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The use of Mass Customization to Improve Environments in Social Housing Neighbourhoods in Brazil

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The use of Mass Customization to Improve Environments in Social Housing Neighbourhoods in Brazil

by

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Abstract

This research examines how mass customization can contribute to promoting better environments in social housing developments in Brazil, both within the units and for the neighbourhood. It focuses on developments of house units for the lowest income range of social housing programs seeking to propose processes and systems that could facilitate the provision of customized house units, allowing the needs of different families to be met as they change over time, without creating problems for the city. The research analyses the ecology of the system of social housing provision, from the proposal of new developments to post-occupancy renovations, in concert with the concept of mass customization, its tools and processes. From this analysis, a practical solution of how mass customization could be implemented in this context is proposed. This mass customization system considers the interests of the stakeholders, their capabilities, and the need for the least amount of changes to current policy and regulation. As part of the mass customization system, this study outlines the necessary functionality of a co-design system to be used with the families in this context. This co-design system is essential to allow the families to visualize, manipulate and validate the design of their units. From the analysis and solution design for this specific social housing context, broader conclusions are drawn contributing to the advancement of knowledge in the areas of social housing in Brazil and mass customization in housing more generally. This research shows how the concept of mass customization could bring benefits to the context of social housing neighbourhoods of the lowest income range. It also shows how a shift in perception, including post-occupancy construction as an integral part of the process of provision of social housing, could result in significantly better environments in these neighbourhoods over time. More generally, this research contributes to the field of mass customization in housing by showing that

it can be advantageous for the mass customization strategy to focus on differentiating the houses post-occupancy. The research also shows that mass customization can be applied with the goal of bringing broader benefits to society by providing individual customization.

Keywords: housing, mass customization, post-occupancy differentiation, social housing.

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Dedication

To my husband and children, Fernando, Fernanda Clara, and Leonardo.

In loving memory of my mother, Neusa Rodrigues Félix, who inspired this journey.

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List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
SNHIS	Social Housing National System
MCMV	My House My Life social housing program
IBGE	Brazilian Institute of Geography and Statistics
NAUrb	Research Centre for Architecture and Urbanism
UFPel	Federal University of Pelotas
CEF	Bank Caixa Econômica Federal
PAR	Program of residential leasing
BRL	Brazilian Real currency
CAD	Canadian Dollar
CAU	Architecture and urbanism professional council
SiNAT	National system of technical evaluation of innovative products
PBPQ-H	Brazilian program of quality and productivity in habitat
DATec	Document of technical evaluation
BIM	Building Information Modeling

Chapter 1. Introduction

This research examines how mass customization can contribute to promoting better environments in social housing developments in Brazil, both within the units and for the neighbourhood. It focuses on developments of house units for the lowest income range of social housing programs. It seeks to propose processes and systems that could facilitate the provision of customized house units, allowing the needs of different families to be met as they change over time, without creating problems for the city.

The Brazilian law that establishes the Social Housing National System (SNHIS) (Lei Nº 11.124, 2005) has, among its objectives, two that allow us to infer what the government means by the term social housing. These objectives state that the SNHIS aims to: (1) enable access of the low-income population to urbanized land, and to dignified and sustainable housing; (2) implement policies and investment and subsidy programs, promoting and enabling access to housing for the low-income population (Lei Nº 11.124, 2005). From these objectives, it is clear that social housing refers to policies and programs to provide adequate housing for the low-income population. However, this legislation does not define what is considered low income or what is considered adequate. A hint is the reference to urbanized land, which in local legislation usually means land that has access to urban infrastructure such as water, sewage and electrical. Subsequent legislation of specific programs establish explicit ranges of low-income determining the maximum income that is eligible to access the programs and minimum criteria to evaluate what is considered adequate housing both in terms of urban infrastructure and the housing unit itself. The current largest program, My House My Life (MCMV) – translated from Minha Casa Minha Vida – establishes such criteria (Lei Nº 11.977, 2009), which is also used as a reference for many other

programs. Therefore, for this research, social housing is considered as dignified housing destined for the low-income population. It considers low-income as anything below the maximum income considered for eligibility under the current largest housing program MCMV, which is currently about seven times the minimum wage. Similarly, in this research dignified housing means housing that achieves the minimum standards required by the MCMV program (further discussed in chapters 2 and 3).

Among the different models of social housing, the government has stimulated housing ownership in Brazil since the early 1960s (Bonduki, 2008), and it is still the primary way of providing social housing. Similar to many Latin American countries, in Brazil the government gives eligible families credit to buy a house or apartment and subsidizes a large part of the cost for private companies to build the developments for such homes. Currently, it is common in social housing developments in Brazil to have only one unit design produced and built repeatedly throughout the development and even in several developments. This repetition occurs regardless of differences in climate, culture, and individual family needs. It is especially problematic considering the lowest income range of social housing programs. In this range, families do not have a choice of development. Furthermore, they are unlikely to be able to move later, since they are not eligible for housing programs a second time, even in other income ranges if their income increases.

The budget for these developments of the lowest income range is highly regulated and limited. Thus, developers need to keep costs to a minimum to guarantee profits. Having the units designed in consultation with the families, in a traditional way, would significantly increase the time and costs for the developer. Also related to reducing costs, these developments are most often on the outskirts of the city, where the land is cheaper. But public transportation to these places is

usually poor, adding to the segregation of these communities (Rolnik, Pereira, Moreira, et al., 2015; Rufino, 2015). In this context, the families start making changes and expanding their units to satisfy their needs and make room for businesses such as small shops and services for the local population.

National and local authorities know that the families will make changes and expand their house units. However, such units are not designed and built to facilitate these changes, making it difficult and more expensive for families to do so (Rufino, 2015). Moreover, most of the changes are designed and built illegally by the homeowners themselves, often resulting in inadequate situations such as the inappropriate discharge of rainwater, encroaching onto the public space, lack of ventilation and natural lighting, among others (Brandão, 2011; Digiacomo, 2004; Palermo, 2013). The problems with these self-designed and built expansions go beyond the families that live in the units and neighbourhood. It affects the municipality and broader society as it diminishes the capacity of public authorities to provide safe and healthy environments and services for its population. This includes many different aspects, from limited access of the public authorities to provide maintenance to services such as public lighting, provision of electricity, water, and sewage to overcrowding of the city's public health system. Providing customized units with costs close to the mass-produced units could help prevent some of these problems.

Individual customization in housing is traditionally seen as hiring an architect to creatively design a unique home that is ideal for a particular family. Mass housing, on the other hand, is when large numbers of identical homes are built and then sold for much less than the uniquely designed homes. Mass customization promises the best of both approaches: uniquely designed products that better fit the user's needs, with mass production efficiency and costs (Pine, 1993; Tseng & Jiao, 2007). Most cases of mass customization in housing do not consider the spatial needs of the user;

the user is limited to choosing their preferences in elements such as surface materials, colours, and finishes (Kolarevic, 2019). However, some examples from industry and research have addressed mass customization in housing also considering the needs in terms of space including the type of spaces, the relationships between them, and how much space, the users need or want (Barlow et al., 2003; Benros & Duarte, 2009; Khalili-Araghi & Kolarevic, 2016; Lo, Schnabel, & Gao, 2015). This kind of mass customization, addressing the spatial needs of the users, shows great potential to allow housing units in the context of Brazilian social housing to better satisfy the needs of the many different families that depend on it.

Several studies and industry examples explore the concept of mass customization within the context of social housing programs in Brazil. However, such studies and examples are usually limited to the higher income ranges of the social housing programs. These ranges of the programs have a company-customer relationship like that of any other product: the customer chooses the product they want to buy and how much they are willing to pay for it. There are only a few studies that explore mass customization for the lowest income range of social housing programs, which do not have this market-oriented logic. While several authors agree that the implementation of mass customization for this income range would benefit the families, the studies usually focus on one specific aspect to facilitate its implementation. For example, Azuma (2016) evaluates the use of physical models for mass customization in this context. Even studies that assess the possibilities of mass customization for providing housing in the lowest income range more broadly (Taube, 2015; Taube & Hirota, 2017), do not consider the post-occupancy processes of renovations and additions. This is the case in most of the literature about mass customization for housing regardless of the geographical or economic context. Several studies that show how mass customization could

be used to satisfy each family's needs in mass housing (Benros & Duarte, 2009; Duarte, 2005; Lo et al., 2015) only show strategies for the initial construction without considering future changes.

Aiming to prevent problematic changes to the units, several studies have addressed the possibilities for making housing more adaptable, showing guidelines for the design, construction possibilities and previous cases built with this intent (Friedman, 2002, 2013; Schneider & Till, 2007). Even though several studies and guidelines are specific for the adaptability of social housing units in Brazil (Brandão, 2002, 2011; Digiacomo, 2004; Larcher, 2005), most developments are still built without adopting such strategies, especially in the lowest income range. One of the reasons for this is that incorporating such adaptability strategies could add costs to the development. Even if there is an initial intent for the units to be more adaptable, the families are left to make the changes on their own and may not realize the possibilities or the code requirements. Further research is needed aiming to facilitate the adoption of such guidelines in the process of provision of social housing, and to indicate ways to assist families in making better design choices.

This research intends to address these gaps by analyzing the process of provision of social housing for the lowest income range, including the post-occupancy processes, to identify challenges to the adoption of mass customization in this context, ways to overcome them, as well as opportunities offered by its adoption. This research focuses on the possibility of improving social housing environments in Brazil as these neighbourhoods evolve over time. It aims to propose processes that allow developments to have customized house units that better meet the needs of each family, aiming to avoid problematic post-occupancy expansions. It also seeks to propose a system to allow homeowners to interact with the design of the unit before changing or expanding it, aiming to achieve more appropriate designs for these changes. This research examines the operational aspects regarding the deployment of mass customization in this context,

considering the capabilities and interests of the stakeholders involved. It seeks to propose processes that maximize the potential for such a strategy to be adopted by the municipalities, and ways to benefit the largest number of stakeholders and broader society.

The motivation for this research came from my previous work and research experiences. From the early stages of my undergraduate studies in architecture and urbanism, I have been involved with research seeking to improve the design process and outcome with digital technologies. Over the years, I became especially interested in the potential of parametrics to solve many kinds of design problems. In parallel, I practiced architecture in several different cities in the south of Brazil, both in private projects and institutional projects in the form of university community outreach as part of my responsibilities as a faculty member. My roles as an architect and faculty member led me to serve on public councils. I served for three years on the Master Plan Council of the city where I lived. This council was responsible for approving developments in the city that the city´s legislation did not predict, had aspects of concern for the city, or which the developer was requesting special approval of certain aspects outside of city rules. This service allowed me to see firsthand the complexities of approving new developments in the city, including many aspects beyond the technical urban and building rules. The influence of political aspects was particularly relevant and often not in line with the technical recommendations. Through this service, I acted as a direct stakeholder in some processes relevant to this research.

