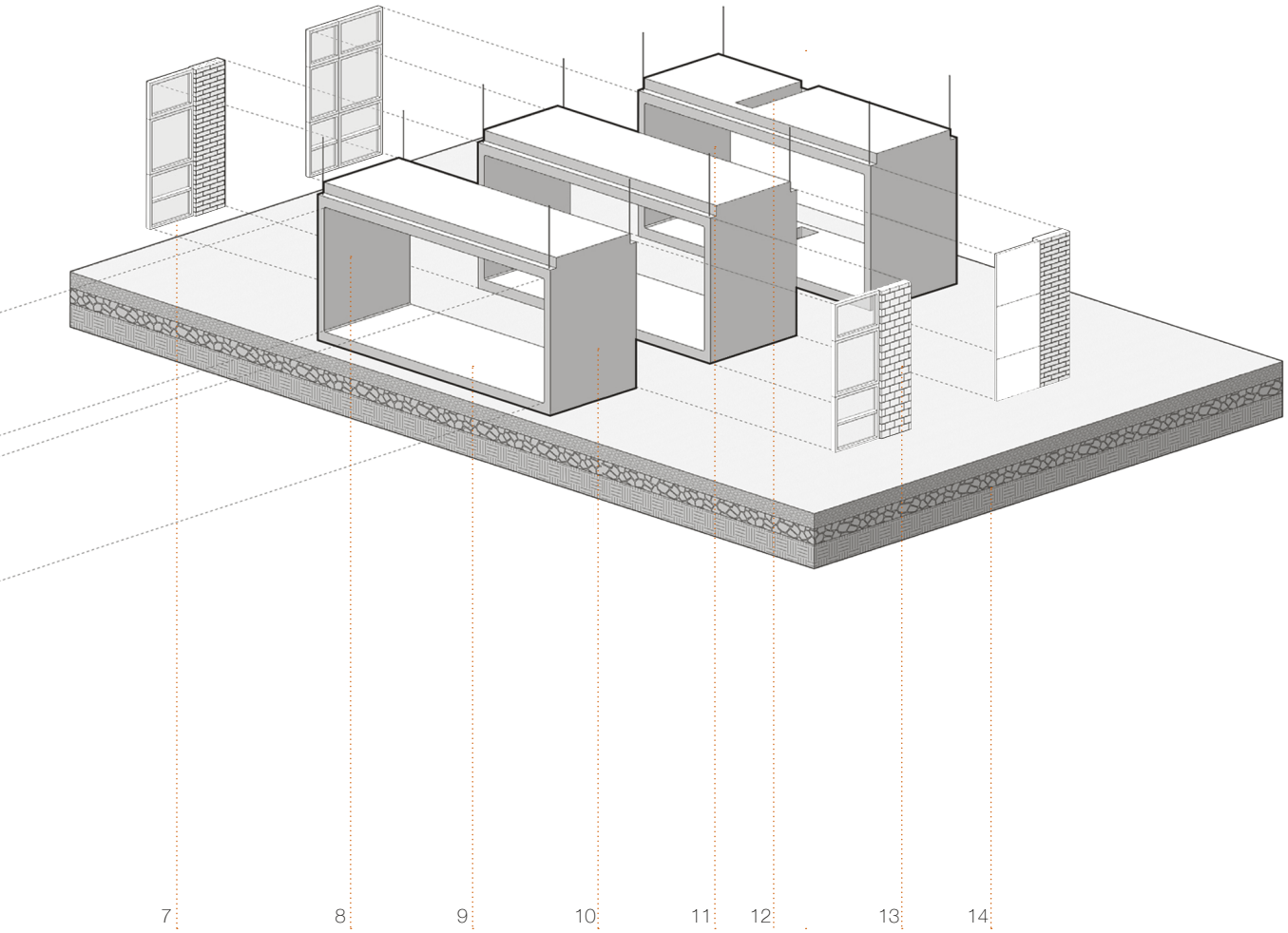
Constructive Details







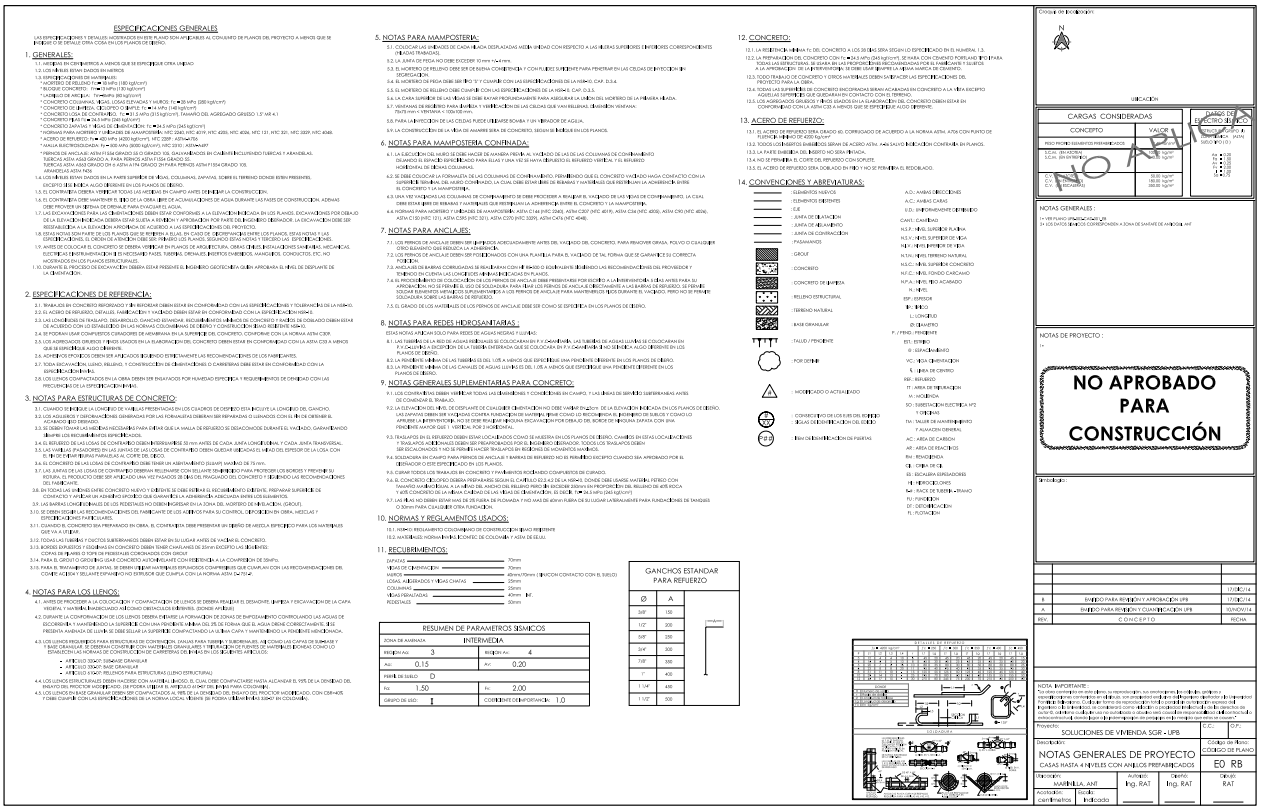


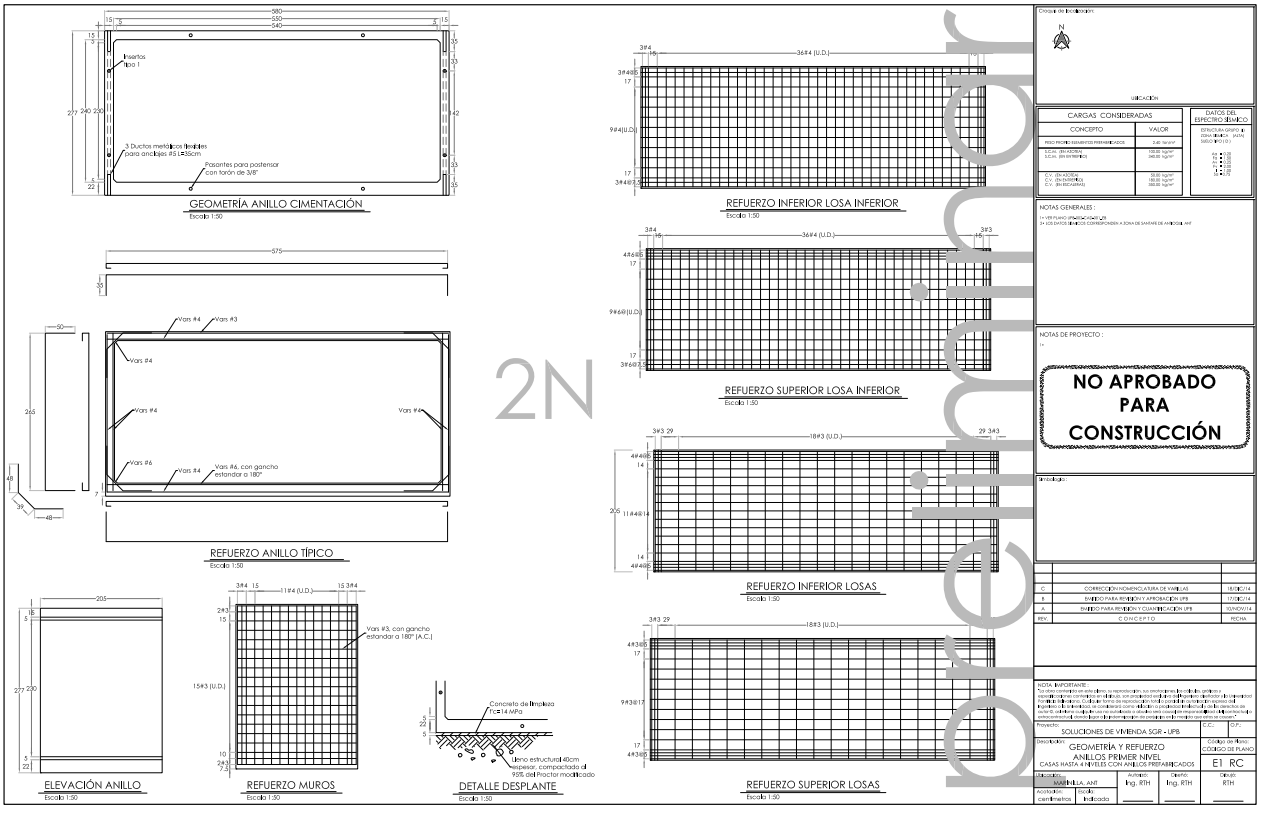


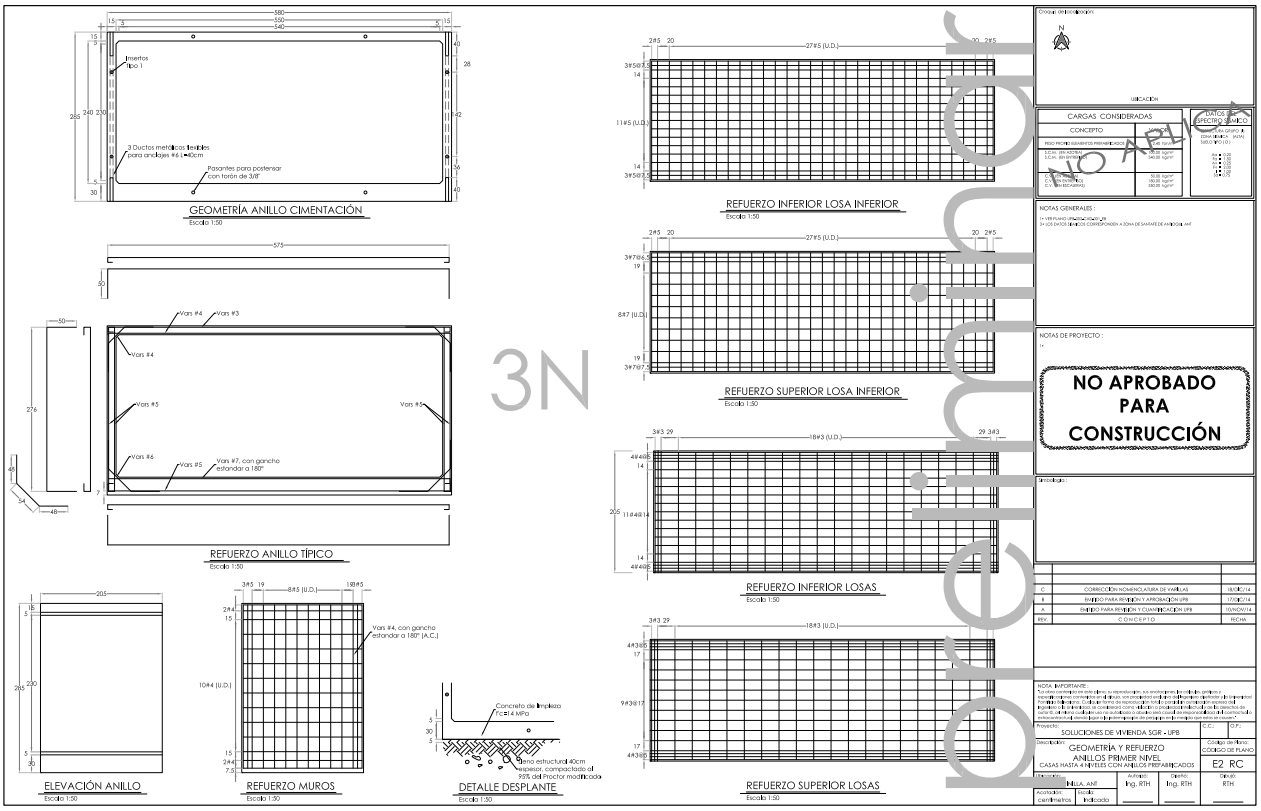
Transversal industrialized frames

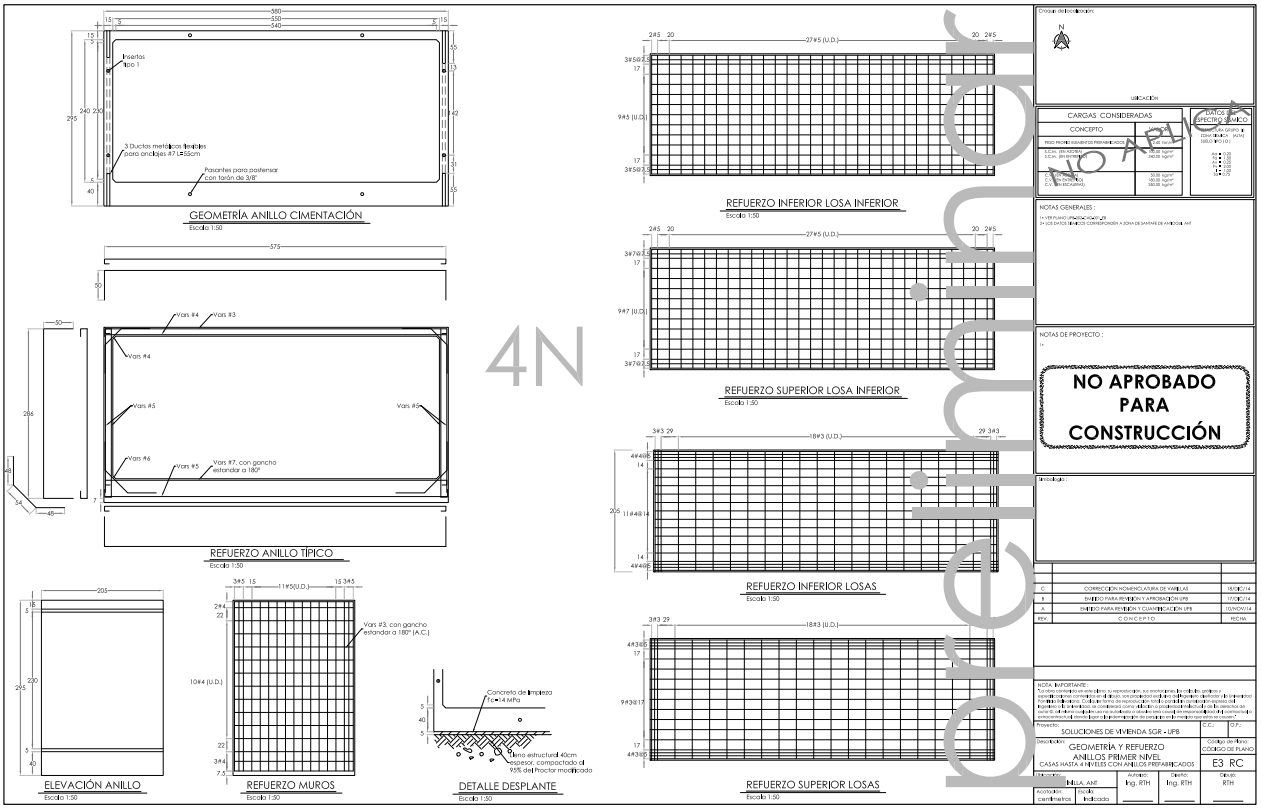


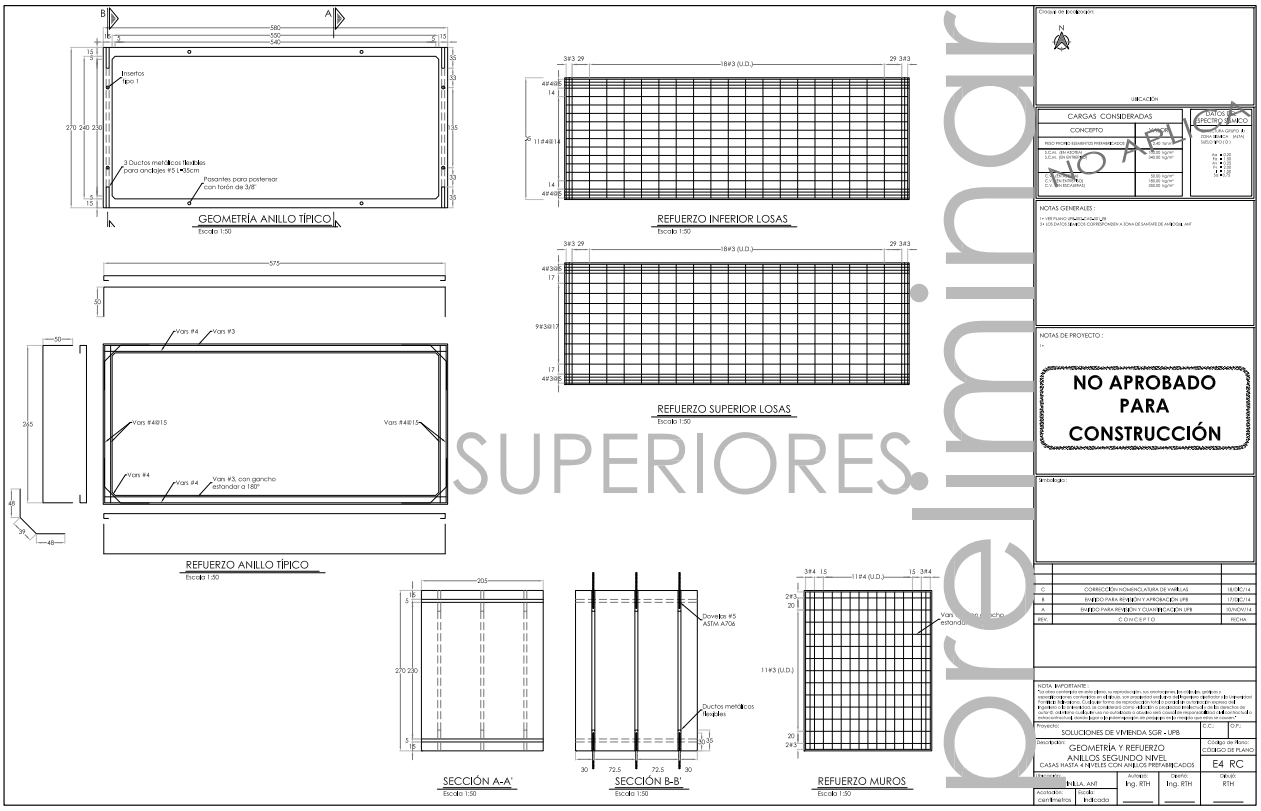
Annex 4 Structural plans

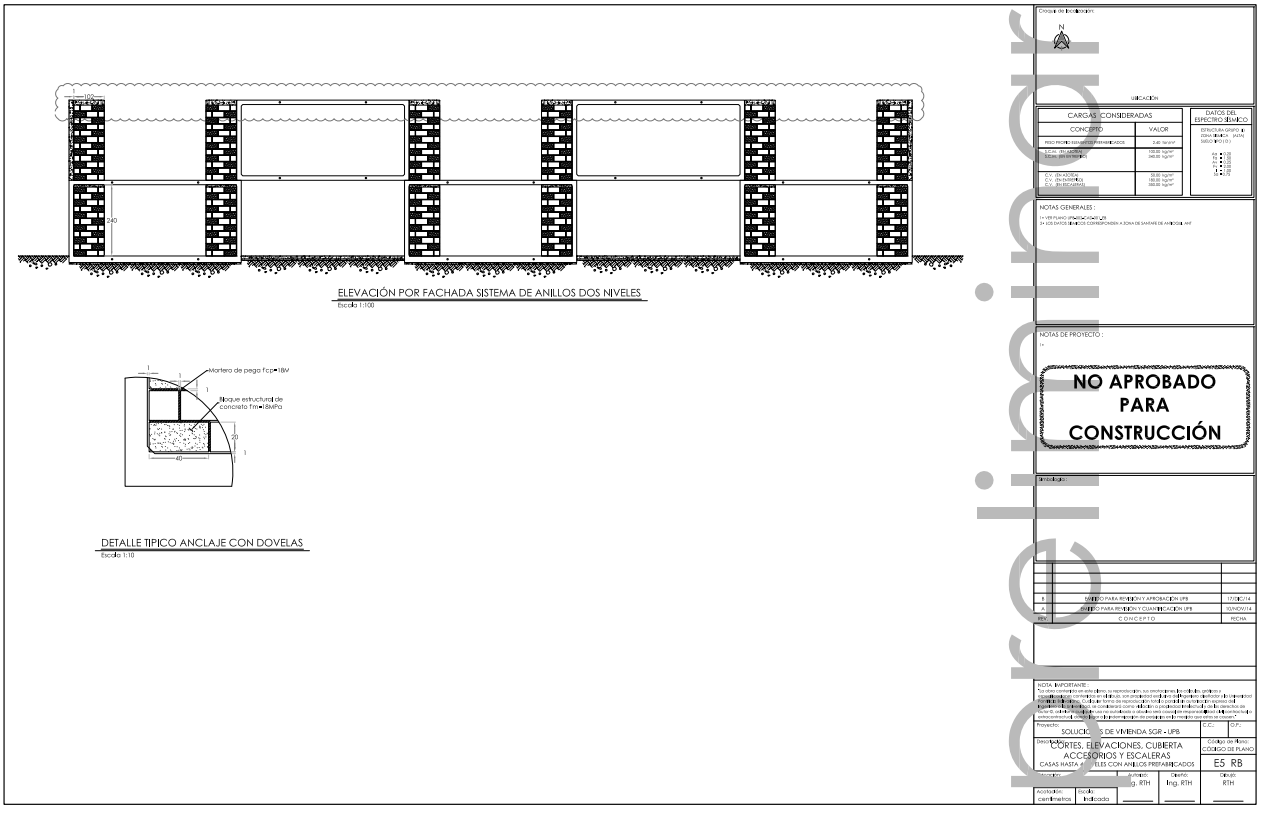

ESPECIFICACIONES GENERALES
1. GENERALES:
2. ESPECIFICACIONES DE REFERENCIA:
3. NOTAS PARA ESTRUCTURAS DE CONCRETO:
4. NOTAS PARA LOS LLENOS:
5. NOTAS PARA MAMPOSTERIA:
6. NOTAS PARA MAMPOSTERIA CONFINADA:
7. NOTAS PARA ANCLAJES:
8. NOTAS PARA REDES HIDROSANITARIAS:
9. NOTAS GENERALES SUPLEMENTARIAS PARA CONCRETO:
10. NORMAS Y REGLAMENTOS USADOS:
11. RECUBRIMIENTOS:
12. CONCRETO:
13. ACERO DE REFUERZO:
14. CONVENCIONES Y ABREVIATURAS:
RESUMEN DE PARAMETROS SISMICOS
GANCHOS ESTANDAR PARA REFUERZO
CARGAS CONSIDERADAS
NOTAS GENERALES:
NOTAS DE PROYECTO:
NO APROBADO PARA CONSTRUCCIÓN
SOLUCIONES DE VIVIENDA SGR - LPB
NOTAS GENERALES DE PROYECTO
CASAS HASTA 4 NIVELES CON ANILLOS PREFABRICADOS
E0 RB