Similarly, I served in the professional association responsible for overseeing and guiding professional practice within the state (CREA/SC). This council is where professionals register each of their projects, indicating for which aspects they are responsible. The council is responsible for ensuring responsible, safe, and ethical professional practice. My service in this council allowed me to gain further knowledge of the legislation as well as better insight into the difference between

the roles and responsibilities required of professionals and the council by legislation and what laypeople perceive as being those roles. Part of my role in this service was to receive and evaluate suspected malpractice cases. While our role in the council was to inspect the professionals, we also received many cases indicating design or construction for which there was no professional involved. In these cases, all we could do was notify the project owner that they are required to have a professional responsible for the project.

Soon after those public service experiences, I moved to Pelotas, my hometown, to start a position as a professor in the Faculty of Architecture and Urban Design at the Federal University of Pelotas (UFPel). There I joined the research group GEGRADI to continue with research in digital processes in design. I started taking part in projects in collaboration with a social housing research group (NAUrb). My role in these research projects, which involved both groups, was focused on developing digital tools and processes that would be used to facilitate certain aspects of the social housing field research. For example, I was involved in developing a digital application to be used with children from social housing neighbourhoods. My proximity to this social housing research group drew my attention to the many different problems faced in this social housing context. Given my digital processes research background, it seemed evident that the solution to allow the needs of each family to be considered in the design of their unit without significantly increasing the costs, was to develop a digital parametric system to allow the families to interact with the design of their house. Through this system, the families would input their needs and make changes to the standard design. At the same time, the system would validate the solutions, directing the family away from problematic situations. Thus, at the start of my studies, the aim was to develop and test such a digital co-design system.

However, as the research evolved, and as I looked back on my other experiences outside of research, especially the service in public councils, it became evident that a technological solution was not enough to overcome the many contextual challenges. The co-design system I envisioned initially would only bring benefits to this social housing context if it were adopted alongside other measures throughout the process of housing provision. Such a broader approach would make it possible to achieve the end goal of customized housing design and more appropriate changes to the units over time. Therefore, the research shifted direction to examine the whole ecology of the system of provision of social housing, proposing a system that would allow the feasible and meaningful adoption of the concept of mass customization within the current capabilities of the different stakeholders involved.

Many aspects of my experiences in architectural practice, the approval of projects within cities, community outreach, and the perception of legal aspects were corroborated by the literature reviewed for this research. Furthermore, my previous experiences allowed me to make connections between the many different documents that I reviewed, which I would not have made by looking at the literature alone. This process also helped me recognize the importance of those personal experiences in understanding the ecology of the system of social housing. This recognition led me to include, in the research design, interviews with stakeholders to draw on their experiences and make further connections between the documents in more aspects of social housing provision.

Thus, the main questions that inform this research are: (1) How can a mass customization system be implemented in the context of social housing for the lowest income range of Brazilian programs? (2) How can the interaction of families with the design of their unit be promoted to engage them in more informed choices that improve the quality of the changes made to their units, also promoting better environments in the unit and the neighbourhood?

1.1.Objectives

1.1.1. General objectives

(1) Examine the context of provision of social housing in the lowest income range, including post-occupancy, in concert with the concept of mass customization, its tools and processes, to determine how mass customization could be applied in this context weighing the barriers, interests and capabilities of the different stakeholders, and the benefits it could bring.

(2) Propose a mass customization system for this context, aiming to promote better environments within the unit and the neighbourhood as they evolve over time.

1.1.2. Specific objectives

- Examine processes and systems that could allow social housing developments in Brazil to provide customized units considering the needs of the different families and allowing the units to change over time as those needs change.
- Identify, in the process of provision of social housing in Brazil, practices that limit the potential for implementation of mass customization and adaptability in social housing developments as well as favourable practices by the different stakeholders.
- Appraise ways of inserting mass customization and adaptability in the process of provision of social housing in Brazil, considering the needs of the users and the interests of the different stakeholders involved.
- Determine the characteristics that a mass customization system should have to be viable and desirable to implement for social housing for the lowest income range in Brazil considering the current process of provision of social housing, the needs of the users of the units, and the interests of the different stakeholders.

- Propose a way for the families to interact with the design of their units to have greater control over the changes and expansions they make to the units, promoting more informed decisions, thus, allowing these changes to be more appropriate for the environments of the unit itself and the neighbourhood and avoiding problematic situations.
- Propose how such an interaction system could be implemented, considering the relationships and interests between the different stakeholders involved.
- Consider and assess the implications and impacts for the stakeholders of the use of the proposed mass customization system and interaction system in social housing contexts.

1.2.Methods

This research is of an applied nature, seeking to solve a problem identified in society, namely, social housing developments not considering the needs of the inhabitants in the design and production of the units. It takes the approach of design sciences research that "aims at developing ways to achieve human goals" (March & Smith, 1995, p. 254). March and Smith (1995) further explain how design science is different from natural science: "Natural science is descriptive and explanatory in intent. Design science offers prescriptions and creates artifacts that embody those prescriptions" (p. 254). This meets the explanation given by Simon (1996) who states that "the natural sciences are concerned with how things are" and that "Design, on the other hand, is concerned with how things ought to be, with devising artifacts to attain goals" (p. 114). However, this does not mean that these artifacts do not consider the natural laws; their creation should be based on a clear understanding of the natural phenomena surrounding them (March & Smith, 1995). In this approach, design is seen broadly as devising "courses of action aimed at changing existing situations into preferred ones" (Simon, 1996, p. 111). This approach seeks to produce knowledge that is applicable and useful for the solution of relevant real-world problems

that require a practical solution. Through the results of the solutions and artifacts developed for the specific problem, it seeks to contribute to the expansion of knowledge of the theories used in the development of the solutions (Azuma, 2016; Dresch, Lacerda, & Antunes, 2015; D. P. Lacerda, Dresch, Proença, & Antunes Júnior, 2013).

The use of the design science research approach has been increasing in several areas where new practical approaches to deal with problems are needed, such as information technology, management, medicine, engineering, and architecture. More specifically, it has been used in the field of mass customization in housing (Azuma, 2016; Rocha, 2011) to allow the proposition of new methods and technologies to solve problems that prevented its application in specific contexts.

Design science research can have a qualitative approach, as is the case with this research. Therefore, my project takes on the characteristics often present in qualitative research, as explained by Groat and Wang (2013). In particular, in this study the researcher plays "an important role in interpreting and making sense of [the collected] data" adopting "practices that embrace interpretation and meaning in context" (p. 2019). In order to propose a mass customization intervention for the lowest income range of social housing programs it was necessary to take holistic approach, analyzing the ecology of the system of social housing provision. Therefore, also relevant is the holistic characteristic which shows a complex picture considering multiple perspectives and the many factors involved (Groat & Wang, 2013). It is relevant to note that this study takes the approach of doing qualitative analysis of qualitative data (Bernard, 2013).

This research uses a design science approach to address the problems that emerge from the evolving built environments in neighbourhoods of the lowest income range of social housing programs in Brazil. It starts from the premise that two main factors contribute to the emergence of those problems: (1) the need to change and add to the original housing unit given that it does not

satisfy the needs of the user; (2) the lack of design, and code knowledge involved in the creation of the changes to the housing units. In this regard, the concepts of mass customization and housing adaptability are considered as significant contributors to the development of a practical solution that could be applied in this context.

This research uses the concept of mass customization as a guide into processes for the production of individually customized products at prices that "approach, and sometimes beat" (Pine, 1993, p. 48) those of mass-produced goods. The concept and processes of housing adaptability is used to guide aspects relating to design and technologies, aiming to provide "occupants with forms and means that facilitate a fit between their space needs and the constraints of their homes either before or after occupancy" (Friedman, 2002). This also encompasses being able to change the environment to suit new circumstances. It is informed by previous studies of adaptability (Brandão, 2011; Friedman, 2002; Schneider & Till, 2007) and considers different aspects such as initial and continuous adaptability. It also considers aspects related to how the housing unit is changed, such as having rooms that can be used in different ways or the possibility of physically changing the rooms themselves (Schneider & Till, 2007). Theoretical references related to these concepts such as mass customization, adaptable housing, and social housing, are studied for the development of the research. Previous studies that use and apply those concepts are also studied, as well as relevant legislation and policies.

Previous studies on social housing processes show significantly different dynamics in city operations and development, including in how social housing is operationalized and the capabilities of the stakeholders, between large cities or metropolitan areas and smaller cities. Considering that there is significantly less research aiming to solve problems present in social housing neighbourhoods in smaller cities, this research focuses on cities that can be considered of

small and medium size. Furthermore, I have previous experiences in cities of this size, having lived and worked as a design professional and academic in four different such cities, which allowed me to see and, in some cases, act as a direct stakeholder in some of the processes being investigated. The Brazilian Institute of Geography and Statistics (IBGE) classifies the hierarchy of cities according to their influence and connection to other cities. For example, in the South region, there are only two cities considered metropolis, both of which have a population larger than one million. These are large cities with an extensive area of influence (IBGE, 2008). Therefore, this study focuses on the other cities, excluding the metropolis and the other cities that create their metropolitan area. This research also focuses on house units within the social housing programs. This type was chosen due to its significant presence in cities of the size considered and fewer studies addressing the problems in neighbourhoods of this type.

With varying approaches, several authors have discussed the main steps that should be included in design science research (Dresch et al., 2015; Kasanen & Lukka, 1993; March & Smith, 1995; Rocha, 2011). For the development of this research I adopt a five-stage approach: (1) find a problem; (2) obtain understanding of the problem; (3) innovate, construct a solution idea; (4) evaluate the solution; (5) show how the solution connects and contributes to the theories used for its creation and broader research area. Figure 1.1 shows an overview of the approach taken for each stage in this research and how they are related. How each stage was approached is further explained in the pages following Figure 1.1, starting with stage 2 since the identification of a problem was previously presented in this chapter.

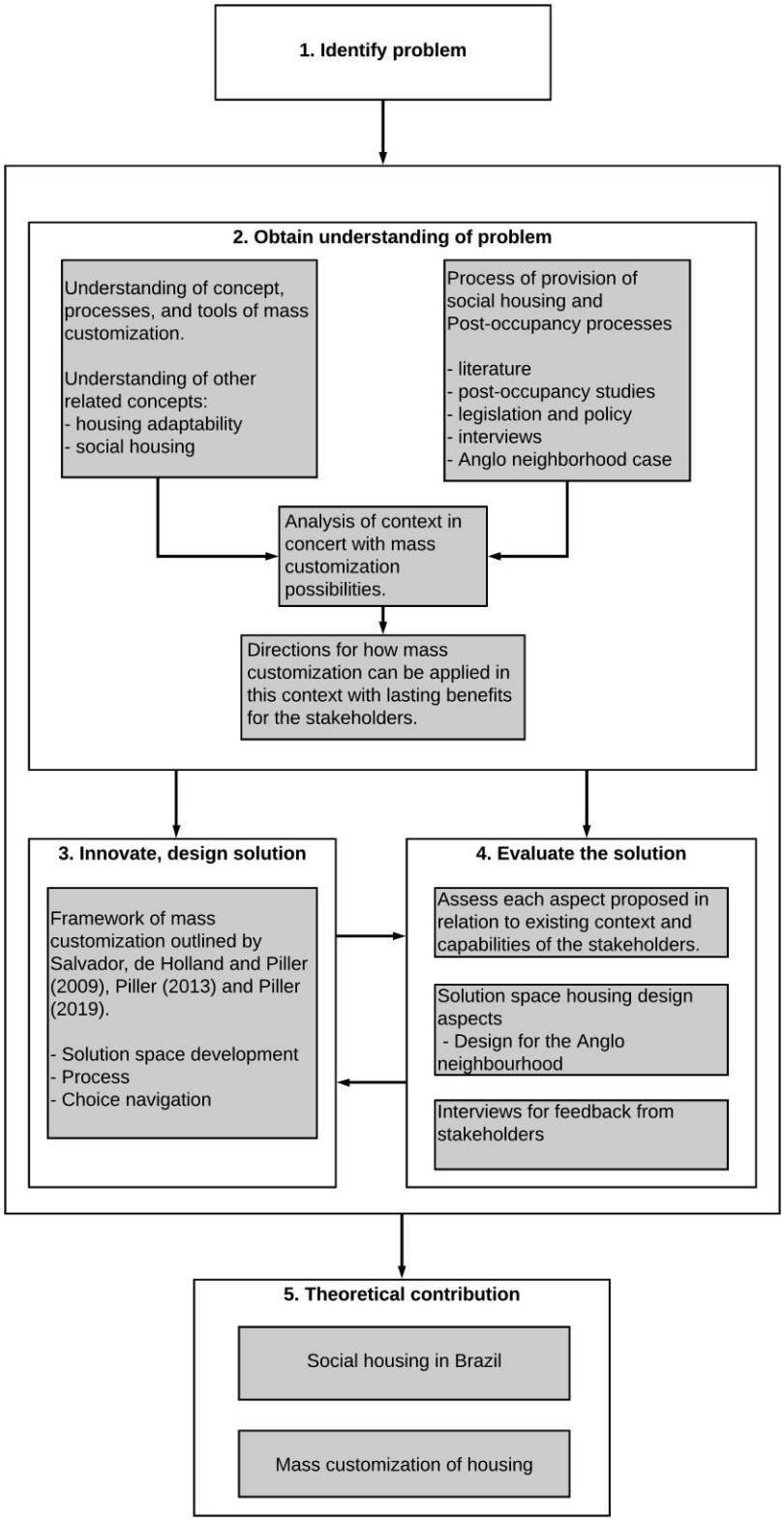

Figure 1.1 Methods flowchart

1.2.1. Stage 2 - Obtain understanding of the problem

This stage is shown in chapters two and three. In Chapter 2, the concepts of mass customization, housing adaptability, and social housing are examined. In parallel, shown in Chapter 3, I study the process of provision of social housing for the lowest income range, identifying the main stakeholders and the consequences of their decisions in the process, policies, and standard practices. As well as an understanding of the problem and context, the two main specific objectives of this stage are: (1) to identify policies and practices that limit or favour the potential for implementing mass customization and adaptability in social housing developments; and (2) to identify the priorities of requirements the families have for their units, and how the families use and change their units over time. I also identify the building systems and housing typologies that are currently used in social housing developments in Brazil, as well as what is the process for approving new building systems. This is done to determine the potential to use existing systems within a mass customization strategy, and the feasibility of proposing new building systems.

To achieve the goals of this stage and gain understanding of the context, I use different approaches. First, the documentary analysis of policies, both on a national level and local level, and secondary literature review of other research that describes and analyses these processes and concepts, including post-occupancy studies. In some cases, the information available in the literature is not enough to make the connections to identify the limitations and potentials present in the current social housing processes in concert with the strategies and tools of mass customization, Therefore, this study also draws on semi-structured interviews with selected key stakeholders. As such, this study received ethics approval from the Conjoint Faculties Research Ethics Board at the University of Calgary under the number REB18-2022. A total of eleven people

were interviewed, divided into six categories of stakeholders. Whenever possible, I sought to interview more than one representative from each category from more than one city. At the same time, I sought to interview at least one representative from each category that had direct influence in the processes for my specific case study, which is further explained later in this section. It is important to highlight that these interviews were not used to generate data to describe the phenomena, but rather, to give context and help make connections between the processes and phenomena described in the literature. Therefore, many of the processes described during the interviews are also present in the literature. However, in the literature, they appear as contained blocks of information since many research projects and publications focus on one or a few specific processes. Typically, they do not show how that process connects to other processes of the provision of social housing. However, for my research, understanding how these blocks fit and operate together to form the ecology of the system of social housing provision is essential. The interviews helped to make these connections. Furthermore, whenever a process that I had not previously identified from the literature was described in an interview, I sought out literature or policies that described those processes. This was done to guarantee that the process reported is part of the provision of social housing in a broad way and not something that is restricted only to the interviewee's city or practice. Thus, throughout this dissertation, especially in Chapter 3, citations of policies and secondary literature review are complemented by references to these stakeholder interviews.

The categories and number of interviews for each are listed below. Because each interviewee's role in the provision of social housing is relevant to this research, the characteristics and background of each of them are also further explained below.

- Three city architects and engineers

  - Interviewee 1 is an architect and urban designer. He has worked both in the housing department and the department of urban planning and management of his city. Some of the projects he has worked on include urban upgrading of neighbourhoods in processes similar to those described for the Anglo neighbourhoods in Chapter 3.
  - Interviewee 2 is an architect and urban designer. She works in the department responsible for the production of social housing in her city. She has worked on social housing developments in cases where the city was responsible for the design. She has also worked closely with social work teams acting in social housing developments both before and after occupancy. Furthermore, she has worked on the approval of social housing developments.
  - Interviewee 3 is a sanitation engineer. He is the manager of the department responsible for sanitation and social housing in his city. He oversees projects in these areas in his city, including interfacing with the developer during project development, approval, and construction.
- Three city social workers
  - Interviewee 4 is responsible for the social work with the families selected to receive a house in social housing developments both before and after occupancy.
  - Interviewee 5 is the head of the social work department responsible for registering low-income families in social programs. She works in the registering and selecting families for the MCMV program within her city and works closely with the teams that carry out the field social work in these neighbourhoods.

    - Interviewee 6 is responsible for social work projects linked to new social housing developments. She is also responsible for leading the social work team's field work in their activities in social housing developments in her city.
- A regional manager from the financial institution Caixa Econômica Federal (CEF).
    - Interviewee 7 is responsible for managing government funds for all social housing projects in his region, which encompasses several cities.
- The national manager for the approval of innovative building technologies for social housing.
    - Interviewee 8 is an architect. She was responsible for setting up, and currently manages, the national system to approve innovative building technologies. Her role is part of the federal government. She works closely with the many entities involved in the approval of innovative building technologies, such as developers, construction companies, and the entities that represent them.
- Owner and manager of a development company
    - Interviewee 9 is a civil engineer. His company has developed many social housing projects for the lowest income range in several different programs over the years, including the MCMV program. The company builds this kind of project in the city where it is based and in many other cities of the region.
- Two social housing experts who research and consult on processes in social housing in the lowest income range.
    - Interviewee 10 is an architect and urban designer who is also a professor. She has researched the lowest income range of social housing programs in two distinct regions of Brazil. Over the years, her research has focused on several different

topics, including post-occupancy studies, housing adaptability, and self-construction within these neighbourhoods.

- Interviewee 11 is an architect and urban designer who works and researches in social housing neighbourhoods. In recent years, her practice and research have been focused on technical assistance in low-income neighbourhoods and informal settlements. She also works in the architecture and planning department of her city.

The semi-structured interview conducted was different in each case due to the different roles of each interviewee. Appendix A shows the starting questions prepared, further questions were also asked depending on the interviewee's responses. All interviews started by asking the interviewee to describe their role in the provision of social housing and later moved to questions relevant to each interviewee's role. Each of the prepared questions marked the start of a new topic block in the interview structure. After each question, interviewees were given the freedom to speak about processes that they felt were important, related to their role, and their perceptions and opinions about the processes and their efficiency. As the interviewees spoke after each question, I took notes of important points to ask follow-up questions during that block of the interview structure or to ask a new question at the end, creating a new block within the structure of the interview. At the end of the interviews, each stakeholder was asked if they could be contacted again. All the interviews were audio-recorded with the consent of the participants. Each of the interviews was then reviewed, searching for the themes previously identified in the literature. The interviews were also reviewed seeking to identify processes that bridge those themes and processes identified in the literature. Furthermore, the interviews were also examined for themes that had not previously been identified in the literature. These new themes led to a further specific search for literature about those themes.

To further investigate how these processes and policies manifest throughout the provision of social housing from early stages to post-occupancy, I examined a case study from the city of Pelotas. This case also allowed to me to use the specific circumstances of this neighbourhood to exemplify the proposed processes in later stages of this research. The Anglo neighbourhood in Pelotas was chosen for several reasons. It is relatively new, with initial construction of this neighbourhood only finished in 2014 despite the project having been approved in 2006. Since 2014, it has already seen significant post-occupancy transformations of the housing units. Furthermore, a significant number of previous studies have been carried out in this neighbourhood, and data regarding post-occupancy transformations were made available to me by the research group NAUrb (Research Centre for Architecture and Urbanism) from the Federal University of Pelotas. I was not involved in collecting this data; instead, I received permission to use the data that the group had previously collected. The data provided by NAUrb included floorplans and sections of the neighbourhood's housing units, indicating the changes made to each unit by the families after occupancy. It also included interior and exterior photographs of all the housing units, and demographic data about the families. Examples of photographs and floorplans are shown in Chapter 3.