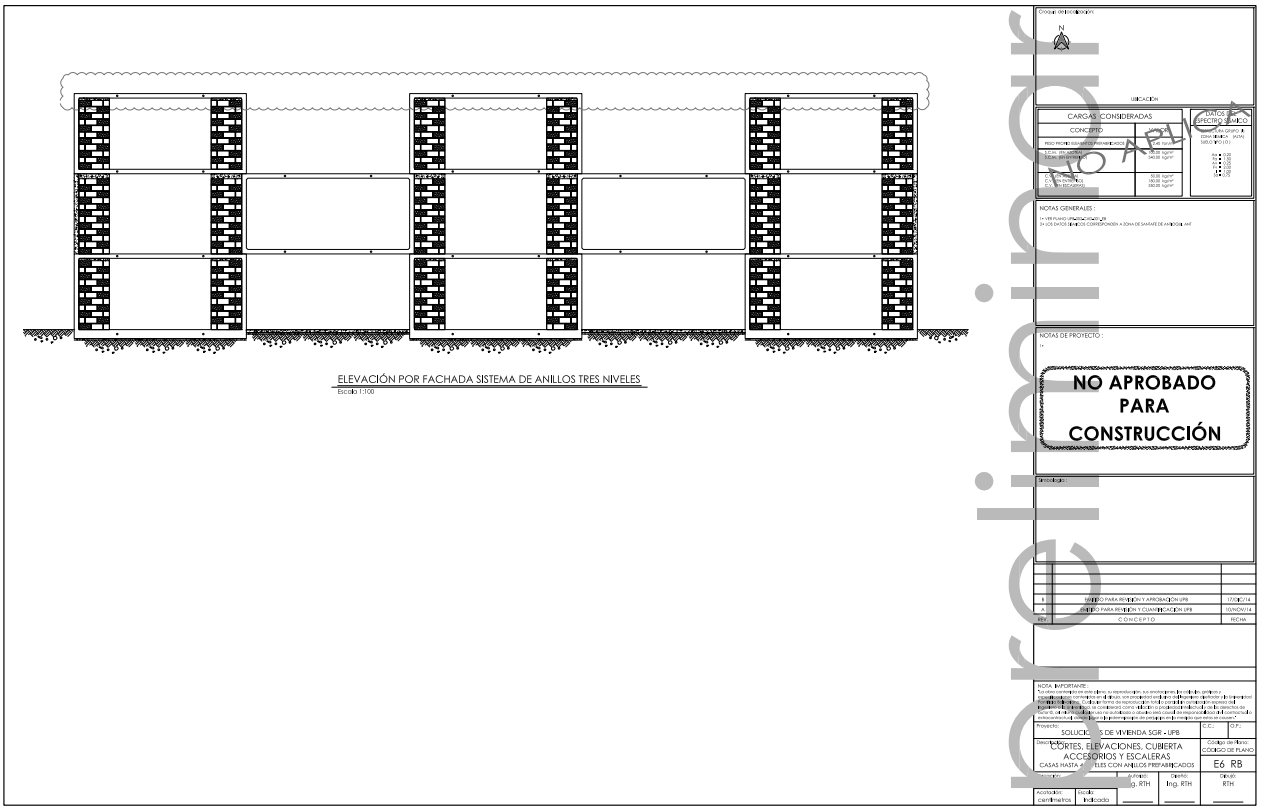

GEOMETRÍA ANILLO CIMENTACIÓN
Escala 1:50
REFUERZO INFERIOR LOSA INFERIOR
Escala 1:50
REFUERZO SUPERIOR LOSA INFERIOR
Escala 1:50
REFUERZO ANILLO TÍPICO
Escala 1:50
REFUERZO INFERIOR LOSAS
Escala 1:50
ELEVACIÓN ANILLO
Escala 1:50
REFUERZO MUROS
Escala 1:50
DETALLE DESPLANTE
Escala 1:50
REFUERZO SUPERIOR LOSAS
Escala 1:50
2N
NOTAS GENERALES:
NOTAS DE PROYECTO:
NO APROBADO PARA CONSTRUCCIÓN
SOLUCIONES DE VIVIENDA SGR - LPB
GEOMETRÍA Y REFUERZO
ANILLOS PRIMER NIVEL
CASAS HASTA 4 NIVELES CON ANILLOS PREFABRICADOS
E1 RC

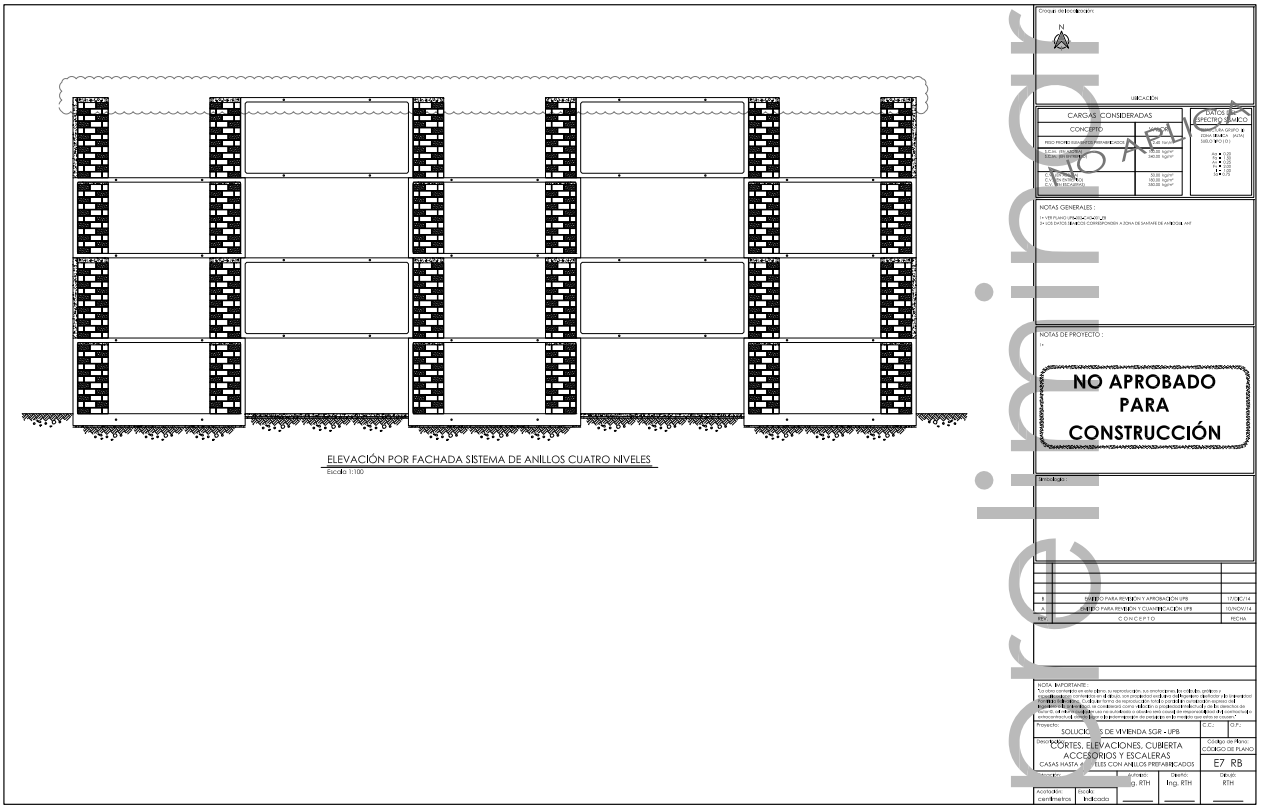

3N
GEOMETRÍA ANILLO CIMENTACIÓN
Escala 1:50
REFUERZO ANILLO TÍPICO
Escala 1:50
ELEVACIÓN ANILLO
Escala 1:50
REFUERZO MUROS
Escala 1:50
DETALLE DESPLANTE
Escala 1:50
REFUERZO INFERIOR LOSA INFERIOR
Escala 1:50
REFUERZO SUPERIOR LOSA INFERIOR
Escala 1:50
REFUERZO INFERIOR LOSAS
Escala 1:50
REFUERZO SUPERIOR LOSAS
Escala 1:50
NO APROBADO PARA CONSTRUCCIÓN
SOLUCIONES DE VIVIENDA SGR - UPB
GEOMETRÍA Y REFUERZO
ANILLOS PRIMER NIVEL
CASAS HASTA 4 NIVELES CON ANILLOS PREFABRICADOS
E2 RC
preliminar