This data has been previously analyzed and published by members of the research group NAUrb. However, previous analysis of this data focused mainly on identifying and grouping the post-occupancy changes into types. Although previous publications mention that the residents' design solutions are different, this difference was not the focus of their analysis. For this study, I used the data about the changes done to the housing units, specifically focusing on the different design solutions that families have effected for the same type of change, and the different kinds of problems resulting from them. It was relevant to examine how those problems, which previous

research has indicated are present in the neighbourhood, manifest in the different design solutions adopted by the families. For example, while previous analysis identified that many units had changes done to increase the area of the kitchen, my analysis focused on the variety of different solutions the families had for expanding the kitchen, and in how they differ from each other. Understanding the extent to which the solutions for the same type of change are different is relevant to determine what a mass customization strategy needs to offer. For this analysis, the floorplans of the changes were used as well as the photographs. The demographic data was considered to give context about the families that made the changes. However, it is also important to note that the conclusions stemming from other kinds of analysis of this data, previously published, are also relevant to this study. Therefore, throughout this dissertation, whenever I refer to an analysis of this data previously done, I cite the material (paper, book, report) where it was published. Where there is no citation is an indication that I am presenting aspects that I analyzed in a different manner from previous studies.

It is also important to note that the Anglo neighbourhood served as a case study. It was used to demonstrate how the general processes identified and discussed as being present throughout the country in programs for the lowest income range manifest in a specific case. Thus, the approach taken in this research was to go from the broad context and then demonstrate those processes in a specific case, and not to look at the specific and then generalize.

1.2.2. Stage 3 - Innovate, construct a solution idea

Based on the findings from stage two, in stage three, I propose a mass customization system for the lowest income range of social housing programs and a co-design system for the interaction of families with the design of their homes to be used within the mass customization system. The proposed mass customization system is shown in Chapters 4 to 6. To organize the different aspects

of the mass customization system, I use, as a starting point, the framework of mass customization proposed by Salvador, De Holan, and Piller (2009) and further discussed by Piller (2013, 2019). These authors indicate three capabilities necessary for mass customization: solution space development, robust process design, and choice navigation, as further discussed in chapter 2.

In this stage, I outline the processes and tools necessary, and how they can be used to allow the mass customization of social housing in the lowest income range. For the co-design system, a descriptive prototype is shown in Chapter 6, outlining the necessary functionality as well as ways in which it can be achieved and used in this context.

1.2.3. Stage 4 - Evaluate the solution

The qualitative evaluation of the proposed system is done by assessing each aspect proposed in relation to the analysis of the existing context. This evaluation is done considering whether the proposed solution conforms to the capabilities and interests of the stakeholders. I show the discussions of the different aspects in concert with the previously identified context conditions alongside the description of the proposed system in Chapters 4 to 6. To further evaluate the aspects of housing design proposed, at the end of chapter four I show a counterfactual exploration of how the proposed processes in that chapter could have been applied in a specific instance of an existing neighbourhood, the Anglo neighbourhood. For this exploration, I compile the local code parameters and design a solution within legal parameters and within what is proposed throughout the chapter to demonstrate the validity, in terms of design, of what is proposed.

This stage seeks to show that it is possible to implement mass customization in the lowest income range of social housing programs and that this would bring significant advantages to the families and broader society. I show that the changes needed to allow cities to take advantage of

the benefits of mass customization in this context are feasible within the current capabilities of the stakeholders involved.

Some interviewees from stage 2 were interviewed again for stage 4 to provide feedback about the proposed mass customization system. For this stage, I contacted only interviewees who take part in processes included in the proposed mass customization system. Therefore, interviewee 8 was not contacted during this stage since her role refers to an adjacent process to social housing provision, and no changes were proposed to that process. Furthermore, some of the interviewees could not be reached or were not available. However, interviews in this stage included interviewees from the categories that involve most of the proposed processes. In this stage, the interviews were with interviewees 1, 2, 3, 5, 9, and 11. It is essential to highlight that the feedback received in these interviews is limited since each interviewee has only a partial understanding of the ecology of the system of social housing provision. However, each follow-up interview provided insight into the portions of the proposal relevant to that person's role in social housing provision.

The interviews for this stage were also semi-structured. The interview structure was outlined in the form of a presentation of the proposed mass customization system with accompanying initial questions. Each presentation was focused on aspects considered most relevant to each interviewee. For example, for the interviews with social workers, I tailored the presentation and questions to spend more time on post-occupancy aspects of assistance to the families. In contrast, interviews with architects included more design aspects. Because the proposed system encompasses many processes of the provision of social housing that happen at different times, the presentation was framed as support for the conversation so that the interviewee felt comfortable talking, asking questions, and providing feedback about portions of the proposed system without having to wait for the end of the presentation. The feedback from these interviews

is discussed at the end of Chapter 6. The customizable presentation that gave structure to these interviews, and sample questions can be seen in Appendix B.

1.2.4. Stage 5 - Theoretical connections and research contribution

In this stage, the broader theoretical contributions of the proposed solution are discussed. It shows how the proposed solution and the path for its development contribute to the advancement of knowledge in the areas of social housing in Brazil and of mass customization more generally. These discussions are shown in Chapter 7.

Regarding social housing in Brazil, this research contributes by showing how the concept of mass customization could bring benefits to this context. It also shows how a shift in perception, to include post-occupancy construction as an integral part of the process of provision of social housing, is feasible and could also result in significantly better environments in these neighbourhoods over time.

More generally, this stage shows, through the system proposed, that mass customization can be applied with the goal of bringing broader benefits to society by providing individual customization. It also contributes to mass customization in housing by showing that the focus of the strategy can be in differentiating the housing units post-occupancy.

1.3. Organization of the dissertation

This dissertation is, thus, organized into seven chapters. Chapter 1 shows the research questions, objectives, and methods. Chapter 2 examines the concepts involved in this research showing an overview of social housing currently in Brazil and relevant information regarding housing adaptability and mass customization, its approaches, and tools. The exploration of the specific context of social housing for the lowest income range, its provision and post-occupancy processes are shown in Chapter 3. This chapter also shows a discussion of the specificities of the

context in concert with mass customization approaches and tools. The following three chapters show the proposed mass customization system. Chapter 4 shows the relevant considerations for the development of a solution space for the mass customization of housing in this context and how it could be applied to a specific case. In Chapter 5, I outline the processes of the mass customization system for the provision of social housing. This chapter draws a parallel to the current processes involved in the provision of social housing outlining desirable changes. The proposed co-design system for the interaction of families with the design of their units is outlined in Chapter 6. At the end of Chapter 6, I discuss the feedback received from the stakeholders about the entire proposed mass customization system outlined in Chapters 4 to 6. Finally, Chapter 7 looks back on the proposed mass customization system and the discussions involved in its proposal, reflecting on the broader theoretical contributions. It also shows the limitations of the research and potential directions for future research.

Chapter 2. Background

This chapter reviews relevant concepts for this research. The first section focuses on social housing, initially presenting a historical overview followed by considerations about the current state of social housing in Brazil. This overview addresses social housing broadly but focuses mostly on programs aimed at the lowest income range of the population. The next section discusses the concept of mass customization. It considers mass customization in general and addresses specific aspects relevant to mass customization for housing. The final section discusses the concept of housing adaptability. First, it considers overarching aspects and then focuses on adaptability in social housing contexts.

2.1.Social Housing

2.1.1. Historic overview

Many of the significant developments in social housing over the years happened at a different pace in different countries. However, it is possible to identify some tendencies when considering several different countries. This section concentrates on these tendencies of social housing developments mainly considering developed western European and North American countries. This builds context for section 2.1.1.1 in which a historic overview of Brazilian social housing is shown.

Several authors (Glynn, 2009; Harloe, 1995; Karakusevic & Batchelor, 2017; Malpass, 2014) attribute the beginnings of social housing to the Industrial Revolution when many people migrated to cities or close to factories. Housing was built privately and rented to workers, negotiating directly with the tenants. Soon, “industrial philanthropists” (Karakusevic & Batchelor, 2017) started building model villages with the aim of housing and improving the conditions of the

poor. Housing associations also started to appear and were funded by wealthy shareholders who expected to profit. Dwyer (2015) indicates that in the UK, the first act to enable social housing was introduced in 1851; it allowed local authorities to regulate lodging housing and to provide their own. Several other policies followed mostly responding to potential risks to public health. Only later, into the 20th century, did government authorities recognize that the provision of "improved housing and planned development could play a role in creating a more egalitarian society"(Karakusevic & Batchelor, 2017, p. 20).

At the end of the 19th century, globally, there were growing concerns with improving sanitation, which had significant effects on housing. In many countries, there was slum clearance and renewed sanitary legislation, which meant that even private landlords often had to improve the conditions of housing (Chiarelli, 2014). In Great Britain organizations were being established to press municipal councils to build (Dwyer, 2015). Concerns and pressure for social legislation were also growing in many other countries in Europe (Harloe, 1995). In the 1920s in Europe, most countries saw more stable conditions and reduced their social rental housing, which had been increased immediately after the war (Ball, Harloe, & Martens, 1988). In Europe and North America, some social housing efforts were renewed in the 1930s for several motives in different countries, including slum clearance, overcoming years of Depression, reducing unemployment (Harloe, 1988). Ball (1988) indicates that by the 1940s, most advanced capitalist countries had accepted "the need for substantial state intervention into housing provision" (p.10). This is a significant development that happened gradually, changing the view from the previous understanding that the government should not intervene.

Several authors (Ball, 1988; Harloe, 1988, 1995; Malpass, 2014) indicate the period after the Second World War as being that of greatest social housing growth, especially in Europe.

Different from the US that could offer social housing only to the poorest, most European countries took longer to recover and had a large part of their population in need of housing, not only the poorest (Harloe, 1988). This context, combined with greater urbanization and population growth and alongside the need to have competitive economies (Harloe, 1988), meant that social housing was widely applied in Europe mostly in the form of rental. Mass production with an industrialized approach to building was much applied in this period. From the late 1970s onward, governments in Europe and North America start selling off public housing stock and placing greater emphasis on homeownership through financing and making it accessible to a more substantial portion of the population. Homeownership was mostly not so much subsidized, thus, they still had the social rental meant for the poorest.