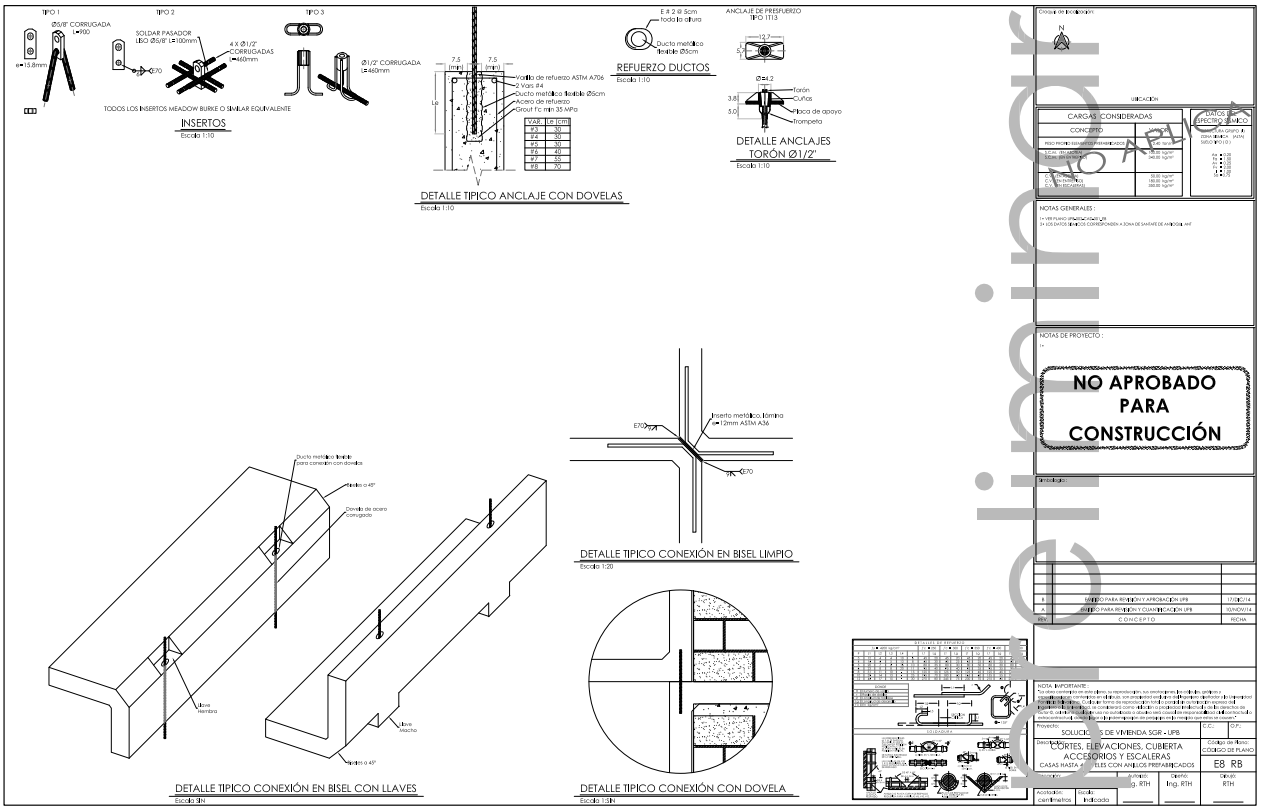

4N
GEOMETRÍA ANILLO CIMENTACIÓN
Escala 1:50
REFUERZO ANILLO TÍPICO
Escala 1:50
ELEVACIÓN ANILLO
Escala 1:50
REFUERZO MUROS
Escala 1:50
DETALLE DESPLANTE
Escala 1:50
REFUERZO INFERIOR LOSA INFERIOR
Escala 1:50
REFUERZO SUPERIOR LOSA INFERIOR
Escala 1:50
REFUERZO INFERIOR LOSAS
Escala 1:50
REFUERZO SUPERIOR LOSAS
Escala 1:50
NO APROBADO PARA CONSTRUCCIÓN
SOLUCIONES DE VIVIENDA SGR - UPB
GEOMETRÍA Y REFUERZO
ANILLOS PRIMER NIVEL
CASAS HASTA 4 NIVELES CON ANILLOS PREFABRICADOS
E3 RC
preliminar


GEOMETRÍA ANILLO TÍPICO
Escala 1:50
REFUERZO INFERIOR LOSAS
Escala 1:50
REFUERZO SUPERIOR LOSAS
Escala 1:50
REFUERZO ANILLO TÍPICO
Escala 1:50
SECCIÓN A-A'
Escala 1:50
SECCIÓN B-B'
Escala 1:50
REFUERZO MUROS
Escala 1:50
NO APROBADO PARA CONSTRUCCIÓN
SOLUCIONES DE VIVIENDA SGR - UPB
GEOMETRÍA Y REFUERZO ANILLOS SEGUNDO NIVEL
CASAS HASTA 4 NIVELES CON ANILLOS PREFABRICADOS
E4 RC
preliminar
SUPERIORES.


ELEVACIÓN POR FACHADA SISTEMA DE ANILLOS DOS NIVELES
Escala 1:100
DETALLE TIPICO ANCLAJE CON DOVELAS
Escala 1:10
NO APROBADO PARA CONSTRUCCIÓN
SOLUCIONES DE VIVIENDA SGR - UPB
CORTES, ELEVACIONES, CUBIERTA ACCESORIOS Y ESCALERAS
CASAS HASTA 4 NIVELES CON ANILLOS PREFABRICADOS
E5 RB
preliminar


ELEVACIÓN POR FACHADA SISTEMA DE ANILLOS TRES NIVELES
Escala 1:100
NO APROBADO PARA CONSTRUCCIÓN
preliminar


ELEVACIÓN POR FACHADA SISTEMA DE ANILLOS CUATRO NIVELES
Escala 1:100
NO APROBADO PARA CONSTRUCCIÓN
preliminar



Preliminary

Annex 5 Patent certification document

REPÚBLICA DE COLOMBIA
SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO

Resolución N° 81016

Ref. Expediente N° 15096687

Por la cual se otorga una Patente de Invención

EL SUPERINTENDENTE DE INDUSTRIA Y COMERCIO
en ejercicio de sus facultades legales, en especial de las conferidas en el numeral 26 del artículo 3° del Decreto 4886 de 2011, y

CONSIDERANDO:

PRIMERO: Que mediante escrito radicado en esta Superintendencia el 28 de abril de 2015 con el N° 15-96687-0000-0000, por UNIVERSIDAD PONTIFICIA BOLIVARIANA, presentó la solicitud de patente de invención titulada "SISTEMA CONSTRUCTIVO MODULAR PREFABRICADO".

SEGUNDO: Que el extracto de esta solicitud fue publicado en la Gaceta de la Propiedad Industrial Nº 743 el 30 de octubre de 2015, sin que se hubieran presentado oposiciones por parte de terceros.

TERCERO: Que realizado el examen de fondo mediante Oficio N° 8325, notificado el 12 de junio de 2017, se requirió al solicitante en los términos del artículo 45 de la Decisión 486 de la Comisión de la Comunidad Andina para que presentara respuesta a las observaciones de carácter técnico, relacionadas con la patentabilidad o cumplimiento de los requisitos establecidos por esta Decisión para la concesión de la patente.

CUARTO: Que el solicitante mediante escrito radicado bajo el N° 15096687 el 07 de septiembre de 2017, respondió oportunamente el requerimiento formulado y presenta(n) nueva(s) reivindicación(es) 1 a 31 que reemplaza(n) la(s) originalmente presentada(s), atendiendo de esta manera las observaciones efectuadas en el examen de fondo. Se acepta este último capítulo reivindicatorio presentado, comoquiera que se ajusta a las prescripciones contenidas en el artículo 34 de la Decisión 486.

QUINTO: Que en virtud de lo dispuesto en el artículo 14 de la Decisión 486 expedida por la Comisión de la Comunidad Andina *"Los países miembros otorgarán patentes para las invenciones, sean de producto o de procedimiento, en todos los campos de la*

Superintendencia de Industria y Comercio
Cra 13 No. 27- 00 pisos 1, 3, 4, 5, 6, 7 y 10 PBX: (571) 5870000
Call center: (571) 5920400 Línea gratuita nacional: 01800-910165
www.sic.gov.co - E-mail: contactenos@sic.gov.co - Bogotá D.C. - Colombia.

REPÚBLICA DE COLOMBIA
SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO

Resolución N° 81016

Ref. Expediente N° 15096687

tecnología, siempre que sean nuevas, tengan nivel inventivo y sean susceptibles de aplicación industrial."

SEXTO: Que en el presente caso la(s) reivindicación(es) 1 a 31 incluida(s) en el radicado bajo el N° 15096687 el 07 de septiembre de 2017, cumple(n) los requisitos indicados en el considerando anterior y, en consecuencia, este Despacho encuentra procedente conceder para la(s) misma(s) la patente solicitada.

RESUELVE

ARTÍCULO PRIMERO: Otorgar patente de invención para la creación titulada:

"SISTEMA CONSTRUCTIVO MODULAR PREFABRICADO"

Clasificación IPC: *E04B 1/00, E04B 1/04.*

Reivindicación(es): *1 a 31 incluida(s) en el radicado bajo el No 15096687 el 07 de septiembre de 2017.*

Titular(es): *UNIVERSIDAD PONTIFICIA BOLIVARIANA.*

Domicilio(s): *Circular 1 No. 73 – 66, Medellín, MEDELLIN, ANTIOQUIA, COLOMBIA.*

Inventor(es): *ALEJANDRO RESTREPO MONTOYA y FELIPE BERNAL HENAO.*

Vigente desde: *28 de abril de 2015* ***Hasta:*** *28 de abril de 2035.*

ARTÍCULO SEGUNDO: El titular tendrá los derechos y las obligaciones establecidos en la Decisión 486 de la Comisión de la Comunidad Andina y en las demás disposiciones legales vigentes sobre propiedad industrial, precisando que para mantener vigente la patente se deberá cancelar la tasa anual de mantenimiento, conforme lo dispone el artículo 80 de la referida norma comunitaria.

ARTÍCULO TERCERO: Notificar el contenido de la presente resolución a la UNIVERSIDAD PONTIFICIA BOLIVARIANA advirtiéndole que contra ella procede el recurso de reposición, ante el Superintendente de Industria y Comercio, el cual podrá

Superintendencia de Industria y Comercio
Cra 13 No. 27- 00 pisos 1, 3, 4, 5, 6, 7 y 10 PBX: (571) 5870000
Call center: (571) 5920400 Línea gratuita nacional: 01800-910165
www.sic.gov.co - E-mail: contactenos@sic.gov.co - Bogotá D.C. - Colombia.

REPÚBLICA DE COLOMBIA
SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO

Resolución N° 81016

Ref. Expediente N° 15096687

ser interpuesto en el momento de la notificación o dentro de los diez (10) días hábiles siguientes a ella.

NOTIFÍQUESE Y CÚMPLASE
Dada en Bogotá D.C., a los 7 de diciembre de 2017

PABLO FELIPE ROBLEDO DEL CASTILLO
Superintendente de Industria y Comercio

Superintendencia de Industria y Comercio
Cra 13 No. 27- 00 pisos 1, 3, 4, 5, 6, 7 y 10 PBX: (571) 5870000
Call center: (571) 5920400 Línea gratuita nacional: 01800-910165
www.sic.gov.co - E-mail: contactenos@sic.gov.co - Bogotá D.C. - Colombia.

Patent certification document
Translation from the original document available at:

http://sipi.sic.gov.co/sipi/Extra/IP/PT/Qbe.aspx?sid=636519837010381498
Keyword/Application number: 15096687

THE REPUBLIC OF COLOMBIA
THE SUPERINTENDENCY OF INDUSTRY AND COMMERCE
CARRERA 13 NUMBER 27 – 00, FLOORS 1, 3, 4, 5, 6, 7 AND 10
BOGOTÁ, D. C., COLOMBIA
TELEPHONE: (+57 1) 587 – 0000 / CALL CENTER: (+57 1) 592 – 0400
www.sic.gov.co / EMAIL: contactenos@sic.gov.co
RESOLUTION NUMBER 81016

File Reference Number 15096687

Through which an Invention Patent is granted

THE SUPERINTENDENCY OF INDUSTRY AND COMMERCE
in exercising its legal powers, especially those conferred in Number 26
of Article 3 of Decree 4886 of 2001, and

CONSIDERING:

FIRST: Through a writing filed in this Superintendency on April 28, 2015, with Number 15-96687-0000-0000 by UNIVERSIDAD PONTIFICIA BOLIVARIANA, a request for an invention patent entitled "PREFABRICATED MODULAR CONSTRUCTIVE SYSTEM" was presented.

SECOND: The extract of this request was published in the Industrial Property Gazette (Gaceta de la Propiedad Industrial) Number 743 on October 30, 2015, without oppositions having been presented by third parties.

THIRD: Having conducted an exhaustive examination through Communiquè Number 8325, notified on June 12, 2017, in the terms of Article 45 of Decision 486 of the Andean Community Commission, the applicant was required to present a response to the observations of a technical nature, related to the patentability or compliance of the requirements established by this Decision for the granting of the patent.

FOURTH: Through a writing filed under Number 15096687 on September 7, 2017, the applicant responded the requirement formulated in a timely manner and presented new assertion(s) 1 to 31, which replaced those originally presented, thus attending the observations made in the exhaustive examination. This last assertion chapter presented is accepted, howsoever it adjusts to the prescriptions contained in Article 34 of Decision 486.

FIFTH: By virtue of the provision in Article 14 of Decision 486 issued by the Andean Community Commission: "Member countries shall grant patents for inventions, either of a product or a procedure, in all the fields of technology, provided that they are new, have an inventive level and are susceptible to industrial application."

SIXTH: In this case, the assertion(s) 1 to 31 inclusive in the file under Number 15096687 of September 7, 2017, comply with the requirements indicated in the previous Consideration and, consequently, this Office finds it appropriate to grant the patent requested thereof.

RESOLVED

ARTICLE ONE: Grant the invention patent for the creation entitled:

"PREFABRICATED MODULAR CONSTRUCTIVE SYSTEM"

International Patent Classification (IPC): E04B 1/00, E04B 1/04

Assertion(s): 1 to 31 included in the File under Number 15096687 of September 7, 2017.

Holder(s): UNIVERSIDAD PONTIFICIA BOLIVARIANA

Domicile(s): Circular 1 Number 73 – 66; Medellín; MEDELLÍN, ANTIOQUIA, COLOMBIA

Inventor(s): ALEJANDRO RESTREPO MONTOYA and FELIPE BERNAL HENAO

Valid from: April 28, 2015 Until: April 28, 2035

ARTICLE TWO: The Holder shall have the rights and obligations established in Decision 486 of the Andean Community Commission and in the other current legal provisions regarding industrial property, specifying that, to maintain the patent valid, an annual maintenance fee shall be paid, in accordance with the provision in Article 80 of the referred-to Community Regulations.

ARTICLE THREE: Notify the content of this Resolution to UNIVERSIDAD PONTIFICIA BOLIVARIANA, warning it that against it, it may present an appeal, before the Superintendency of Industry and Commerce, which may be interposed at the time of notification or within the ten (10) business days following the notification.

TO BE NOTIFIED AND FULFILLED

Given in Bogotá, D. C., on December 7, 2017.

Illegible signature
PABLO FELIPE ROBLEDO DEL CASTILLO
Superintendent of Industry and Commerce

Concrete Home

Precast Concrete as a System to Improve Efficiency in the Design and Construction of Social Housing in Antioquia.

Author

Alejandro Restrepo-Montoya. Architect, Professor at *Universidad Pontificia Bolivariana* (UPB)
Faculty of Architecture. Medellín, Colombia.
Director of Strategic Urban Projects for Medellín, Colombia, 2016 – 2020
Scientific Ambassador for the German Academic Exchange Service (*Deutscher Akademischer Austauschdienst,* DAAD) in Colombia.

Director

Professor Florian Musso, Architect. Technische Universität Munchen (TUM). Faculty of Architecture. *Lehrstuhl für Entwerfen, Baukonstruktion und Baustoffkunde* (EBB). Munich, Germany.

Advisor

Professor Hubert Klumpner, Architect. Department of Architecture D-ARCH, *Eidgenössische Technische Hochschule* (ETH). Chair of Architecture and Urban Design. Zürich, Switzerland.

Technical group for the construction of prototypes (in alphabetical order)

Iván Darío Solano Mejía., Architect. Hydro sanitary design
Jesús Abelino Saldarriaga Molina, Civil engineer. Electrical and lighting advisor
Jorge Eduardo Arbeláez Rojas, Civil engineer. Structural design
Juan Fernando Gómez Ángel, Civil engineer. *Proyectar* Architectural Budget Firm. Medellín, Colombia
Martha Lucía Gómez, Civil engineer. Construction of the prototypes
Nathalie Rúa Alzate, Civil engineer. Proyectar Architectural Budget Firm. Medellín, Colombia
Ricardo Trujillo Henao. Civil engineer. Structural design

This work has been developed with the support of (in alphabetical order):

Deutscher Akademischer Austausch Dienst (DAAD). Bonn, Germany
Technische Universität München (TUM). Munich, Germany
Universidad Pontificia Bolivariana (UPB). Medellín, Colombia

Graphics (in alphabetical order)

Alejandro Restrepo-Montoya, Architect. Professor *Universidad Pontificia Bolivariana* (UPB), Faculty of Architecture. Medellín, Colombia
Daniel Molina, Architect. *Universidad Nacional* (UNAL). Medellín, Colombia
Daniel Zuluaga, Architect. *Universidad Nacional* (UNAL). Medellín, Colombia
Juliana Zapata Agudelo, Architect. *Universidad Pontificia Bolivariana* (UPB). Medellín, Colombia
Sebastián Ramírez Arroyave, Architect. *Universidad Nacional* (UNAL). Medellín, Colombia

English Grammatical Revision

Jane S. Losada, Ed. D.

This dissertation has been written in:

The *Technische Universität München* (TUM). Faculty of Architecture. L*ehrstuhl für Entwerfen, Baukonstruktion und Baustoffkunde* (EBB). Munich, Germany
Universidad Pontificia Bolivariana (UPB). Faculty of Architecture. *Laboratorio de Estudios y Experimentación Técnica en Arquitectura* (LEET) and *Laboratorio de Arquitectura y Urbanismo* (LAUR). Medellín, Colombia

Content

	Preface	
	Introduction	**3**
1	**Problem**	**5**
1.1	The problem in quantitative terms	6
1.2	The problem in qualitative terms	6
1.3	Current policy of social housing	7
1.3.1	Priority Social-Interest Housing (Vivienda de Interés Social Prioritario, VIP)	7
1.3.2	Social-Interest Housing (Vivienda de Interés Social, VIS)	8
1.4	The deficit	8
1.4.1	The quantitative deficit	9
1.4.1.1	Construction cost	9
1.4.1.2	Construction time	9
1.4.2	The qualitative deficit	9
1.4.2.1	Objective criteria: Non-compliance of minimum social housing requirements	10
1.4.2.2	Subjective criteria: Informal processes of planning and building	10
1.4.3	The accumulated deficit	10
1.4.3.1	The accumulated deficit in 1993	10
1.4.3.2	The accumulated deficit in 2005	10
1.4.4	Variations in the deficit	10
1.4.4.1	Quantitative	11
1.4.4.2	Qualitative	11
1.4.4.3	Accumulated	12
1.5	Hypothesis	12
1.5.1	Industrialization: serial production of structural elements	12
1.5.2	Customization: individualization during design, production and construction	12
1.5.3	Transformation: improvement and personal contribution after occupation	13
	Summary	14
2	**Context**	**17**
2.1	Geography	18
2.1.1	Topography	18
2.1.2	Seismology	18
2.1.3	Hydrography	18
2.1.4	Climate	19
2.2	Society	19
2.2.1	Population	19
2.2.2	Culture	20
2.2.3	Quality of life	20
2.3	Economy	21
2.4	Infrastructure	21
2.4.1	Transport	21
2.4.2	Public utilities	22
2.5	Industry	22
2.6	Political context	22
2.7	Precast concrete: technical regulations	22
	Summary	24
3	**Social Housing**	**27**
3.1	History and evolution of the concept of social housing	28
3.1.1	In Western Europe	28
3.1.1.1	Minimum housing	28
3.1.1.2	Mass housing	29
3.1.1.3	The neighborhood unit	29
3.1.2	In Latin America	30
3.1.2.1	Workers' housing	30
3.1.2.2	State housing	31
3.1.2.3	Experimental housing	31
3.1.3	In Colombia and Antioquia	32

3.1.3.1	Hygienist (1918-1942)	32
3.1.3.2	Institutional (1942-1965)	33
3.1.3.3	Transitional (1965-1972)	33
3.1.3.4	Corporate (1972-1991)	34
3.1.3.5	Conception of market and subsidies on demand (from 1991)	34
3.2	Urban, architectural and technical design of social housing in the XXI Century	36
3.2.1	Western Europe	40
3.2.1.1	Urban planning	40
3.2.1.2	Housing	40
3.2.1.2.1	Typologies	40
3.2.1.2.2	Program	40
3.2.1.3	Construction techniques	40
3.2.2	Latin America	41
3.2.2.1	Urban planning	41
3.2.2.2	Housing	41
3.2.2.2.1	Typologies	41
3.2.2.2.2	Program	41
3.2.2.3	Construction techniques	42
3.2.3	Colombia and Antioquia	42
3.2.3.1	Urban planning	42
3.2.3.2	Housing	42
3.2.3.2.1	Typologies	42
3.2.3.2.2	Program	42
3.2.3.3	Construction techniques	44
	Summary	45
4	**Precast-Concrete Technology**	**47**
4.1	Generalities	48
4.1.1	Continuity	48
4.1.1.1	Structural continuity	48
4.1.1.2	Spatial continuity	48
4.1.1.3	Constructive continuity	48
4.1.2	Flexibility	48
4.1.2.1	On an urban scale	48
4.1.2.2	On the scale of a building	49
4.1.2.3	On a housing scale	49
4.1.2.4	On the scale of other constructive subsystems	49
4.1.3	Prefabrication systems in concrete	49
4.1.3.1	Closed	49
4.1.3.2	Open	49
4.1.3.3	Partially industrialized	50
4.2	Components of precast reinforced concrete	50
4.2.1	Conglomerated material	50
4.2.2	Aggregates	50
4.2.3	Reinforcements	51
4.2.3.1	Linear	51
4.2.3.1.1	Passive reinforcements	51
4.2.3.1.2	Active reinforcements	51
4.2.3.2	Continuous	51
4.2.3.3	Discontinuous	51
4.2.4	Additives	52
4.2.5	Established developments	52
4.2.5.1	Lightweight precast concrete	53
4.2.5.1.1	With expanded aggregates	53
4.2.5.1.2	With wood particles	53
4.2.5.1.3	Cellular concrete	53
4.2.5.2	Precast concrete with recycled aggregates	54
4.2.5.2.1	Concrete with fly ash	54
4.2.5.2.2	Precast concrete with recycled materials from construction processes	54
4.2.5.2.3	Concretes with blast furnace slag cement	55
4.2.5.3	Precast concrete reinforced with textiles and fibers	55
4.2.5.3.1	Precast concrete reinforced with textile meshes	55

4.2.5.3.2 Steel-fiber reinforced precast concrete 56
4.2.5.3.3 Glass-fiber reinforced precast concrete (GRC) 56
4.2.5.3.4 Polyethylene-fiber reinforced precast concrete 56
4.2.5.4 Ultra High-Performance Precast Concrete (UHPC) 56
4.2.5.5 Pre-tensioned and post-tensioned precast concrete 57
4.2.5.5.1 Pre-tensioned precast concrete 57
4.2.5.5.2 Post-tensioned precast-concrete 58
4.2.6 Resistance evaluation 58
4.2.7 Technical design 59
4.3 Formworks 60
4.3.1 Rigid 60
4.3.1.1 Metallic 60
4.3.1.2 Wood boards 61
4.3.1.3 Wood slats 61
4.3.1.4 Polyester laminated with fiberglass 61
4.3.1.5 Glass fiber-reinforced concrete (GRC) 61
4.3.2 Flexible 61
4.4 Production 62
4.4.1 Industrial plants 62
4.4.2 Field factories 62
4.5 Transport 62
4.5.1 Ground transportation 62
4.5.1.1 Permissible weights and lengths 62
4.5.1.2 Characteristics and classification of roads 63
4.5.2 River transportation 63
4.5.2.1 Permissible weights and lengths 63
4.5.2.2 Characteristics and classifications of rivers 64
4.5.3 Rail transportation 64
4.5.3.1 Permissible weights and lengths 64
4.5.3.2 Characteristics and classifications of railroads 64
4.6 Structural systems 64
4.6.1 Skeletal 64
4.6.1.1 Elements 64
4.6.1.1.1 Foundations 64
4.6.1.1.2 Columns 65
4.6.1.1.3 Beams and joists 65
4.6.1.1.4 Consoles 67
4.6.1.1.5 Slabs 67
4.6.1.2 Joints 68
4.6.2 Walls 69
4.6.2.1 Elements 69
4.6.2.1.1 Foundations 69
4.6.2.1.2 Walls 70
4.6.2.1.3 Beams and joists 70
4.6.2.1.4 Consoles 70
4.6.2.1.5 Slabs 70
4.6.2.2 Joints 71
4.6.3 Spatial cells 71
4.6.3.1 Elements 72
4.6.3.1.1 Foundations 72
4.6.3.1.2 Cells 72
4.6.3.2 Joints 72
4.7 NSR-10 Regulations for the joints of precast elements 73
4.8 New developments: Outlook 75
4.8.1 Bio-concrete (Self-Healing Concrete) 75
4.8.2 Concrete reinforced with natural fibers 75
4.8.3 Concrete reinforced with nanoparticles 76
4.8.4 Transformable (post-formable, cutting or graphic) concrete 77
4.8.5 Textile formworks 77
Summary 79

5	**Case Studies**	**81**
5.1	1940s and 1950s	86
5.1.1	Camus System, France, 1948	86
5.1.2	Novoa - Sandino System, Cuba, 1950	92
5.1.3	G-57, Former Czechoslovakia, 1957	98
5.1.4	IMS System, Former Yugoslavia, 1957	104
5.1.5	1-335, Former Soviet Union, 1959	110
5.1.6	Other Projects	116
5.1.6.1	Muzú Neighborhood Unit (Unidad Vecinal Muzú). Bogotá, Colombia, 1949	116
5.1.6.2.	1-510, Former Soviet Union, 1957	116
5.1.6.3	K-7, Former Soviet Union, 1958	117
5.1.6.4	Large Panel IV (Gran Panel IV). Cuba, 1959	117
5.2	1960s	118
5.2.1	VAM, The Netherlands, 1961	118
5.2.2	Saint Andrews Dormitory, Scotland, 1964	124
5.2.3	Large Soviet Panel, Cuba, 1965	130
5.2.4	Skarne S66, Sweden, 1966	136
5.2.5	Habitat 67. Montreal, Canada, 1967	142
5.2.6	Other Projects	148
5.2.6.1.	PREVI Experimental Housing Project. Lima, Peru, 1966	148
5.2.6.1.1	Precast houses designed by James Stirling	148
5.2.6.1.2	Precast houses designed by Llanos and Mazzarri	148
5.2.6.1.3	Precast houses designed by ATELIER 5	149
5.2.6.1.4	Precast houses designed by Montagne and Morales	149
5.2.6.2	Larsen & Nielsen, Denmark, 1960	150
5.2.6.3	1-464, Former Soviet Union, 1960	150
5.2.6.4	Jugomont 61, Former Yugoslavia, 1961	151
5.2.6.5	Ital-Camus, Italy, 1960	151
5.3	1970s	152
5.3.1	Large Panel 70 (Gran Panel 70). Cuba, 1970	152
5.3.2	WBS 70 (Wohnhungsbauserie 70). Former German Democratic Republic, 1970	158
5.3.3	Genter Straße Residential Complex. Munich (Phase 1), Germany, 1972	164
5.3.4	Soviet KPD System (Krupnopanelnoye Domostroyenie). Chile, 1972	170
5.3.5	Martinsviertel. Cologne, Germany, 1977	176
5.3.6	Other projects	182
5.3.6.1	Southgate Estate Residential Complex, England 1977	182
5.3.6.2	Precast Affordable Housing (Viviendas Económicas Prefabricadas, VEP). Chile, 1975	182
5.3.6.3	Residential Building. Monza, Italy, 1972	183
5.3.6.4	Brecast, United Kingdom, 1970	183
5.3.6.5	Residences in the Olympic Village. Munich, Germany, 1971	184
5.3.6.5.1	Men's residences	184
5.3.6.5.2	Women's residences	184
5.4	1980s, 1990s and 2000s	186
5.4.1	Bachué City III (Ciudad Bachué III)	186
5.4.2	Niza Residential Complex (Urbanización Niza). Pereira, Colombia, 1980	192
5.4.3	Viviendas de protección oficial. Alcobendas, Spain, 1995	198
5.4.4	Residential and comercial building. Rathenow, Germany, 1997	204
5.4.5	Elemental - Milan House Prototype. Italy, 2008	210
5.4.6	Other projects	216
5.4.6.1	Ciudad Bachué I	216
5.4.6.2	Ciudad Bachué II	216
	Summary	217
6	**Efficiency**	**221**
6.1	Quantity (qn)	222
6.1.1	Products (p)	223
6.1.1.1	Dwellings	223
6.1.1.2	Area	223
6.1.2	Resources (r)	224
6.1.2.1	Cost	224
6.1.2.1.1	According to the function	224
6.1.2.1.2	According to their identification with an activity.	224