In 1948 the United Nations approved the Universal Declaration of Human Rights, which recognized housing as a human right as part of the right to an adequate standard of living. In 1991 the UN Committee's General Comment no.4 (UN E/1992/23, 1992) on the right to adequate housing further built on the previous recognition of housing as a human right. This was particularly relevant, especially for developing countries, as it goes on to explain what is considered adequate housing (UN E/1992/23, 1992). Building on previous documents, this brought the understanding that adequate housing was more than providing walls and a roof and includes security of tenure, accessibility ensuring priority to disadvantaged groups, and location allowing access to employment and services such as health care and schools among others (UN E/1992/23, 1992).

In analyzing developed countries from Europe and North America over the 20th century, Harloe (1995) considers that housing provision evolved under "the impact of major changes in social, economic and political structures and relationships"(p.5). This author identifies two main models to social housing that appear at different times, the 'mass' and the 'residual' approaches

(Harloe, 1995). Malpass (2014) describes the residual model as focusing on providing the minimum possible social housing to the "least well off as a safety-net service" (p.262). The mass model, on the other hand, focuses on providing housing more broadly, focusing on a range of income groups, not only the poor (Malpass, 2014). Harloe (1995) considered that the mass model prevailed in two periods in Europe, a short period after the First World War, and a longer period after the Second World War. This is understandable given the need for housing and reconstruction after the wars, even by those who in other times might have been able to afford housing with their own means. According to Harloe (1995) the residual model dominated in Europe in the period of the late 1920s and 1930s and from the 1970s on, and in all the periods in America. Scanlon, Whitehead, & Arrigoitia (2014) have a slightly different approach to these developments, stating that there was an important distinction, in Europe, between "countries that saw social housing as a mechanism for providing for all types of household, and those that emphasized provision for lower-income households" (p.2). These differences became more prominent as the housing shortages started being overcome (Scanlon et al., 2014). Therefore, in periods when housing was in high demand by everyone, after the wars, these differences were less prominent, and it appeared as though the mass model was present in most countries. The approach by Scanlon et al. (2014) in meticulously analysing the differences in social housing policy and delivery in many European countries seems to be in accordance to other authors, such as Malpass (2014), who criticize Harloe (2003) for attempting to indicate overall similarities in social housing development across Europe and North America in the 20th century.

Several authors (Kemeny, 1994; Malpass, 2014; Whitehead, 2003) consider that there were two main approaches to social rental in Europe. In a dual rental market, the policies for rental are significantly different for the social and private sectors. In this approach, policies encourage

unhindered profit rental market, forcing a residual social rental to appear, which is deliberately kept separate from the profit rental market and ultimately leads to the government increasingly encouraging owner occupation (Kemeny, 1994). In the unitary rental approach, governments seek ways to minimize the differences between the social and private rental sectors which compete with each other (Kemeny, 1994; Malpass, 2014).

Despite these differences, Whitehead (2003) suggests that most countries were, at the end of the last century, converging in terms of policy and outcomes. Stating that "in almost all contexts the direct role of social provision is being reduced and replaced by income-related benefits, and more targeted supply subsidies, usually to independent providers" (Whitehead, 2003, p. 61). This author goes on to show that this also happens in many countries worldwide, thus the tendency being to enable more private production instead of direct government involvement in the provision and support of local initiatives (Whitehead, 2003).

Rolnik (2013) and Glynn (2009) support this indicating that privatization and incentives to homeownership and financialization are dominant since the late 1970s. The US and many European countries started cutting back on subsidies and funding for building and maintenance of social housing, which led to the reduction of social housing stock, deterioration of what was left, and even discrimination against people who depended on it. Although selling public housing to the tenants is often seen by governments as a way to increase homeownership while reducing government expenditure, this had significant consequences to the most vulnerable, affecting their ability to support themselves. These authors mostly criticize this approach and blame this, the financialization and viewing of housing increasingly as a commodity, for the financial crisis that started in 2007. In the 2000s with increased emphasis on homeownership, and more global influences in the financing, even households that would have previously not been eligible to

housing credits were now encouraged to it. This increases the risks for private companies as social rental becomes more and more restricted to the most impoverished populations. Rolnik (2013) considers that the financial crisis that took over in 2007 and 2008 was foreseen, but no actions were taken to prevent it. This author also considers that in consequence of this crisis, we have not seen, as was expected, more social rental; instead, we have seen growth in government intervention in the financialization process.

More recently, there have been increased developments aiming at mixed-income, which reserve a part of the housing units in market-oriented developments to low-income residents. This approach has often been implemented with the intent of increasing "access to resources and benefits the city provides that were denied in the context of social isolation and concentrated poverty"(Chaskin & Joseph, 2013, p. 482) and also to allow low-income populations "greater access to improved services, amenities and organizations" (Chaskin & Joseph, 2013, p. 482). However, this approach has received much criticism, especially in cases of re-development of areas that were previously public housing. The main negative aspect in these cases is replacing 100% public housing, which often, although old, is currently well located in the city, with developments in which relatively few of the units are aimed at low-income residents (Vale & Shamsuddin, 2017). This drives many low-income residents out of well-located areas where they had lived in for many years. Nevertheless, several aspects of mixed-income developments are seen as positive, especially in new developments.

2.1.1.1. Historic overview of Brazilian social housing

After the abolition of slavery in Brazil in 1888, the massive intake of immigrants, the increase in industrialization and growth in cities, led private industry leaders to start building worker villages close to the industries (Bonduki, 1994). Although the government encouraged the

creation of such housing enterprises, it was believed at the time that it was not the government's role to intervene in private property. Therefore, similar to what was happening in Europe previously, rental was negotiated between tenants and landlords without regulation.

Some of the key motivations driving private investors to provide improved housing were also similar to those in Europe: the unsanitary conditions in which the working class lived, overcrowded accommodations highly susceptible to the spread of diseases, and the need to keep critical workers always close to the industries (Bonduki, 1994; Harloe, 1995). In most cases, landlords also wanted to accommodate more people in the least amount of land. Thus, in many cases in Brazil, housing was built in the form of row houses aligned onto the street.

It was not until the First World War, associated with internal revolutions in Brazil, that the building of private housing came to a halt, and this shortage started driving up rental prices. In this context, a tenant's law froze rental pricing from 1921 to 1927. Although considered as the first social housing law in Brazil, it was of little success since it did not stop tenants from being evicted (Bonduki, 1994). Despite a few previous attempts, it was in this interwar period, well into the 1920s, that pressure grew in Brazil for social reform. In the 1930s, several laws of work regulation and worker's rights were approved. Housing was a popular topic for the government which recognized the need for the state to build and provide housing to the least advantaged working force, but this was not done with major government funding and was often carried out by worker's unions and retirement funds (Bonduki, 1994; Chiarelli, 2014).

The renewal of a tenant's law that froze rental prices from 1942 (Bonduki, 1994), came with the intention of keeping wages low as the country sought greater industrialization. However, this led to a large number of evictions as it became unprofitable for the private owners to keep tenants. It was also at this time that unified social housing policies started to appear in Brazil,

especially with the creation of the Popular House Foundation (Fundação da Casa Popular) in 1946 (Bonduki, 1994; Chiarelli, 2014). Bonduki (1994) expresses that this foundation failed in the provision of social housing mostly because of its ambitious objectives, which included not only building housing units, but also bridges, infrastructure and training personnel, among others. However, it is widely acknowledged that this was an important moment for social housing in Brazil, especially due to the government's recognition of the need and relevance of addressing, through government intervention, the growing housing crisis. It was at this time, late 1940s, that precarious self-building in areas without infrastructure grew, originating the "favelas," although even greater growth of these settlements occurred in the 1970s.

Although the Universal Declaration of Human Rights had vast repercussions worldwide, Chiarelli (2014) highlights that in Brazil, this did not result in actions but instead in political discourse. It is only after the military takeover in 1964 and the creation of the National Housing Bank (Banco Nacional de Habitação) that large scale social housing took off, primarily in the form of mass-produced apartment blocks resembling some of the post-war housing blocks built in Europe. However, the bank also subsidized lots with infrastructure and embryo units, tiny unfinished houses made up of a single room with kitchen space and a bathroom meant for further development by the owners. These lots and embryo units were meant for people earning up to three times the minimum wage. This bank was the primary source of financing not only for housing but also for infrastructure and sanitation until it went extinct in 1986. The long term legacy of this bank goes beyond the housing stock and infrastructure built. Cardoso (2007) highlights that the idea that local governments are dependent on Federal initiatives is a legacy from this bank. This idea is still mostly the norm today, embedded in most of the current social housing legislation as well as legislation of other sectors. The idea of subsidizing most of the cost of housing for families

earning up to three times the minimum wage is also still present in the current social housing legislation.

Much of the resources of the National Housing Bank were directed at financing homeownership. Different from North America and Europe, in Brazil, it was the subsidized financing of homeownership that was meant for the most impoverished formal workers. The least well-off were mostly still excluded, thus the extensive growth in slums (favelas). Attempting to deal with this exclusion, some building initiatives by the National Housing Bank were specific to the removal of favelas, transferring people to new apartment blocks. However, this ultimately failed as these populations moved back to the slums illegally selling their apartments to people of higher income (Cardoso, 2007).

To start addressing the UN Committee's General Comment no.4 (UN E/1992/23, 1992) on the right to adequate housing and the outcome of the 1996 United Nations Conference on Human Settlements, subsequent social housing legislation in Brazil associated the building of new social housing neighbourhoods with the provision of services and public transportation. Despite these efforts, unstable economic and political circumstances of the late 1980s to early 2000s significantly limited the provision of social housing, especially for poorer municipalities (Cardoso, 2007; Chiarelli, 2014). Throughout the country, fewer local social housing initiatives took place while financing options were available to those with higher incomes. Even programs meant for lower-income families tended to, in fact, only benefit those in the higher end of what is considered low-income for several reasons including the lowest-income people often having informal work arrangements (Chiarelli, 2014). Rolnik (2013) highlights that the housing deficit grew significantly in South America between 1990 and 2000, resulting in an increase in informal arrangements. It is important to highlight that despite the international debate and even Brazilian efforts around the

right to adequate housing, it is only in 2000 that the right to adequate housing is incorporated in Brazilian legislation (Chiarelli, 2014).