6.1.2.1.3	According to the moment in which they were calculated.	224
6.1.2.1.4	Types of costs according to their behavior:	225
6.1.2.1.5	Types of costs according to the time or construction periods:	225
6.1.2.2.	Time	225
6.1.3	Minimum quantities required	226
6.2	Quality (ql)	226
6.2.1	Objective criteria	227
6.2.1.1	Modularity	227
6.2.1.2	Replicability	227
6.2.1.3	Transportability	227
6.2.1.4	Adaptability	228
6.2.1.5	Accessibility	228
6.2.2	Subjective criteria	228
6.2.2.1	Simplicity	228
6.2.2.2	Flexibility	228
6.2.2.3	Comfort	229
6.2.2.4	Beauty	229
6.2.2.5	Transformability	229
6.2.3	Minimum qualities required	230
	Summary	231
7	**Conclusion**	**235**
7.1	Increasing quantity and quality	236
7.2	Increasing quantity, maintaining quality	236
7.3	Maintaining quantity, increasing quality	236
7.4	Maintaining quantity and quality	237
7.5	Industrializing, customizing, transforming	237
7.5.1	Industrializing	237
7.5.2	Customizing	237
7.5.3	Transforming	237
7.6	Industrializing the essential, customizing the necessary, transforming the ideal	238
7.7	Rationality and identity	238
	Summary	239
8	**Experimental research**	**241**
8.1	Concept	242
8.1.1	Industrialization	242
8.1.2	Customization	243
8.1.3	Transformation	243
8.2	System	243
8.2.1	Quantities (qn)	243
8.2.1.1	Products (p)	243
8.2.1.1.1	Dwellings	243
8.2.1.1.2	Area	244
8.2.1.2	Resources (r)	244
8.2.1.2.1	Cost	244
8.2.1.2.2	Time	244
8.2.2	Qualities	244
8.2.2.1	Objective criteria	244
8.2.2.1.1	Modularity	244
8.2.2.1.2	Replicability	244
8.2.2.1.3	Transportability	244
8.2.2.1.4	Adaptability	245
8.2.2.1.5	Accessibility	245
8.2.2.2	Subjective criteria	245
8.2.2.2.1	Simplicity	245
8.2.2.2.2	Flexibility	247
8.2.2.2.3	Comfort	247
8.2.2.2.4	Beauty	247
8.2.2.2.5	Transformability	247
8.3	Typologies	248
8.3.1	Social Housing A. Linear industrialized frames	248

8.3.1.1	Two-story house	248
8.3.1.2	Five-story house	256
8.3.2	Social Housing B. Transversal industrialized frames	264
8.3.2.1	Two-story house	264
8.3.2.2	Five-story house	272
8.3.3	Social Housing C. Mixed grouping: lineal and transversal industrialized frames	280
8.4	Prototypes	288
8.4.1	Prototype A	288
8.4.2	Prototype B	290
8.4.3	Formwork	292
8.4.4	Structural reinforcements	292
8.4.5	Production of precast structural frames	292
8.4.6	Transport	293
8.4.7	Assembly	293
8.4.8	Dwellings	294
8.4.8.1	Social Housing A. Linear industrialized frames	294
8.4.8.2	Social Housing B. Transversal industrialized frames	294
8.5	Results	295
8.5.1	In quantitative terms	295
8.5.1.1	Products	295
8.5.1.1.1	Area for the Type A housing prototype	295
8.5.1.1.2	Area for the Type B housing prototype	295
8.5.1.2	Resources	295
8.5.1.2.1	Costs and construction time for the two-story Type A housing prototype	295
8.5.1.2.2	Costs and construction time for the five-story Type A housing prototype	295
8.5.1.2.3	Costs and construction time for the two-story Type B housing prototype	295
8.5.1.2.4	Costs and construction time for the five-story Type B housing prototype	296
8.5.2	In qualitative terms	296
8.5.2.1	Objective criteria	296
8.5.2.1.1	Modularity	296
8.5.2.1.2	Replicability	296
8.5.2.1.3	Transportability	296
8.5.2.1.4	Adaptability	296
8.5.2.1.5	Accessibility	296
8.5.2.2	Subjective criteria	296
8.5.2.2.1	Simplicity	296
8.5.2.2.2	Flexibility	297
8.5.2.2.3	Comfort	297
8.5.2.2.4	Beauty	297
8.5.2.2.5	Transformability	297
	Summary	300
9	**Perspectives**	**303**
9.1	Open U-shaped structural frames in precast concrete	304
9.1.1	In quantitative terms	304
9.1.2	In qualitative terms	304
9.1.2.1	Objective criteria	304
9.1.2.2	Subjective criteria	304
9.2.	Structural framework with metal profiles and masonry	312
9.2.1	In quantitative terms	312
9.2.2	In qualitative terms	312
9.2.2.1	Objective criteria	312
9.2.2.2	Subjective criteria	312
	Summary	320
10	**Bibliography**	**323**
	Annexes	**331**
Annex 1	Conceptual structure	333
Annex 2	Time and costs	336
Annex 3	Components of the system	343
Annex 4	Structural plans	349
Annex 5	Patent certification document	355

List of Tables

Table 1. Regulatory requirements and commercial offerings for Priority Social-Interest Housing (VIP) and Social-Interest Housing (VIS) in the real-estate market in Colombia and Antioquia.
Table 2. Indicators used by DANE to measure the quantitative housing deficit.
Table 3. Indicators used by DANE to measure the qualitative housing deficit.
Table 4. Minimum standards and technical conditions for precast elements (NSR-10)
Table 5. Continuity requirements in precast concrete: structural, spatial, constructive.
Table 6. Demands for flexibility in designs and construction with precast concrete: on urban, building and housing scales, and on the scale of other construction subsystems.
Table 7. Classification of prefabrication systems in concrete: closed, open and partially industrialized
Table 8. Standards for the use of fibers in precast concrete in Colombia
Table 9. Discontinuous reinforcements for precast concrete: metallic, organic and inorganic fibers
Table 10. Dosages frequently used in Colombia and Antioquia for precast concrete structural elements
Table 11. Fiber-reinforced UHPC variants.
Table 12. Criteria for the evaluation of resistance of precast concrete
Table 13. Ranges for gross vehicular weight (GVW) defined in NTC 4788
Table 14. Average dimensions and weights for fluvial transportation in Antioquia
Table 15. Cargo dimensions and volumes permitted for rail transport with gondolas, flatbeds and platforms
Table 16. Technical specifications for joints between precast concrete elements, according to NSR-10
Table 17. Camus System, France, 1948. Information taken from: Alonso and Palmarola, 2014, pp. 216-217, 257, 306-309
Table 18. Novoa - Sandino System, Cuba, 1950
Table 19. G-57, Former Czechoslovakia, 1957
Table 20. IMS System, Former Yugoslavia, 1957
Table 21. I-335, Former Soviet Union, 1959
Table 22. VAM, The Netherlands, 1961
Table 23. Saint Andrews Dormitory, Scotland, 1964
Table 24. Large Soviet Panel, Cuba, 1965
Table 25. Skarne S66, Sweden, 1966
Table 26. Habitat 67 - Montreal, Canada, 1967
Table 27. Large Panel 70 (Gran Panel 70). Cuba, 1970
Table 28. WBS 70 (Wohnhungsbauserie 70). Former German Democratic Republic, 1970
Table 29. Genter Straße Residential Complex. Munich (Phase 1), Germany, 1972
Table 30. Soviet KPD System (Krupnopanelnoye Domostroyenie). Chile, 1972
Table 31. Martinsviertel. Cologne, Germany, 1977
Table 32. Bachué City III (Ciudad Bachué III). Colombia, 1980
Table 33. Niza Residential Complex (Urbanización Niza). Pereira, Colombia, 1980
Table 34. Official Protection Housing (Viviendas de Protección Oficial). Alcobendas, Spain, 1995
Table 35. Residential and commercial building. Rathenow, Germany, 1997
Table 36. Elemental - Milan House Prototype. Italy, 2008
Table 37. Strategies to reduce the quantitative deficit from the indicators used by DANE.
Table 38. Minimum quantitative requirements for the construction of precast-concrete social housing in the Department of Antioquia
Table 39. Strategies to reduce the qualitative deficit, based on the indicators used by DANE
Table 40. Minimum qualitative requirements for the construction of precast-concrete social housing in the Department of Antioquia
Table 41. Industrialize, customize and transform: components, actors and conditions
Table 42. Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)
Table 43. Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)
Table 44. Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)
Table 45. Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)
Table 46. Areas of the housing project (including façade walls, dividing walls, interior walls and circulations)
Table 47. Design of the K-type mixture for the construction of precast concrete structural elements. Housing Construction Cost Index (ICCV), Colombia, February 2015. Prices provided by Proyectar architectural budget firm, located in Medellín, Colombia. Engineers Juan Carlos Gómez and Nathalie Rúa, December 2016. The design of the mixture was conducted with the advice of Engineer Cipriano Londoño, Medellín, Colombia. Manufacture of the specimens conducted in the Comité de Prefabricados de Antioquia. Evaluations of the mixture for compressive resistance conducted in the Comité de Prefabricados de Antioquia.
Table 48. Comparison of costs and time in the construction of the dwellings' typologies
Table 49. Comparison of costs in the construction of the prototypes

List of Figures

Figure 1. A view of Medellín from the northwestern mountains. In the foreground, lots available for construction and the social housing buildings built by the local Government. In the background, housing built by families classified as belonging to the quantitative deficit.

Figure 2. A view of Medellín toward the northeastern mountains. Houses in the qualitative deficit that do not meet the safety and living conditions established by existing regulations. Photo: M. Vásquez.

Figure 3. The most used conglomerating material is Portland cement, formed by a mixture of clinker (calcified clay and limestone) and gypsum

Figure 4. Fine and coarse aggregates, classified according to the fineness modulus and maximum nominal sizes

Figure 5. Corrugated metal rods, passive precast concrete reinforcements. Accessed December 12, 2015; available at: http://img.aws.ehowcdn.com/intl-1200x630/ds-photo/getty/article/110/41/92828224.jpg

Figure 6. Single and multi-strand cables. Active linear reinforcements in pre-stressed and post-tensioned precast concrete structures

Figure 7. Continuous reinforcements used in precast concrete: metal structural mesh and textile reinforcements

Figure 8. Fibers used as discontinuous reinforcements for precast elements

Figure 9. Lightweight aggregates with a cellular structure that provides low density and permits thermal insulation. Expanded clay and slate. Photo: Weigler, Helmut; Karl, Sieghart. Stahlleichtbeton. Bauverlag, Berlin and Wiesbaden, 1993

Figure 10. Surface of a concrete element built with wood particles as aggregates. Technische Universität München (TUM)

Figure 11. Cellular concrete. Air cavities cause the mix to be lighter and less dense. Because of its conformation, it has acoustic and temperature insulation properties

Figure 12. Fly ash. Industrial waste that can be used in the construction of precast concrete structural and non-structural elements

Figure 13. Stone, ceramic and concrete materials obtained from demolition processes could be used as recycled aggregates to produce precast-concrete elements

Figure 14. Blast-furnace slag, used to produce precast concrete elements when it is mixed with clinker and gypsum. Accessed December 11, 2015; available at: http://i01.i.aliimg.com/photo/v0/167791269/COPPER_SLAG.jpg

Figure 15. Multiaxial networks. Composed of layers of fibers grouped in rovings or in yarn and arranged in different directions. Photo: Detail. Munich: Institut für internationale Architektur-Dokumentation GmbH & Co. KG, 2005

Figure 16. Mesh separator. Tridimensional element with two layers of mesh united by strands perpendicular to the plane of the fabric. Photo: Detail. Munich: Institut für internationale Architektur-Dokumentation GmbH & Co. KG, 2005

Figure 17. Textile tubes to reinforce hollow elements. Photo: Detail. Munich: Institut für internationale Architektur-Dokumentation GmbH & Co. KG, 2005

Figure 18. Sandwich panels: two concrete sides and a core of insulating material

Figure 19. Elements in a hollow box with an expanded polystyrene core or with voids between the outer layers of concrete. Photo: Dresden International University and RWTH Aachen University, 2012

Figure 20. Metal fibers to reinforce the concrete. Accessed December 12, 2015; available at: http://www.emaresa.cl/construccion/images/stories/virtuemart/product/fibra_maccaferri.jpg

Figure 21. Glass fibers in the precast concrete panels. Prefabricados Moià, Barcelona, January 2013

Figure 22. Recycled polyethylene fibers for the construction of precast concrete elements

Figure 23. Ribbed plate in UHPC and the installed element as a façade panel. Barcelona, January 2013

Figure 24. Pre-stressed process of an alveolar slab. Accessed July 17, 2014; available at: http://www.prensoland.com/admin/uploads/imatges/thumbnailsG/20101011122056.jpg

Figure 25. Pre-stressed, precast concrete alveolar slabs. Accessed December 13, 2015; available at: https://plexa.com.mx/sites/default/files/ct/gdi/ALVEOLAR2.jpg

Figure 26. Pre-stressed, precast concrete beams. Accessed December 13, 2015; available at: http://www.forsecusa.es/s/cc_images/cache_10816935.jpg

Figure 27. Pre-stressed, precast-concrete elements installed through post-tensioning processes. Photos, Tectónica. 1998

Figure 28. Pre-stressed, precast-concrete elements installed through post-tensioning processes. https://alrededordelaarquitectura.files.wordpress.com/2013/07/nave.jpg, accessed December 13, 2015

Figure 29. Pre-stressed, precast-concrete elements installed through post-tensioning processes. http://blogs.elpais.com/.a/6a00d8341bfb1653ef017c324343e6970b-pi, accessed December 13, 2015

Figure 30. Horizontal fissuring of a precast concrete element along the axis is occupied by structural reinforcements

Figure 31. Structural continuity in precast concrete elements through the design of their connections. Photo: Elematic

Figure 32. Surface obtained using a metal formwork. Photo: Cementos Argos, Medellín 2010
Figure 33. Concrete surfaces obtained through the use of wood boards. Photo: Cementos Argos, Medellín 2010
Figure 34. Concrete surface obtained through the use of a wooden-board formwork. Photo: Cementos Argos, Medellín, 2010
Figure 35. Concrete surface obtained through the use of a formwork built with polyester and laminated with fiberglass. Photo: Cementos Argos, Medellín, 2010
Figure 36. Concrete surface obtained through the use of a formwork in GRC. Photo: F. Regás and J. Bolaños, Piedra Moldeada: GRC y hormigón arquitectónico, 2010
Figure 37. Concrete surface obtained through the use of a formwork in polyurethane elastomers. Photo: F. Regás and J. Bolaños, Piedra Moldeada: GRC y hormigón arquitectónico, 2010
Figure 38. Operating systems and spatial organization in a precast element production plant. Model taken from the production organization of the Elematic firm in Helsinki, Finland, June 2013. Elematic. Complete precast plant. SEMI, PRO, EDGE Catalogues. Aldus, Finland, 2013. Helsinki, Finland, June 2013
Figure 39. Model of the field factory commercially offered by Weiler, Germany
Figure 40. Construction of a building with a precast skeletal structure. The assemblies among beams, columns and slabs must ensure the continuity of the structure. Photo: Montagebau Konstruktiver Entwurf
Figure 41. Bio-concrete (Self-Healing Concrete. Research developed by the Delft UT-wide Self-Healing Materials Research Program at the Delft Center for Materials (DCMat)
Figure 42. Concrete reinforced with natural fibers. Research developed by Universidad Pontificia Bolivariana (UPB) in Medellín, Colombia
Figure 43. Single Wall Carbon Nano-Tubes (SWCNT) and Multi-Wall Carbon Nano-Tubes (MWCNT). Accessed December 11, 2015; available at: http://www.mdpi.com/sensors/sensors-15-01564/article_deploy/html/images/sensors-15-01564f3-1024.png
Figure 44. Single Wall Carbon Nano-Tubes (SWCNT) and Multi-Wall Carbon Nano-Tubes (MWCNT). Accessed December 11, 2015; available at: http://www.mdpi.com/sensors/sensors-15-01564/article_deploy/html/images/sensors-15-01564f3-1024.png
Figure 45. Curved concrete, a micromechanical material with resistances to tension and deflection stresses is more lightweight than traditional concrete
Figure 46. Cutting concrete, material that can be transformed through manual or mechanical procedures
Figure 47. Graphic concrete, a material that combines silkscreens and photographic etching techniques on the surface of concrete elements
Figure 48. Structural elements obtained from the use of textile formworks. Photo: CAST Brochure. Accessed December 11, 2015; available at: http://umanitoba.ca/cast_building/
Figure 49. Prototype A. Grouping system model
Figure 50. Prototype B. Grouping system model
Figure 51. The manufacturing process of the formwork was done in the Industria Leguz workshops; Itagüí, Antioquia, February and March 2015
Figure 52. Assembly process of the reinforcement meshes for the structural frames. Comité de Prefabricados de Antioquia. April 2015
Figure 53. Casting process of the structural frames
Figure 54. The transport process of the structural frames from the production plant to the site of installation
Figure 55, Installation process of the structural frames in the two prototypes
Figure 56, Installation process of the structural frames in the two prototypes
Figure 57. Installation process of the structural frames in the two prototypes
Figure 58, The prototype with linear structural frames and a central courtyard
Figure 59, The prototype with linear structural frames and a central courtyard
Figure 60. The prototype with linear structural frames and a central courtyard
Figure 61, The two-story prototype with transversal structural frames
Figure 62, The two-story prototype with transversal structural frames
Figure 63. The two-story prototype with transversal structural frames
Figure 64. The prototypes constructed, in the alternate campus of Universidad Pontificia Bolivariana. Marinilla, Antioquia.

List of Graphics

Graphic 1. The accumulated quantitative and qualitative deficit in Colombia and in Antioquia in 1993 and 2005, according to the official figures from DANE.
Graphic 2. Variations in the quantitative, qualitative and accumulated deficit in Colombia and Antioquia between 1993 and 2005, according to the official figures from DANE.
Graphic 3. Colombia´s location in South America and Antioquia´s location in Colombia
Graphic 4. Topographic zoning of the Department of Antioquia
Graphic 5. Areas of seismic risk in Antioquia
Graphic 6. Hydrographic maps of the Department of Antioquia
Graphic 7. Temperatures in the municipalities of Antioquia, according to the altitude above sea level (IGAC, 2009)
Graphic 8. The 2015 population projection in Antioquia (DANE, 2015)
Graphic 9. Average household size in urban and rural areas in Antioquia (The Quality of Life and Principal Indicators in Antioquia Survey, 2013).
Graphic 10. Labor conditions in Antioquia's population (DANE, 2005)
Graphic 11. Land transportation networks in Antioquia (Colombian Ministry of Transport, 2015)
Graphic 12. Public utilities available in homes located in urban and rural areas (Quality of Life Survey, 2013)
Graphic 13. Housing proposed through the Existenzminimum housing model. Weißenhofsiedlung, Stuttgart. Architect: Mart Stam
Graphic 14. Industrially produced mass housing. Ville Radieuse. Architect: Le Corbusier
Graphic 15. A neighborhood unit with garden city housing models. Garden City. Architect: Le Corbusier
Graphic 16. Living models for working-class housing in Latin America. Matute Housing Units, La Victoria, Lima. Architect: Santiago Agurto Calvo
Graphic 17. Living models of State housing in Latin America. José Martí District, Santiago de Cuba. Architects: Dean, Baeza, López, Cárdenas, Rodríguez and Azze
Graphic 18. Collective housing in Latin America (experimental model). Lima. Architect: John Turner
Graphic 19. Housing models built in Colombia in the Hygienist Period. Colombia Neighborhood, Bogotá. Architects: BCH
Graphic 20. Housing models built in Colombia in the Institutional Period. Antonio Nariño Urban Center, Bogotá. Architects: Gutiérrez, Esguerra Sáenz, Urdaneta and Suárez
Graphic 21. Housing models built in Colombia in the Transitional Period. El Parque Residences, Bogotá. Architect: Rogelio Salmona
Graphic 22. Collective housing built in Colombia by the ICT during the Corporate Period. Marco Fidel Suárez Towers, Medellín. Architect: Eduardo Arango
Graphic 23. Urban social housing built in Colombia during the conception period of market and demand subsidies. La Playa Residences, Medellín. Architects: Ana E. Vélez and Juan B. Echeverri
Graphic 24. Disperse city context. Rosenberg Conversion, Winterthur. Architects: EM2N
Graphic 25. Modern city context. Brasilia, Brazil. Architect: Lucio Costa
Graphic 26. Expansive urban context. Pajarito La Aurora Housing Units, Medellín. Architects: Instituto Social para la Vivienda y el Hábitat de Medellín, ISVIMED
Graphic 27. Central urban context. Emile Chaíne Area Regeneration, Paris. Architects: Moussafir, Katz and Tachon
Graphic 28. Recycled city context. Puerto Madero, Buenos Aires
Graphic 29. Re-densified city context. Neighborhood Zone, Caracas
Graphic 30. Elementary geometry
Graphic 31. Nucleated services
Graphic 32. Served spaces
Graphic 33. Intermediate spaces
Graphic 34. Technology and bioclimatics
Graphic 35. Perception
Graphic 36. Prototype balcony
Graphic 37. Prototype indoor walkway
Graphic 38. Prototype gallery
Graphic 39. Prototype patio
Graphic 40. Joints in the precast concrete foundations for skeletal structures. Graphics taken by Böttger, Dietrich. Montagebau. Berlin: VEB Verlag für Bauwesen, 1974, p. 125
Graphic 41. Rectangular and circular section precast concrete columns. FDB Germany, 2013.
Graphic 42. Rectangular section precast concrete beam and consoles. FDB Germany, 2013.
Graphic 43. Precast-concrete trapezoidal, "I" and "C" beams. FDB, Germany, 2013
Graphic 44. Precast concrete "T", hollow and box girders beams.
Graphic 45. Types of consoles in precast concrete. FDB, Germany, 2013
Graphic 46. Types of precast concrete slabs. FDB, Germany, 2013
Graphic 47. Joints with friction support between components
Graphic 48. Connections through the continuity between the reinforcements and a final casting of concrete to increase its rigidity

Graphic 49. Joints between metallic elements embedded in the concrete, which are joined through metallic pins or through welding
Graphic 50. Metallic elements installed during the mounting process that stiffens the joint between precast elements
Graphic 51. Post-tensioned joints that are stiffen after the installation of precast elements
Graphic 52. Types of joints in precast concrete foundations: joints by geometries between the precast elements or overlapped between their metallic reinforcements plus a subsequent concrete casting. Graphics taken by Böttger, Dietrich. Montagebau. Berlin: VEB Verlag für Bauwesen, 1974, p. 125
Graphic 53. Walls in precast concrete. FDB, Germany, 2013
Graphic 54. Types of beams and joists for the system of structural walls in precast concrete
Graphic 55. Types of consoles precast in concrete. FDB, Germany, 2013
Graphic 56. Slabs in precast concrete. FDB, Germany, 2013
Graphic 57. Joints with friction support between components
Graphic 58. Connections through the continuity between reinforcements and a final casting of concrete to increase rigidity
Graphic 59. Joints between metallic elements embedded in the concrete, which are joined through metallic pins or through welding
Graphic 60. External metallic elements to join two or more precast elements
Graphic 61. Post-tensioned joints that stiffen after the installation of the precast elements
Graphic 62. Foundations for precast spatial cells
Graphic 63. Walls and slabs behave monolithically to generate unique, seamless elements
Graphic 64. Joints for simple or friction support between spatial cells
Graphic 65. Connections between the reinforcements and a final casting of concrete to increase its rigidity
Graphic 66. Joints between metallic elements embedded in the concrete, which are joined through metallic pins or through welding
Graphic 67. Exterior metallic elements installed during the mounting process that stiffen the joint between precast elements
Graphic 68. Post-tensioned joints that stiffen after the installation of the precast elements
Graphic 69. Collective housing seen from its history and from the construction technique, as a response to the political, social, technical, economic and housing conditions of their contexts
Graphic 70. Exterior view
Graphic 71. Components: floor plans and façade
Graphic 72. Components: axonometry
Graphic 73. Construction process
Graphic 74. The technical system and the architectural language
Graphic 75. Constructive details
Graphic 76. Exterior View
Graphic 77. Components: floor plans and façade
Graphic 78. Componentes: axonometry
Graphic 79. Construction process
Graphic 80. The technical system and the architectural language
Graphic 81. Constructive details
Graphic 82. Exterior view
Graphic 83. Components: floor plans and façade
Graphic 84. Components: axonometry
Graphic 85. Construction process
Graphic 86. The technical system and the architectural language
Graphic 87. Constructive details
Graphic 88. Exterior view
Graphic 89. Components: floor plans and façade
Graphic 90. Components: axonometry
Graphic 91. Construction process
Graphic 92. The technical system and the architectural language
Graphic 93. Constructive details
Graphic 94. Exterior view
Graphic 95. Components: floor plans and façade
Graphic 96. Components: axonometry
Graphic 97. Construction process
Graphic 98. The technical system and the architectural language
Graphic 99. Constructive details
Graphic 100. Construction process
Graphic 101. Construction process
Graphic 102. Construction process
Graphic 103. Construction process
Graphic 104. Exterior view

Graphic 105. Components: floor plans and façade
Graphic 106. Components: axonometry
Graphic 107. Construction process
Graphic 108. The technical system and the architectural language
Graphic 109. Constructive details
Graphic 110. Exterior view
Graphic 111. Components: floor plans and façade
Graphic 112. Componentes: axonometry
Graphic 113. Construction process
Graphic 114. The technical system and the architectural language
Graphic 115. Constructive details
Graphic 116. Exterior view
Graphic 117. Components: floor plans and façade
Graphic 118. Components: axonometry.
Graphic 119. Construction process
Graphic 120. The technical system and the architectural language
Graphic 121. Constructive details
Graphic 122. Exterior view
Graphic 123. Components: floor plans and façade
Graphic 124. Components: axonometry
Graphic 125. Construction process
Graphic 126. The technical system and the architectural language
Graphic 127. Constructive details
Graphic 128. Exterior view
Graphic 129. Components: floor plans and façade
Graphic 130. Components: axonometry
Graphic 131. Construction process
Graphic 132. The technical system and the architectural language
Graphic 133. Constructive details
Graphic 134. Construction process
Graphic 135. Construction process
Graphic 136. Construction process
Graphic 137. Construction process
Graphic 138. Construction process
Graphic 139. Construction process
Graphic 140. Construction process
Graphic 141. Construction process
Graphic 142. Exterior view
Graphic 143. Components: floor plans and façade
Graphic 144. Components: axonometry
Graphic 145. Construction process
Graphic 146. The technical system and the architectural language
Graphic 147. Constructive details
Graphic 148. Exterior view
Graphic 149. Components: floor plans and façade
Graphic 150. Components: axonometry
Graphic 151. Construction process
Graphic 152. The technical system and the architectural language
Graphic 153. Constructive details
Graphic 154. Exterior view
Graphic 155. Components: floor plans and façade
Graphic 156. Components: axonometry
Graphic 157. Construction process
Graphic 158. The technical system and the architectural language
Graphic 159. Constructive details
Graphic 160. Exterior view
Graphic 161. Components: floor plans and façade
Graphic 162. Components: axonometry
Graphic 163. Construction process
Graphic 164. The technical system and the architectural language
Graphic 165. Constructive details
Graphic 166. Exterior view
Graphic 167. Components: floor plans and façade

Graphic 168. Components: axonometry
Graphic 169. Construction process
Graphic 170. The technical system and the architectural language
Graphic 171. Constructive details
Graphic 172. Construction process
Graphic 173. Construction process
Graphic 174. Construction process
Graphic 175. Construction process
Graphic 176. Construction process
Graphic 177. Construction process
Graphic 178. Exterior view
Graphic 179. Components: floor plans and façade
Graphic 180. Components: axonometry
Graphic 181. Construction process
Graphic 182. The technical system and the architectural language
Graphic 183. Constructive details
Graphic 184. Exterior view
Graphic 185. Components: floor plans and façade
Graphic 186. Components: axonometry
Graphic 187. Construction process
Graphic 188. The technical system and the architectural language
Graphic 189. Constructive details
Graphic 190. Exterior view
Graphic 191. Components: floor plans and façade
Graphic 192. Components: axonometry
Graphic 193. Construction process
Graphic 194. The technical system and the architectural language
Graphic 195. Constructive details
Graphic 196. Exterior view
Graphic 197. Components: Floor plans and façade
Graphic 198. Components: axonometry
Graphic 199. Construction process
Graphic 200. The technical system and the architectural language
Graphic 201. Constructive details
Graphic 202. Exterior view
Graphic 203. Components: floor plans and façade
Graphic 204. Components: axonometry
Graphic 205. Construction process
Graphic 206. The technical system and the architectural language
Graphic 207. Constructive details
Graphic 208. Constructive process
Graphic 209. Constructive process
Graphic 210. For the construction of 10 homes, 10 groups of structural frames are needed
Graphic 211. The intermediate frames can be eliminated, using only the structural elements necessary
Graphic 212. If the system is configured with five groups of frames, the continuity of the structure remains. The upper frames may be closed or eliminate the upper concrete slab
Graphic 213. Two floor slabs, two walls and the rooves are necessary to go from five to 10 homes
Graphic 214. The diversity of the façades adapts the project to other environmental, social and cultural contexts
Graphic 215. The transformation of the inhabited domestic spaces gives the project the uses and identity sought by each family
Graphic 216. Modularity. Geometry and dimensional coordination
Graphic 217. Replicability. Industrialized production
Graphic 218. Transportability. Delivery
Graphic 219. Adaptability. Placement in different contexts
Graphic 220. Accessibility. Urban design
Graphic 221. Simplicity. Geometry and types of connections
Graphic 222. Flexibility. Housing typologies
Graphic 223. Comfort. Bioclimatic and sustainability
Graphic 224. Beauty. Architectural languages
Graphic 225. Transformability. Improvements after occupation
Graphic 226. Components: floor plans and façade
Graphic 227. Constructive process
Graphic 228. General floor plans
Graphic 229. Typologies of housing

Graphic 230. Sections
Graphic 231. Façades
Graphic 232. Constructive details
Graphic 233. Constructive process: installation of prefabricated structural elements
Graphic 234. Constructive details
Graphic 235. Constructive process: installation of non-structural elements (walls and façades)
Graphic 236. The technical system, the architectural language and the public space
Graphic 237. Components: floor plans and façade
Graphic 238. Constructive process
Graphic 239. General floor plans
Graphic 240. Typologies of housing
Graphic 241. Sections
Graphic 242. Façades
Graphic 243. Constructive details
Graphic 244. Constructive process: installation of prefabricated structural elements
Graphic 245. Constructive details
Graphic 246. Constructive process: installation of non-structural elements (interior walls and façades)
Graphic 247. The technical system, the architectural language and the public space
Graphic 248. Components; floor plans and façade
Graphic 249. Constructive process
Graphic 250. General floor plans
Graphic 251. Typologies of housing
Graphic 252. Sections
Graphic 253. Façades
Graphic 254. Constructive details
Graphic 255. Constructive process: installation of prefabricated structural elements
Graphic 256. Constructive details
Graphic 257. Constructive process: installation of non-structural elements (interior walls and façades)
Graphic 258. The technical system, the architectural language and the public space
Graphic 259. Components: floor plans and façade
Graphic 260. Constructive process
Graphic 261. General floor plans
Graphic 262. Typologies of housing
Graphic 263. Sections
Graphic 264. Façades
Graphic 265. Constructive details
Graphic 266. Constructive process: installation of prefabricated structural elements
Graphic 267. Constructive details
Graphic 268. Constructive process: installation of non-structural elements (interior walls and façades)
Graphic 269. The technical system, the architectural language and the public space
Graphic 270. Components: floor plans and façade
Graphic 271. Constructive process
Graphic 272. General floor plans
Graphic 273. Typologies of housing
Graphic 274. Sections
Graphic 275. Façades
Graphic 276. Constructive details
Graphic 277. Constructive process: installation of prefabricated structural elements
Graphic 278. Constructive details
Graphic 279. Constructive process: installation of non-structural elements (interior walls and façades)
Graphic 280. The technical system, the architectural language and the public space
Graphic 281. Architectural floor plans
Graphic 282. Sections
Graphic 283. Façades
Graphic 284. Architectural floor plans
Graphic 285. Sections
Graphic 286. Façades
Graphic 287. Components: floor plans, façade and Axonometry.
Graphic 288. Constructive process with linear and open “U”-shaped precast-concrete structural frames
Graphic 289. Constructive process with transversal and open “U”-shaped precast-concrete structural frames
Graphic 290. Constructive details
Graphic 291. Constructive process: installation of prefabricated structural elements
Graphic 292. Constructive details

Graphic 293. Constructive process: installation of non-structural elements (interior walls and façades)
Graphic 294. The technical system, the architectural language and the public space
Graphic 295. Components: floor plans and façade
Graphic 296. Constructive process of a metallic structural frame with elements in masonry
Graphic 297. Constructive process: linear metallic structural frames and masonry
Graphic 298. Constructive process: transversal metallic structural frames and masonry
Graphic 299. Constructive details
Graphic 300. Constructive process: installation of metallic structural frames
Graphic 301. Constructive details
Graphic 302. Constructive process: installation of masonry between the metallic structural frames
Graphic 303. The technical system, the architectural language and the public space

Abbreviations and acronyms

Here, the name of many entities in Colombia and some values that accompany the figures are indicated through abbreviations or acronyms. This is a complete alphabetical list of the acronyms used in each chapter.