In 1999 the Brazilian government authorized a new housing program based on the French leasing program (Chiarelli, 2014). This program in Brazil is called PAR (program of residential leasing) and had some significant differentiating elements in comparison to its French inspiration. The main difference being the option of ownership at the end of the 15-year lease agreement (Chiarelli, 2014). This program initially was aimed at families earning from three to six times the minimum wage but was later expanded to families earning up to three times the minimum wage. The cost of the lease was subsidized depending on the income of the family. Following the international emphasis on housing ownership, further legislation was passed in 2007 to allow early ownership due to internal pressure to overcome the financial deficit in this sector.

Following the financialization trend, in Brazil, a new government program was established in 2009, the MCMV program which subsidizes up to 90% of the cost for low-income families to buy homes in a financing process. Its implementation sought to benefit large developer companies and the private housing sector just as much as provide adequate housing for the poorest. This program was implemented following similar programs previously implemented in other Latin American countries such as Chile and Mexico. The role of the state in these programs does not go much beyond providing the money for private companies to build housing for the poor. Even though the government establishes some rules, the companies are mostly free to choose the location, typology, and size of the development. As a result, these developments often remove populations from well-located informal settlements to distant isolated but formally owned housing. Rolnik (2013) highly criticizes this approach stating that studies in Chile, where it first started,

have shown that far from a permanent solution, it has contributed to creating new problems of urban ghettos in the peripheries.

Since the mid-2000s, there has been an increase in emphasis, in Brazil and other Latin American countries, in urbanizing informal settlements in order to keep the populations where they are. Several initiatives have been, to a less or greater extent, successful in bringing infrastructure and better living conditions to existing informal settlements. Some examples include the famous case of Quinta Monroy in Chile in which the population was kept in the same place being provided with half a house that could be expanded, as a way to get around the higher cost of land (Aravena, Montero, Cortese, de la Cerda, & Iacobelli, 2004), and the favela urbanization initiatives in Rio and São Paulo (Serapião, 2016).

It is important to consider that many of the identified tendencies in how social housing developed are linked to other factors such as wars, economic aspects, and overall social development. Although some tendencies can be identified worldwide, it is the local context that will determine more specific policies and regulations. Therefore, while it is relevant for countries to look beyond their borders for potential solutions to their social housing problems, these solutions must be carefully analyzed and adapted to the local context. Furthermore, over the years, many solutions and policies implemented to mitigate problems in social housing resulted in creating new unintended problems. Thus, interventions in social housing must carefully consider the existing context and anticipate as much as possible potential problems that may arise with the proposed intervention or changes in policy.

2.1.2. Social Housing in Brazil Currently

Currently, social housing in Brazil is provided mainly through the national program called Minha Casa Minha Vida (MCMV) (My House My Life). This program finances housing-

ownership to eligible families at lower interest rates and can subsidize part of the costs depending on the family's income. For urban housing, this program considers families in four income ranges for which it has different advantages, as can be seen in Table 1 Ranges of benefits for MCMV.

Table 1 Ranges of benefits for MCMV.

Based on "Caixa Habitação Urbana - Minha Casa Minha Vida" (2019)

Program range	Income	Main program benefits
Range 1	up to $1800 BRL (approximately two times the minimum wage)	-Subsidy of up to 90% - Fixed monthly payments up to 120 months - Monthly payment amount from $80 to $270 BRL (approximately $26 to $88 CAD) depending on the family's monthly income
Range 1.5	up to $2600 BRL (approximately three times the minimum wage)	- Subsidy of up to $47500 BRL ($15580 CAD) - Interest rate of only 5% per year - Up to 30 years for payment
Range 2	up to $4000 BRL (approximately four times the minimum wage)	- Subsidy of up to $29000 BRL ($9500 CAD) - Interest rate of up to 7% per year
Range 3	up to $7000 BRL (approximately seven times the minimum wage)	- Reduced interest rate compared to the market, up to 8.16% per year

For the lowest income range of the population, the program subsidises up to 90% of the cost for families to acquire a home in developments which are specially built for this purpose by private companies. The program allows developments of up to 2000 units when the development is isolated or up to 3000 units if the development is contiguous to the existing urban fabric. Although the program has been successful, to some extent, in reducing the housing shortfall since its implementation in 2009 (Menezes, 2017), it also has received much criticism especially regarding how it is operated.

With this program, the role of the national bank responsible for financing, Caixa Econômica Federal (CEF), and of private companies significantly increased in relation to local housing and planning authorities (Rufino, 2015). Because the construction company is responsible

for proposing these developments which have limited funding, the choice of cheaper land on the outskirts of cities – often in areas previously considered rural – and the standardization of design became the norm to increase profits (Rufino, 2015). Local authorities, pressured by the building companies, in many cases have made this process easier by changing urban policy, urban perimeters and local construction rules. These changes were made to allow the construction of developments in rural areas, with reduced requirements of green and public spaces, reduced unit requirements, and reduced taxes for the construction companies (Ribeiro, Kruger, & Oliveira, 2017; Rufino, 2015). According to Ribeiro et al. (2017), these changes in local legislation highlight that the power of choice of location and typology lies with the construction companies.

One of the main problems resulting from this way of implementing the program is that new developments for the lowest income range of the population are usually distant from services and commerce and most importantly from where the jobs are, increasing the segregation of these populations and costs with transportation (Ribeiro, Kruger, & Oliveira, 2017; Rolnik, Pereira, Lopes, et al., 2015; Rufino, 2015). Some authors indicate that this leads to these new developments becoming ghettos of violence and drug traffic often dominated by militias, especially in large cities (Rolnik, 2013; Rufino, 2015). Furthermore, it also diminishes the retention rate, with many units illegally sold while families move back to better located informal arrangements (Rufino, 2015). It is important to highlight that this is a problem not only for those who live in the social housing developments, but to all of society. For example, it significantly increases urban sprawl and the problems that come with it, especially the demand for public authorities to provide adequate services – such as health centers, schools, sewage, policing, and public transportation – to these areas.

The current program MCMV also has a possibility for communities to self-organize called Minha Casa Minha Vida Entidades (My House My Life Entities). This section of the program is meant for groups of low-income families, within range 1 of the program, to organize themselves through cooperatives, associations or even through private non-profit organizations ("Minha Casa Minha Vida - Entidades," n.d.). In this case, the entity is responsible for managing the project with the families. Therefore, despite falling within the rules of MCMV, the entity has more control over where and how the housing units will be built. This part of the program is responsible for only 1% of the units built through MCMV (Stiphany & Ward, 2019). Despite allowing the families to be more involved from the beginning of the process, Stiphany and Ward (2019) still criticize this specific segment of the program, stating that it also encourages families to leave well-located informal settlements relocating to isolated, peripheral land.

Another critical aspect to consider is the increased cost of formal living (Rufino, 2015). Many families, especially those removed from informal settlements in risk areas, have difficulties to bear the costs of formal housing such as condominium (in the case of apartments), as well as water and electricity which were previously accessed illegally. This is another significant factor contributing to families opting to sell their units illegally and move back to informal living, often in the same risk areas they were in before. Brazilian legislation does have social tariffs of water and electricity that should be applied for these families. However, often they are not applied, and even when they are, it still increases the costs associated with housing when compared to informal settlements. This inability of some families to bear these costs further demonstrate that having only one main program based solely on homeownership is not adequate to meet the housing demands of different groups with different social, economic and cultural characteristics (Rolnik, Pereira, Lopes, et al., 2015; Rufino, 2015).

Also stemming from the increased decision power left to private companies, usually for these developments there is one unit design which the company has already pre-approved and which is repeated throughout the development and even in several different developments (Palermo, 2013; Rufino, 2015; Taube, 2015) making these neighbourhoods homogeneous and monotonous. Furthermore, no consideration is given to the differences in location, culture and family composition (Rolnik, Pereira, Lopes, et al., 2015). The objective is to contemplate the minimum required by the program and build it in the cheapest way possible. Several authors have demonstrated that soon after construction, pathologies – such as cracks and mould – start to appear in these developments due to the lack of attention to quality and errors made during construction (Berr, Echeveste, Lorenzi, & Formoso, 2015; Rufino, 2015).

Furthermore, this standardization of the housing product is inadequate for the variety of families who live in these developments. Rolnik et al. (2015) highlight this aspect in the analysis of seven such developments where they found units in which only one person lived, right up to units with extended families living in them with more than five people. Overcrowding can increase health problems (Rolnik, Pereira, Lopes, et al., 2015). These problems of standardization in the developments were also present in previous housing programs and are a consequence of not taking into account demand in the production process being as the families are only selected and assigned to units at the end of the process (Palermo, 2013; Rolnik, Pereira, Lopes, et al., 2015; Taube & Hirota, 2017).

In most cases, not only are the units all equal, but the building system adopted makes it difficult to make future changes, to contemplate the changing needs of the families. This is especially grave when considering apartments in which there is no room to expand outside the initial unit and given that once a family receives a unit through this program they are ineligible to

purchase housing through this program ever again ("Programa Minha Casa, Minha Vida - PMCMV," 2016), even if their income condition or family situation changes.

When it comes to house units, therefore, it is expected that the families will start changing and expanding their units. These changes are made to show their territoriality and increase the sense of ownership by differentiating themselves from their neighbours and also to better satisfy their needs and to make room for businesses (Brandão, 2011; Palermo, 2013). This is especially necessary given the single-use zoning (housing) of these neighbourhoods, the distance to areas with shops and services, and often poor public transportation. However, because the initial units are not built with adaptability in mind, it is more difficult and expensive for the families to make these changes. Moreover, many of these expansions are carried out illegally often resulting in inadequate situations that can result in negative consequences not only for the family but also for the neighbourhood and the city.

It is relevant to note that other smaller programs exist and are usually operated locally. However, these are still mostly dependent on federal financing sources and result in similar neighbourhoods as those of MCMV and previous national programs. Although these other programs have a significantly smaller housing production than MCMV, they allow the municipalities to have more control over the process and target specific populations. For example, through national sanitation and infrastructure programs some cities were able to capture resources to build housing to relocate families that were living in risk areas but may not have been eligible for MCMV housing, or areas where infrastructure construction was going to take place. In some of these cases, the families do not pay mortgage or rent but are granted the right to live in the unit for a specified amount of time, for example 50 years renewable for another 50 years, while the municipality retains ownership. In such cases, usually, the families are not allowed to make

changes even to house units. However, in many cases, changes are carried out illegally to satisfy their needs better. Furthermore, there are many cases of illegal sales and rental of units, and families driven out of their unit by drug traffickers, among others.