Afc	Savings Accounts for the Promotion of Construction (Ahorro para el Fomento a la Construcción).
Ais	Colombian Association of Seismic Engineering (Asociación Colombiana de Ingeniería Sísmica).
AMVA	Metropolitan Area of the Aburrá Valley (Área Metropolitana del Valle de Aburrá).
BCH	Central Mortgage Bank (Banco Central Hipotecario).
BRE	British Building Research Establishment.
Camacol	Colombian Chamber of Construction (Cámara Colombiana de la Construcción).
CAV	Housind and Savings Corporations (*corporaciones de ahorro y vivienda*).
CAST	The Centre for Architectural Structures and Technology. University of Manitoba (Canada).
Cenac	Center for the Study of Construction and Urban and Regional Development (Centro de Estudios de la Construcción y el Desarrollo Urbano y Regional).
Cepal	The United Nations Economic Commission for Latin America and the Caribbean (Comisión Económica para América Latina y el Caribe).
CIAM	International Congress of Modern Architecture (Congreso Internacional de Arquitectura Moderna).
Colciencias	Administrative Department of Science, Technology and Innovation (Departamento Administrativo de Ciencia, Tecnología e Innovación).
CTVU	Technical Center for Housing and Urban Planning (Centro Técnico de la Vivienda y el Urbanismo).
DAAD	German Academic Exchange Service (Deutscher Akademischer Austausch Dienst).
DANE	National Administrative Department of Statistics of Colombia (Departamento Administrativo Nacional de Estadística).
DAP	Administrative Planning Department (Departamento Administrativo de Planeación).
DNP	National Planning Department of Colombia (Departamento Nacional de Planeación).
EBB	Chair of Building Construction and Material Science (Lehrstuhl für Entwerfen, Baukonstruktion und Baustoffkunde).
Eclac	United Nations Economic Commission for Latin America and the Caribbean.
EDU	Urban Development Corporation (Empresa de Desarrollo Urbano).
Efnarc	European Federation of National Associations Representing Producers and Applicators of Specialist Building Products for Concrete.
Ehe	Spanish Instruction for Structural Concrete (Instrucción Española del Hormigón Estructural).
Expocamacol	The International Construction, Architecture and Design Convention. Held every two years in Medellín and sponsored by Camacol.
FDB	The German Professional Association for the Precast Concrete Construction (Fachvereinigung Deutscher Betonfertigteilbau e.V.).
FIB	International Federation for Structural Concrete (Fédération Internationale du Béton).
FNA	National Savings Fund (Fondo Nacional del Ahorro).
Fonvivienda	The National Housing Fund (Fondo Nacional de Vivienda).
GDP or PIB	Gross Domestic Product (Producto Interno Bruto).
GDR	German Democratic Republic.
GRC	Glass Reinforced Concrete.
Hud	U. S. Department of Housing and Urban Development.
IADB	Inter-American Development Bank.
ICCV	Housing Construction Cost Index (Índice de Costos de Construcción de Viviendas).
ICPC	Colombian Institute of Cement Producers (Instituto Colombiano de Productores de Cemento).
ICT	Institute for Territorial Credit (Instituto de Crédito Territorial).
Ideam	The Colombian Institute of Hydrology, Meteorology and Environmental Studies (Instituto de Hidrología, Meterología y Estudios Ambientales.
IGAC	The Agustín Codazzi Geographic Institute (Instituto Geográfico Agustín Codazzi).
IMS	Institute for the Testing of Materials of Serbia (Instituto para la prueba de materiales de Serbia).
Ingeominas	Colombian Institute of Engineering and Mining (Instituto Colombiano de Ingeniería y Minería). Known today as the Colombian Geological Service (Servicio Geológico Colombiano).
Inurbe	National Institute of Social Interest Housing and Urban Reform (Instituto Nacional de Vivienda de Interés Social y Reforma Urbana).
Itec	Institute for the Technology of Construction of Catalunya (Institut de Tecnología de la Construcción de Catalunya).
KPD	KPD companies (a Russian acronym that means “Large Soviet Panels”).
Laur	The Universidad Pontificia Bolivariana Architecture and Planning Laboratory (Laboratorio de Arquitectura y Urbanismo).
Leet	The Universidad Pontificia Bolivariana Architectural Technical Experimentation and Studies Laboratory (Laboratorio de Estudios y Experimentación Técnica en Arquitectura).

MASL	Meters above sea level.
MWCNT	Multi-Wall Carbon Nano-Tubes.
NTC	Colombian Technical Standard (Norma Técnica Colombiana).
PBV or GVW	Gross Vehicular Weight (*peso bruto vehicular*).
PET	Polyethylene terephthalate.
PND	National Development Plan (Plan Nacional de Desarrollo).
PVA	Polyvinyl Alcohol.
RAE	Royal Spanish Academy of Language (Real Academia de la Lengua Española).
RWTH	Rheinisch-Westfälische Technische Hochschule Aachen.
Sakb	Specialized Architectural and Design Institute.
Sena	National Apprenticeship Service (Servicio Nacional de Aprendizaje).
SGR	General System of Royalties of the Republic of Colombia (Sistema General de Regalías).
SMMLV	Minimum Monthly Wages (*salarios mínimos mensuales legales vigentes*).
SWCNT	Single-Wall Carbon Nano-Tubes.
TGA	Thermo-gravimetric analysis.
TUM	Technical University of Munich (Technishe Universität München).
UHPC	Ultra High-Performance Concrete.
UN	United Nations.
Un-Habitat	United Nations - Habitat (División del Hábitat, Naciones Unidas).
UPAC	Constant Purchasing Power Unit (Unidad de Poder Adquisitivo Constante).
UPB	Universidad Pontificia Bolivariana.
USSR	Union of Soviet Socialist Republics.
VEP	Prefabricated economic housing (*viviendas económicas prefabricadas*).
VIP	Priority Social-Interest Housing (*vivienda de interés social prioritario*).
VIS	Social-Interest Housing (*vivienda de interés social*).
VIVA	The Housing Company of Antioquia (Empresa de Vivienda de Antioquia).

Equations and equational abbreviations

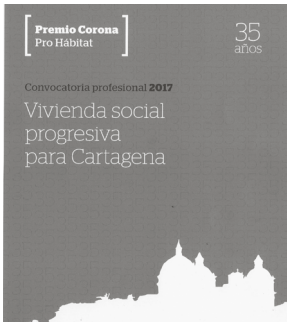
e	Efficiency.
qn	Quantity.
ql	Quality.
r	Resources.
p	Products.
c	Cost.
t	Time.
e = (qn x ql)/r	Efficiency = (quantity of homes x quality of the homes) / quantity of costs and time.
(cam)	Monthly administrative cost.
(cat)	Total administrative cost.
(cc)	Cargo capacity of the vehicle.
(cd)	Direct cost of the project in a traditional system.
(cf)	Construction cost of field factory.
(cr)	Cost of each trip.
d	Deficit.
Mpa	Mega Pascals.
(µm)	Microns.

Veröffentlichungen / Publications

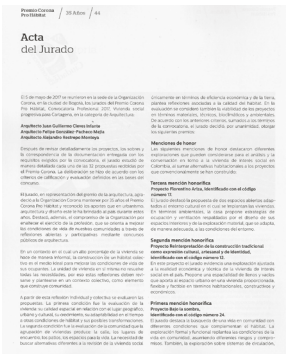
Mobilität in Medellín Bedeutet Gleichheit, Integration und Begegnung
In: Baunetzwoche #507
www.baunetz.de/cid/5340078
März 2018



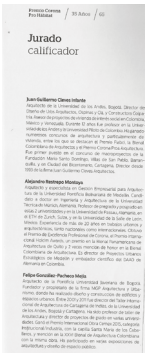
Beiträge zu den Ingenieurwissenschaften
In: Prämie Corona Pro Hábitat, Progressive Sozialwohnungen für Cartagena
ISSN:2346-1713
Seite 38
Juni 2017



Veröffentlichung Protokoll der Jury Prämie Corona Pro Hábitat 2017
In: Prämie Corona Pro Hábitat, Progressive Sozialwohnungen für Cartagena
ISSN:2346-1713
Seiten 44-45



Jurymitglied Prämie Corona Pro Hábitat 2017
In: Prämie Corona Pro Hábitat, Progressive Sozialwohnungen für Cartagena
ISSN:2346-1713
Seite 65



Lehrstuhl Corona 2017
In: Prämie Corona Pro Hábitat, Progressive Sozialwohnungen für Cartagena
ISSN:2346-1713
Seite 65



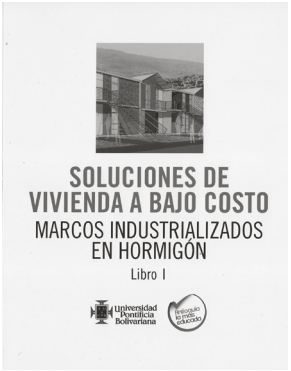
Moravia Kindergarten
In: Green Building Magazine
ISSN: 712977-741126-12
Seiten 32-37
Januar 2017



Coverstory (Interview)
In: Green Building Magazine
ISSN: 712977-741126-12
Seiten 28-31
Januar 2017



Lösungen für preiswerten Wohnraum: Industrielle Betonrahmen, Buch 1
ISBN 978-958-764-323-7 (Druckfassung)
ISBN 978-958-764-322-0 (digitale Fassung)
CO-MdUPB / spa / rda
SCDD 21 / Cutter-Sanborn
Editorial Universidad Pontificia Bolivariana, Medellín
108 Seiten



Film Ursprungscode ROUTE N
Interview mit Alejandro Restrepo Montoya
https://www.youtube.com/watch?v=VSQX6alCgPQ
Medellín, Juni 2016



Der Gastgeber
In: Zeitschrift Revista Universitas Científica: Revista de Divulgación Científica, UPB
Band XVIII, Nummer 1
ISSN 1692-0155
Seiten 67-71
Juni 2015



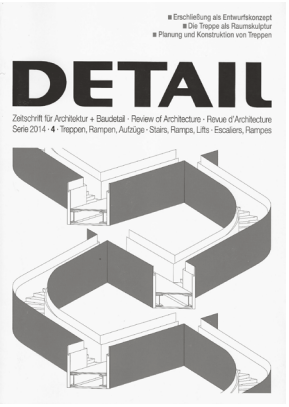
Der Frieden wird mit menschenwürdigen Wohnraum gebaut.
In: Zeitschrift Revista Universitas Científica: Revista de Divulgación Científica, UPB
Band XVIII, Nummer 1
ISSN 1692-0155
Seiten 34-41
Juni 2015



Kindergarten Jardín Infantil El Pinal
In: Zeitschrift Revista RD 2
Architekturschule der Provinz Buenos Aires
Seiten 88-93
Januar 2015



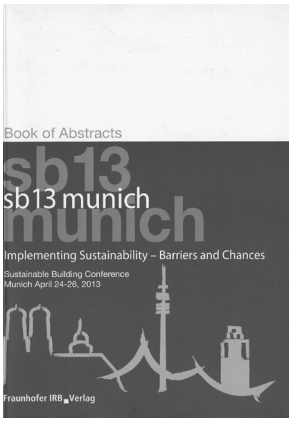
Planung und Konstruktion von Treppen
In: Detail, Zeitschrift für Architektur (Review of Architecture)
Serie 2014, Nummer 4: Treppen, Rampen, Aufzüge.
ISSN: 0011-9571 B 2772
Seiten 334-340
August 2014, München, Bundesrepublik Deutschland



Medellín´s City Process
In: IAES Documents. New Directions in Architecture Education.
3rd. International Architectural Education Summit
ISBN 978-3-44083-01-8
Seiten 136-139.
September 2013, Aedes Network Campus, Berlin


MEDELLIN'S CITY PROCESS

Learning and Community Life: Educational and Cultural Buildings to improve the Quality of life in Medellín, Kolumbien.
In: Book of Abstracts SB 13 Munich Implementing Sustainability – Barriers and Chances Sustainable Building Conference
ISBN 978-3-8167-8965-9
Seiten 165-166
München, 24. – 26. April 2013



Towards the Industrialisation and Sustainability of Social Housing Projects in Colombia
In: Book of Abstracts SB 13 Munich Implementing Sustainability – Barriers and Chances Sustainable Building Conference
ISBN 978-3-8167-8965-9
Seiten 379-380
München, 24. – 26. April 2013


Learning and Community Life: Educational and Cultural Buildings to Improve the Quality of life in Medellín, Colombia

Summary

Entwicklung von vorübergehenden Unterkünften zu permanenten Wohnraum: Vorschläge ökologischer und nachhaltiger Architektur für vertriebene und bedürftige Bevölkerungsgruppen
In: Prämie Corona Pro Hábitat 30 Jahre. Vorübergehende Unterkunft und permanenter Wohnraum für Überschwemmungsgebiete.
ISBN 978-958-57307-1-7
Seite 14
Kolumbien, 2012



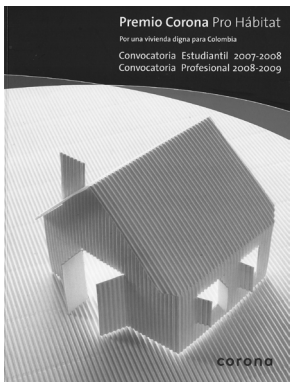
Paneele aus Abfällen der Bananenagrarindustrie.
In: Prämie Corona Pro Hábitat 30 Jahre. Vorübergehende Unterkunft und permanenter Wohnraum für Überschwemmungsgebiete.
ISBN 978-958-57307-1-7
Seite 16
Kolumbien, 2012


2008/9 XV CONVOCATORIA PROFESIONAL CATEGORÍA INGENIERÍA
"POR UNA VIVIENDA DIGNA PARA COLOMBIA"
Paneles generados a partir de residuos de la agroindustria platanera

Aler: Produktion von ausgedehnten porigen Zuschlagsreststoffen bei vorgefertigten Paneelen
In: Prämie Corona Pro Hábitat 30 Jahre. Vorübergehende Unterkunft und permanenter Wohnraum für Überschwemmungsgebiete.
ISBN 978-958-57307-1-7
Seite 17
Kolumbien, 2012


2008/9 XV CONVOCATORIA PROFESIONAL CATEGORÍA INGENIERÍA
"POR UNA VIVIENDA DIGNA PARA COLOMBIA"
Aler, producción de áridos ligeros expandidos residuales aplicados en paneles prefabricados

Paneele aus Abfällen der Bananenagrarindustrie (erster Platz Nationale Prämie Corona Pro Hábitat, Kapitel Ingenieurwissenschaften, 2008-2009)
In: Prämie Corona Pro Hábitat, für menschenwürdigen Wohnraum für Kolumbien
ISBN 978-958-8402-13-0
Seiten 46-49
Kolumbien, 2009


Premio Corona Pro Hábitat
Por una vivienda digna para Colombia
Convocatoria Estudiantil 2007-2008
Convocatoria Profesional 2008-2009
corona

Produktion von ausgedehnten porigen Zuschlagsreststoffen bei vorgefertigten Paneelen (zweiter Platz Nationale Prämie Corona Pro Hábitat, Kapitel Ingenieurwissenschaften, 2008-2009)
In: Prämie Corona Pro Hábitat, für menschenwürdigen Wohnraum für Kolumbien
ISBN 978-958-8402-13-0
Seiten 50-51
Kolumbien, 2009


Producción de áridos ligeros expandidos residuales aplicados en paneles prefabricados

Flexibles Haus: modular, erweiterbar und nachhaltig
In: Contacto-i
Newsletter Boletín Informativo del Centro de Ciencia y tecnología de Antioquia CTA
Stadtverwaltung von Medellín
Oktober 2008


Oportunidad CONSTRUCCIÓN
VIVIENDA FLEXIBLE: MODULAR, AMPLIABLE Y SOSTENIBLE

XXI. Kolumbianische Architekturbiennale, 2008
Literaturpark, Ehrenauszeichnung, Kategorie Stadtplanung und Landschaftsbau
ISBN 978-958-97992-4-6
Seiten 98-101
Oktober 2008


XXI BIENAL COLOMBIANA DE ARQUITECTURA 2008
SOCIEDAD COLOMBIANA DE ARQUITECTOS
CONSTRUYENDO VALOR CON LA POÉTICA DEL LUGAR

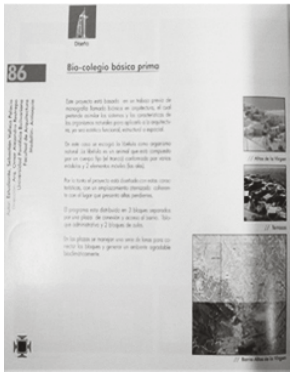
Zeitschrift Revista Semana
Die grüne Architektur
Ausgabe 1378
ISSN 0121-4837
Seite 98
29. September bis 29. Oktober 2008


La arquitectura verde
Una planta constructiva

Das flexible Haus: passt sich an deine Bedürfnisse an
In: WEB-Seite Univisión, 2008
http://www.univision.com/content/content.jhtml?cid=1663228
September 2008


La Casa Flexible
Se adapta a tus necesidades
Rafael Cores.
Univision Online
MEDELLÍN
Con solo empujarla
Básicamente, una vivienda flexible es aquélla que permite cambios en su disposición sin tener que recurrir a grandes obras ni procesos externos. Y, ¿por qué es útil?
Fotos
Imagínate que ahora vives con tu pareja pero no tienes hijos, por lo que sólo necesitas un dormitorio y prefieres tener un gran salón-comedor. En el momento en que necesitaras una habitación extra, una vivienda flexible podría fácilmente reconvertirse de manera que parte del espacio de otras áreas se dedicara a esa nueva habitación.

Zeitschrift Revista Hito Nummer 22
Bio-Schule Grundschule
Akademisches Titelprojekt der Architekturfakultät Universität Universidad Pontificia Bolivariana, Student Sebastián Vallejo Palacio
ISSN 1657-9186
Seite 86
April 2008



Zeitschrift Revista del Buen Gobierno
Von vorübergehenden Unterkünften zu permanentem Wohnraum: Vorschläge nachhaltiger und ökologischer Architektur für einkommensschwache und durch Naturkatastrophen vertriebene Bevolkerungsgruppen
Nummer 7
ISSN 1909-3101
Seiten 42-47
Februar 2008



Zeitschrift Revista Noticreto
Ingenieurschule, Universität Universidad Pontificia Bolivariana: Ein Hochhaus, das zwischen Architektur und Wohlbefinden navegiert
Nummer 85
ISSN 0120-8489
Seiten 12-18
Dezember 2007



Zeitschrift Revista INFODOMUS - Spanien
Nachhaltige Konstruktion und Energieeffizienz: Block 11A Universität Universidad Pontificia Bolivariana
Band 13
ISSN 18868762
Seiten 81-87
Oktober 2007



Die Bibliothek La Piloto wird ein Platz von Licht und Schatten sein
In: Zeitung El Colombiano
Seite 6C
17. Oktober 2006



Buch Labor Null
Ingenieurschule, Universität Universidad Pontificia Bolivariana von Medellín
Seiten 7, 32, 67, 72, 156
ISBN 958-97871-0-X
September 2006



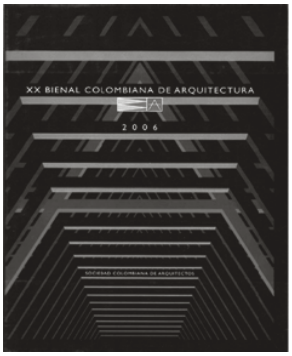
Zeitschrift Revista El Mueble y la Madera
Spanplatten: eine Lösung für Sozialwohnungen
Nummer 52
ISSN 0122-6908
Seiten 48-54
Juni bis August 2006



Sustainable Construction Holcim Awards 2005/2006
Encouragement Prize Latin America
From Temporary Shelters to Permanent Housing, Medellín, Kolumbien
ISBN 978-3-7266-0076-1
Seite 129
2006



XX. Kolumbianische Architekturbiennale 2006
Hochhaus 11A Ingenieurschule, Universität Universidad Pontificia Bolivariana
Auswahl Architekturprojekt
ISBN 978-958-97992-0-8
Seiten 120 und 121
2006





XV. Panamerikanische Architekturbiennale von Quito, 2006
Hochhaus für Hörsäle, Ingenieurschule, Universität Universidad Pontificia Bolivariana von Medellín
ISBN 9978-300-54-6
ISBN 978-9978-300-54-6
2006



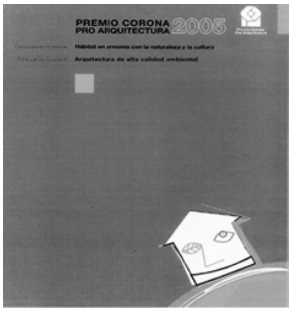
Bericht über nachhaltige Entwicklung Holcim Kolumbien 2005
Ausgezeichnete kolumbianische Projekte: Von vorübergehenden Unterkünften zu permanentem Wohnraum
Seiten 27-31
2005



Bericht über nachhaltige Entwicklung Holcim Kolumbien 2005
Wir sind dazu berufen, Lösungen zu realen Problemen beizutragen
Seite 32
2005



Buch Von vorübergehenden Unterkünften zu permanentem Wohnraum
ISBN 958696448-5
33 Seiten
Editorial Universidad Pontificia Bolivariana
2005



Prämie Corona Pro Arquitectura 2005
Architektur grosser ökologischer Qualität: Überlegungen der Jury zu den Projekten
ISBN 958-97632-5-1
Seiten 48-51
2005


Universitas Científica

La construcción de espacios arquitectónicos utilizando la técnica de estructuras laminares en Hormigón

Soporte teórico y referente técnico de la investigación en membranas de hormigón reforzadas con fibras sintéticas

Objetivo General

Objetivos Específicos

Resumen

Die Konstruktion architektonischer Räume unter Anwendung der Technik der Betonlamellenstruktur: Theoretischer Support und technischer Bezug der Erforschung von mit Kunstfasern verstärkten Betonmembranen
In: Universitas Científica, Revista de Divulgación Científica y Académica del CIDI, Universität Universidad Pontificia Bolivariana, Band VI
Seiten 112 und 113
ISSN 1692-0155
Dezember 2005


Universitas Científica

Las Escuelas de Arquitectura: Espacio para la Investigación, la Innovación y el Desarrollo Tecnológico

Resumen

Die Architekturschulen: Räume für Forschung, Innovation und technologische Entwicklung
In: Universitas Científica, Revista de Divulgación Científica y Académica del CIDI, Universität Universidad Pontificia Bolivariana, Band VI
Seiten 140-142
ISSN 1692-0155
Dezember 2005


Artículos libres

Lo íntimo, lo colectivo

Proyectos domésticos multifamiliares en la Facultad de Arquitectura de la Universidad Pontificia Bolivariana de Medellín experiencia académica del taller de proyectos, semestre de vivienda colectiva

Introducción

Das Intime, das Kollektive: Häusliche Mehrfamilienhäuserprojekte der Architekturfakultät der Universität Universidad Pontificia Bolivariana von Medellín. Akademische Erfahrung des Workshopprojekts, Semester Kollektivunterkunftt
In: Universitas Científica, Revista de Divulgación Científica y Académica del CIDI, Universität Universidad Pontificia Bolivariana, Band VI
Seiten 143-145
ISSN 1692-0155
Dezember 2005


Universitas Científica

El Hormigón arquitectónico y sus posibilidades de acabado en pisos interiores

Der architektonische Beton und seine Möglichkeiten beim Bodeninnenausbau
In: Universitas Científica, Revista de Divulgación Científica y Académica del CIDI, Universität Universidad Pontificia Bolivariana, Band VI
Seiten 146-147
ISSN 1692-0155
Dezember 2005


Universitas Científica

El Laboratorio de Estudios y Experimentación Técnica en Arquitectura LEET

Die Laborstudien und die technische Erprobung in der Architektur LEET
In: Universitas Científica, Revista de Divulgación Científica y Académica del CIDI, Universität Universidad Pontificia Bolivariana, Band VI
Seiten 156 und 157
ISSN 1692-0155
Dezember 2005

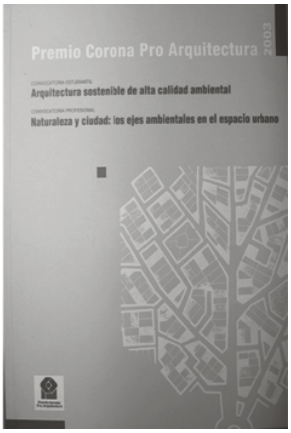


XIX. Nationale Architekturbiennale, 2004
Von vorübergehenden Unterkünften zu permanentem Wohnraum
Ehrenauszeichnung Kategorie Beliebte Lebensräume
ISBN 958-96587-4-1
Seite 221
2004

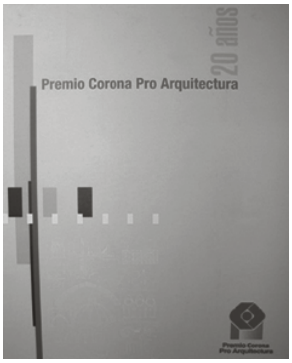


XIV. Panamerikanische Architekturbiennale von Quito, 2004
Von vorübergehenden Unterkünften zu permanentem Wohnraum
Internationale Auszeichnung und Anerkennung
ISBN 9978-300-08-2
Seite 98
2004

Prämie Corona Pro Arquitectura 2003
Nachhaltige Architektur mit grosser ökologischer Qualität
Entwicklung von vorübergehenden Unterkünften zu permanenten Wohnräumen: Vorschläge der ökologischen und nachhaltigen Architektur für vertriebene und bedürftige Bevölkerungsgruppen
Erster Platz Nationale Prämie Corona Pro Arquitectura
ISBN 958-97368-1-5
Seiten 14-19
2003



Prämie Corona Pro Arquitectura 20 Jahre
Verbesserung im Stadtteil San Benito, Bogotá
Erste Ehrenauszeichnung im Nationalen Wettbewerb Corona Pro Arquitectura
Seite 49
2002



Lectures

Conference at *Catedra Corona 2017, Premio Corona Pro Habitat* in Bogotá:
"Industrial modular system for the popular habitat"
Bogotá, Colombia. June, 2017

Conference at the Biennial of Architecture of Lima and in the Regional Congress of Architects of the Andean Group:
"Medellín, Example of Urban Reinvention"
Lima, Peru. November, 2016

Conference at *Universidad Santo Tomás* in Medellín:
"Industry and Social Housing"
Medellín, Colombia. August, 2016

Conference at *Universidad de la Salle.* Faculty of Architecture, León, México:
"Housing in the Urban and Environmental Plan in the Center of Medellín"
León, México. August, 2016

Conference at *Universidad Meridiano.* Faculty of Architecture, León, México:
"The Concrete Home"
León, Mexico. February, 2016

Conference at the International Architectural Seminar "EXPOCAMACOL":
"Prefabrication for the Social Dwelling in Medellín, Colombia"
Medellín, Colombia. August, 2014
Event organized by the *Cámara Colombiana de la Construcción*

Conference at the International Architectural Seminar "Laufenmanifest: Aesthetics with Ethics":
"Next Step: the Social Dwelling in Medellín, Colombia"
Laufen, Germany. October 18-20, 2013
Event organized by ETH, Zürich and the *Technische Universität München* (TUM)

Conference at the 3rd International Architectural Education Summit (IAES):
Lecturer. New Directions in Architecture Education
"Medellín City Process"
Berlín, Germany. September 13-14, 2013
Event organized by ANCB and The Metropolitan Laboratory

Conference at the *Technische Universität München* (TUM):
Lecturer. "Architecture, Sustainability and Society: Prefabrication, Modular Design, Natural Resources and Social Projection"
Munich, Germany. January 18, 2013
An encounter organized by the *Deutscher Akademischer Austausch Dienst* (DAAD)

Conference at the *Corona Cátedra Viajera* Seminar:
Lecturer. "House, Industry and Society: Domestic Architecture from the Production of New Knowledge and the Generation of Sustainable Industrial Processes"
Medellín, Colombia. August 29, 2012
Event organized by *Organización Corona*

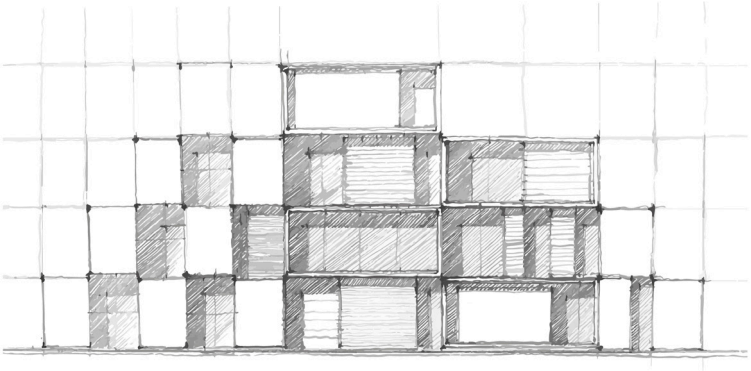
Conference at the International Precast Seminar:
Lecturer. "1 + 1: Architecture through prefabrication, efficiency and sustainability"
Medellín, Colombia. August 24, 2012
Event organized by the Colombian Chamber of Construction (*Cámara Colombiana de la Construcción,* CAMACOL)

Conference at the 2012 Biocasa Seminar:
Lecturer. "House and Industrialization"
Cali, Colombia. August 10, 2012
Event organized by the Colombian Chamber of Construction (*Cámara Colombiana de la Construcción,* CAMACOL)

Conference in the *Technische Universität München* (TUM)
Lecturer. "Society in Change: The Case of Medellín. Nine reflections in Eight Years"
Technische Universität München, Germany. December 2, 2011
An encounter organized by the *Deutscher Akademischer Austausch Dienst* (DAAD)

Presentation of the doctoral dissertation in *Metodisches Kolloquium*
"Concrete Home"
Technische Universität München (TUM). Germany, July 6, 2011
Event organized by the Institute for Spatial and Territorial Development

This investigation has been carried out to bring the architecture of social housing and its construction techniques closer to the life of the communities, to the place they have occupied and transformed, to their traditions, and their ways of living. It has been inspired by those families who have maintained the illusion of finding a home within reach of their dreams, where the doors and windows are open as a reflection of life itself, as an act of hope.



This book was published in digital version, November 2020.

Through concepts linked to architecture, engineering, urban planning, economy, technology and the human habitat, this research developed a new model for the designing and construction of social housing. Its first moment industrializes the precast-concrete support structure, which defines the inhabitable spaces and guarantees security and efficiency through a standardized production. A second moment allows, through the projects' architecture, language and spatial aspects, the adaptability of the housing units to social, cultural and environmental conditions. Finally, in the occupation of the units, families may transform their houses and adapt them to specific needs or tastes, through the initial technical conditions used to build them. This research gathers results, and presents a detailed proposal of industrialization, individualization and transformation; one that includes on-site installation processes. It also considers the need and pertinence to diversify constructive techniques and models of social housing in a local context. This project was carried out in the Architecture Faculties of the ***Technische Universität München*** TUM, Germany, and the *Universidad Pontificia Bolivariana,* UPB in Medellín, Colombia, between October 2010 and January 2018.

Concret Home

Precast Concrete to Improve Efficiency in the Design and Construction of Social Housing for Antioquia

UNIVERSIDAD PONTIFICIA BOLIVARIANA
EDITORIAL