Regardless, despite operational differences among the housing programs, both previous and current, the types and sizes of units built are similar, as are the deficiencies. The need to change and expand the units is also present throughout social housing developments. It is clear from this overview that sometimes well-meant policies can result in other unforeseen problematic situations. As this study focuses specifically on possibilities to improve environments for families in the lowest income range by looking at the unit design, more detailed and focused information about the process of provision of social housing, and the post occupancy processes in neighbourhoods of this range are presented and discussed in chapter 3.

2.2. Mass Customization

Mass customization was initially conceptualized as a business strategy that was called ‘mass customization’ by Stanley Davis in 1987, who outlined it in a chapter of his book *Future Perfect*. This author explained that: “mass customization of markets means that the same large number of customers can be reached as in the mass markets of the industrial economy, and simultaneously they can be treated individually as in the customized markets of pre-industrial economies” (Davis, 1987, p. 169). Da Silveira, Borenstein, and Fogliatto (2001) consider Davis’ view to be a broad, visionary concept. In analyzing years of literature produced since Davis’ book, these authors synthesized what they consider to be more practical concepts, defining mass customization as “a system that uses information technology, flexible processes, and organizational structures to deliver a wide range of products and services that meet specific needs of individual customers (often defined by a series of options), at a cost near that of mass-produced

items" (p.2). This definition meets what Pine (1993) observed about companies that practiced mass customization saying that they aim to develop, produce, market and deliver goods and services that are affordable and "with enough variety and customization that nearly everyone finds exactly what they want." (p. 44).

It is relevant to consider that individual customization has always been an option for customers for many products; however, it cost much more than to buy a mass-produced product. Mass customization seeks to change this since, as noted before, in this approach, companies strive to offer great variety or even individual customization while maintaining prices close or even beating those of mass-produced goods (Pine, 1993). Thus, it can be seen as "the mass production of individually customized goods and services" (Pine, 1993, p. 48). Another definition that denotes this is offered by Tseng and Jiao (2007): "Mass customization is a new paradigm for industries to provide products and services that best serve customer needs while maintaining near-mass production efficiency" (p. 685).

Pine (1993) highlights that while in mass production costs are kept low through economies of scale in which there is "lower unit costs of a single product or service through greater output and faster throughput of the production process", in mass customization costs are kept low mainly through economies of scope in which there is "the application of a single process to produce a greater variety of products or services more cheaply and more quickly" (p. 48). However, this author highlights that companies often achieve both economies of scope and scale (Pine, 1993). This is consistent with the view of researchers who highlight the importance of mass customization in achieving economies of scale. Jiao, Ma, and Tseng (2003) highlight that economy of scale (mass efficiency) is one of three requirements of mass customization, the other two being variety (customization) and time-to-market (quick responsiveness).

From these definitions, it is possible to identify two relevant principles of mass customization. First, the idea of satisfying individual customers' needs implies a customer-centric approach. Fogliatto, da Silveira, and Borenstein (2012) highlight this "customer-centric" focus stating that mass customization "is characterized by focus on customer preferences rather than by use of a particular technology or product mix" (p.16). This also means that how the product is presented to the customer and how the customer interacts with the company is also very important. The second principle refers to the goal of coming close to mass-production efficiency or close to the low costs of mass-produced goods means that there must be careful consideration of the processes involved.

The logic through which companies operate, and profit, in mass customization, is different from mass production. Pine (1993) indicates that in mass production "lower prices resulted in greater sales, greater sales in higher volumes, higher volumes in lower costs, and lower costs looped back around to allow even lower prices, and so on" (p.44). In mass customization, however, it is the company that better satisfies the customers' individual needs that will sell more. Thus, this company will then have more profit and understand even better what customers want, allowing them to provide even more variety. This will allow them to further fragment the market "because it is out distancing its competitor in variety and customization, market fragmentation allows it once again to better satisfy its customers' individual wants and needs" (Pine, 1993, p. 44). Therefore, in this new logic, the company has more customers, or more returning customers, because it is offering them exactly what they want or need. Furthermore, because of this added value to the customer, in many cases, they are willing to pay a premium for the customized product. However, it is important to note that mass customization might not be the best alternative in all cases, and

some authors such as Alptekinoglu and Corbett (2008) have found that mass producers can coexist with mass customizers and both be profitable.

Salvador, De Holan, and Piller (2009) explain three fundamental capabilities that determine a company's ability to mass customize: solution space development, robust process design, and choice navigation. Solution space development is the ability of a company to identify in which attributes of the product customers' preferences diverge most and outline what the company will offer. The company defines what it is going to offer and what it is not going to offer creating a solution space (Piller, 2019). Robust process design is the capability of a company to "reuse or recombine existing organizational and value-chain resources" (p.74). It refers to how the company organizes its processes to achieve the mass customization goals. Choice navigation, refers to being able to support the customers in identifying what they need and the solution that will satisfy those needs, while reducing complexity and the burden of choice. Several of the approaches proposed by Salvador et al. (2009) to achieve each of these capabilities involved the use of advanced technologies. This is consistent with findings from other authors (Da Silveira et al., 2001; Fogliatto et al., 2012; Pine, 1993) who have, over time, indicated their current technologies as an important factor in enabling and facilitating mass customization.

Piller and Kumar (2006) consider that having stable processes is essential for maintaining mass-production efficiency, which is the main differentiating factor between mass customization and craft production. The use of stable processes, even though flexible and responsive, characterize the finite solution space in which mass customization occurs (Piller & Kumar, 2006). This could lead to the idea that in mass customization, the number of different products offered is limited. However, current technologies allow a larger degree of freedom in customer manipulation while still maintaining the same fabrication speed and cost. The designers can set the range within which

the customer can freely manipulate, for example, the shape of an object; the amount of possible different products this approach allows is close to infinite. The use of digital fabrication processes makes it just as cheap to fabricate as if there were many but limited amounts of options.

As noted by Salvador et al. (2009), mass customization should be seen as a process in which the company develops the organizational capabilities to allow them to move towards knowing exactly what the customers want and being able to manufacture those individualized goods at mass production costs. Even successful mass customizer companies learn from their clients, not only about their preferences but also about how to elicit them better. Furthermore, the adjustment of processes in design, manufacturing and supply chain coordination, to reuse more processes while making them more flexible and increasing responsiveness, allows companies to come ever closer to the ideal of mass customization initially envisioned: individual customization at mass production costs.

In the following sections, relevant aspects of mass customization are explored as well as aspects relevant to mass customization in housing specifically.

2.2.1. Mass customization in housing.

To achieve mass customization, careful consideration must be given to the design and manufacturing processes as well as the interaction with costumers. It is essential to highlight that significant differences exist between housing and most other products. These differences influence the way each of those processes can be approached. Kendall (2013) states that trying to compare housing production to automobile production, for example, is not a good model primarily because of the fixed place aspect of housing and construction. This placeless aspect is present for most products that are currently mass customized and therefore have a different production approach from housing. Comparing the product development process of the construction industry to the

development process of other products, Rocha (2011) also indicates this aspect as one of the main differences. A construction project has a particular plot with particular environmental features that must be addressed; furthermore, a particular supply chain is usually set up, which is unlikely to be the same in other projects (Rocha, 2011). Even in cases where most of the house is built in a factory offsite, the same developer may use different factories for the pre-fabrication for different projects, according to the location of the project, as can be seen in some examples shown by Smith (2010).

The number of stakeholders who have influence over the final housing product is often different from other products. Often the stakeholder making the decisions as to, for example, how much they are willing to pay for the product is not the end-user, as is the case in social housing developments. Furthermore, many municipalities are not prepared to deal with mass customization of housing that goes beyond materials and finishes. For example, in large developments of multiple units, the developer usually receives approval for a standard floor plan, which must be done before construction. If there is no standard floor plan and the final plan for each unit is only going to be decided after construction is well underway, this could potentially bring problems for the company to receive building permits.

When considering social housing developments, mass customization shows great potential to provide individually customized units without making it unfeasible in terms of costs. An approach demonstrating this potential was explained by Noguchi and Hernandez-Velasco (2005) to address developments in Mexico, which are similar to the Brazilian social housing developments. These authors explain that greater customization can be achieved without significantly increasing costs by allowing users to choose from standard components to create a custom home (Noguchi & Hernandez-Velasco, 2005). They divide the housing components into three categories: volume, exterior, and interior (Noguchi & Hernandez-Velasco, 2005). The

exterior components refer to elements such as openings, balconies and roofs; the interior components refer to elements such as kitchens, sanitary facilities and interior finishes; the volume components refer to components that define the spatial limitation of interior space (Noguchi & Hernandez-Velasco, 2005).

The higher customization of housing units, through allowing the customers to choose from such standardized exterior and interior components, is easier to achieve when compared to geometric customization since these components are mostly mass-produced and different options are readily available through many suppliers. In Brazil, several construction companies have started mass customizing their housing products for the higher income ranges of the housing program using this approach of only allowing the customization of interior and, very little, exterior elements. This approach makes a significant difference in terms of the customer demonstrating their individuality, territoriality and increasing sense of ownership. However, the different spatial needs are not addressed because the definition of how much space and how it is organized stays the same.

Since different families have different compositions and different ways in which they use their homes, this spatial aspect is significant and should also be addressed. Several authors have shown that mass customization of housing that includes this volume aspect is possible through modularity in which the customer can combine standard volume modules to create a custom home. Barlow et al. (2003) show several successful examples from the housing industry in Japan, which allow different levels of customization. Most of these cases consider large portions of the houses being prefabricated off-site. In a different approach, Rocha, Formoso, and Tzortzopoulos (2015) show a case in which customization was available to customers for apartments that used building

systems considered traditional in Brazil, therefore, without pre-fabrication. This example also was based on modules that could be chosen by the customers.

An interesting approach to expand the use of mass customization in housing is using the idea of fit-out kits (Kendall, 2013). In this approach, drawing on principles of open building (Kendall & Teicher, 2000), the building is divided into two spheres of decision making: the base building and the fit-out. One construction company would build the base building, including structure and main distribution of services, and the owners could choose their fit-out kits from different companies (Kendall, 2013). However, for the full potential of this approach to be achieved requires several companies to adopt this strategy, different from other approaches in which just one construction company would provide customized housing. Although this approach was developed considering apartment buildings, it demonstrates the ability of adaptability strategies to be helpful as a design approach in allowing the postponement of the differentiation of individual units both for apartments and houses. For example, the use of floors without load-bearing walls (Friedman, 2013) as a strategy to allow future change to be easily made in a house, could also be used by the construction company as a strategy to almost complete construction before significant layout choices can still be made by the future owners.

One of the reasons that these kinds of approaches are not being more widely used could be the fact that there is a significant increase in design effort to achieve a product that allows the interchangeability of modules and still achieves integrity of utilities and spatial relationships between rooms (Rocha et al., 2015). However, considering the large volumes of housing that a company builds in social housing developments, this initial effort and cost would not significantly increase the cost per each unit built. Such an approach could allow families to choose the arrangement of housing that best suits them and even how much space they can afford. The cost

of an extra bedroom within a massive construction operation is lower than building it individually afterwards. Therefore, the adoption of mass customization in social housing developments would be significantly advantageous for the families who live in such developments.

As explained by Piller (2013), the mass customizer company must clearly outline what it is going to offer; this means that not every possibility is going to be available as part of the customization strategy. Therefore, understanding what is meaningful for the customer is extremely important. Hentschke, Formoso, Rocha, and Echeveste (2014) developed a framework to identify which attributes add the most value for future owners of apartments to support the development of the product. Although this approach was successful in identifying what was most important for the customers, it considered mostly aspects such as surface materials and finishes.

Mass customization in housing has been associated with environmental sustainability for its potential to reduce waste from changes made by the occupants once they move in, and also to social sustainability for increasing people's sense of identity and ownership (Rocha et al., 2015). However, its implementation faces many challenges to achieve greater efficiency in terms of design, supply chain organization, construction and communication with customers. Initial investments to address these challenges become more feasible the more housing units the company intends to build using those solutions. In Brazil, while most challenges for mass customization in housing are similar to the rest of the world, some contextual challenges ere posed especially when it comes to publicly funded housing.

2.2.2. Modularity

How a product is designed is important for the success of the mass customization operation. Ulrich (1995) explains that a product architecture is "the scheme by which the function of a product is allocated to physical components" (p. 419), and indicates that there are two main types of

product architecture, modular and integral. An integral product architecture either has complex mapping between the functional elements and physical components, or the interfaces between components are coupled, or both (Ulrich, 1995). In modular architecture, functional elements and physical components are mapped one-to-one, and the interfaces between components are de-coupled – changes to one component do not necessarily require changes to the other components. This author outlines the implications of the choice of product architecture not only for production but also for future changes to the product.

Many authors indicate that modularity is essential to being able to achieve mass customization. In modular architectures, a system is separated into "independent parts or modules that can be treated as stand-alone logical units"(Jiao et al., 2003). With this approach, "each module serves one or more well-defined functions of the product and is available in several options that deliver a different performance level for the function(s) the product is intended to serve" (Piller, 2013, p. 71). This approach is considered especially relevant for mass customization of fabricated products (Piller & Kumar, 2006) as it could allow the company to reduce the costs of production and the time for delivery. For example, a company could mass-produce several standard modules from which the customer can choose for each part of the product, once the customer has made the choices the company can quickly put the customized product together and deliver. However, it is important to highlight that the modules do not necessarily need to be standardized.

Modularity is often associated with the concepts of product platform and product family. Product platform uses a "collection of assets that are shared by a set of products" (Robertson & Ulrich, 1998, p. 20), and product family "refers to a group of related products" (Khalili-Araghi, 2017, p. 47). Several authors indicate that the use of a product platform and product families can

be a good design approach to enable mass customization (Jiao et al., 2003; Khalili-Araghi, 2017; Robertson & Ulrich, 1998) because these approaches allow the delivery of many different products while still having standardized processes and, often, components.

The product platform can be seen "as a basic common module that is implemented in several variants of a product family" (Blecker & Abdelkafi, 2006). Alizon, Shooter, and Simpson (2009) describe an example of this kind of approach regarding the Ford Model T. In this case, the underbody of the car – including engine, pedals, wheels and steering wheel among others – was the same and shared by all the family. The body of each model was different from the other models. Furthermore, the underbody could be sold by itself, allowing the body to be customized by other manufacturers. The Model T is seen as a successful case of product platform. In addition, Alizon et al. (2009) consider that it was a case of mass customization. These authors indicate that by having a product platform with a family of different products and outsourcing customization, the Model T maintained mass production efficiency while satisfying specific customers' needs. This example highlights how a well-designed product platform can be a facilitator for mass customization.

Considering how the modules interact in their interface, Ulrich (1995) indicates three different types of modular product architecture: sectional, bus, and slot. In sectional architecture, "all interfaces are of the same type and there is no single element to which all the other components attach" (Ulrich, 1995, p. 424). In bus architecture, there is one main module to which all the others attach with the same type of interface; thus, they can be attached to different places of the main module interchangeably. In contrast, in Slot architecture, the interface of the various components are different and cannot be interchanged (Ulrich, 1995).

As shown in some of the examples from the previous section, modularity is often present when geometric customization is available as part of the mass customization strategy in housing. However, Rocha, Formoso, and Tzortzopoulos (2015) indicate fundamental differences between manufacturing and construction that affect product modularity. One crucial difference is that while most products can be divided into components that perform specific functions contributing to the function of the product, buildings are a combination of components and spatial voids (Rocha et al., 2015), both of which are equally important for the function of the product.

These authors propose a conceptualization of product modularity for housing that includes three elements: product architecture considering functions of elements and physical components divided into spatial voids and solid mass; interfaces among interacting modules being spatial interactions and geometric interactions considered especially relevant; and operational tools to support decision making (Rocha et al., 2015). Using this conceptualization, the authors were able to improve the modular approach for two construction companies, reducing the overall number of modules while maintaining the same amount of variety offered to customers (Rocha et al., 2015). However, achieving a housing product in which different modules can be chosen interchangeably while maintaining the function of transition between rooms, structural integrity, and function of utilities adds significant effort in the design stage. It is worth this energy if the operation is large enough that these efforts are compensated by avoiding certain design problems for many individual cases.

2.2.3. Order decoupling point.

The customer order decoupling point refers to the stage along the production that the specific customer order influences the outcome of the product. That is, up to this point, activities are based on speculation and from this point on they are specific to the order (Wikner & Rudberg,

2005). Therefore, it is an important aspect to consider for the mass customization operation. Although different models have been developed to address this point, often considering one specific product, many authors agree on four possibilities for the order decoupling point: engineer to order, make to order, assemble to order, and make to stock. In engineer to order, the customer is involved from the start of the process and the product is engineered to their order. This offers the most customization but also generally takes longer and costs more. Generally, the closer this point is to the end of the production process, less customization can be offered, but it takes less time to process the individual order. Make to stock is usually considered mass-production.

Postponement of the differentiation of the product until the last moment possible has also been indicated by several authors as an important aspect to achieve mass customization in housing (Piller, 2013; Rocha et al., 2015; Taube & Hirota, 2017). Barlow et al. (2003) showed, through analyzing house building in Japan, that different levels of mass customization were possible depending on where the decoupling point is in the value chain. The closer the decoupling point is to the start of the process, the more choice the customer can have; however, the cost and lead-time also increase (Barlow et al., 2003). At one end of the spectrum, when the customer gets involved only at the end of the process, is "Pure standardization," that is, mass production, at the other end is pure customization. Three middle possibilities are considered mass customization: segmented standardization in which final assembled modules are mass-produced; customized standardization in which standard components are used to pre-fabricate modules with the customers' requirements; tailored customization in which "standardized components and subassemblies" are configured to the customers' requirements on-site (Barlow et al., 2003). This division is very similar to that of mass customization in manufacturing and considers high amounts of pre-fabrication.

In a later study, Rocha (2011) introduces the idea of Customization Units as the building blocks of a strategy in which each Unit corresponds to a customizable attribute and the range of possibilities for its customization. This approach demonstrates the nature of change that comes with each unit, allowing companies to more clearly identify the scope of the customization strategy (Rocha, 2011). This author proposes that for the construction of housing, it is important to map out which activities during the construction process will be affected by customization allowing the company a better understanding of where the decoupling point should be (Rocha, 2011). This approach is especially useful when prefabrication is not used for the mass customization strategy, as it allows the identification of the specific processes of construction that can happen before the customer's involvement, as well as changes that could be made in the construction process to delay differentiation.

2.2.4. Pre-fabrication.

Prefabrication is another aspect considered relevant to the mass customization of housing. Although some examples of mass customization in housing do not necessarily use pre-fabrication, in most of the literature it is seen as an important enabler.

Prefabrication in construction is usually associated with parts of a building being fabricated offsite (Khalili-Araghi, 2017). However, in some cases, parts of a building can be prefabricated on-site before being moved into place in the building; this is the case with some concrete and ceramic wall panels employed in social housing in Brazil ("Desempenho Técnico para HIS," n.d.). However, for mass customization, offsite prefabrication comes closer to the efficiency of mass production as it allows greater reuse of processes and consistency in quality.

A significant advantage of using prefabrication in construction is the reduction in time for construction since several parts of the building can be fabricated at the same time (Smith, 2010).

For example, while site and foundation work are taking place on-site, the rest of the house can be made in a factory. Greater control of quality is also an important advantage as prefabrication allows for greater control of processes and does not depend on the weather (Knaack, Chung-Klatte, & Hasselbach, 2012; Smith, 2010). For example, prefabricated reinforced concrete has greater consistency across pours that would be difficult to achieve on-site (Smith, 2010).

However, prefabrication demands more careful consideration of transportation and assembly on site. Transportation costs may increase, for example, if carrying whole rooms in which case much space will be empty (Knaack et al., 2012; Smith, 2010). The limitations regarding the size and shape of what can be transported has to be carefully considered in the design stage. Likewise, provisions for assembly, such as craning, must also be considered in the design stage.

A significant advantage of using prefabrication in housing in Brazil refers to the reduction in waste, which can bring significant savings during the construction. It is widely recognized that traditional construction methods in Brazil have high percentages in material losses as well as unnecessary labour costs due to the redoing certain aspects of construction that could be avoided. The losses with ceramic brick, for example, reach 48% in some cases, being the average loss around 21%, for gypsum the average in losses is 45% reaching 120% in some cases (Agopyan, Souza, Paliari, & Andrade, 2003). These losses are tightly associated with how construction is carried out. For example, in traditional brick construction, the walls are entirely built and then purposely broken to place plumbing and electrical wiring. Thus, the use of prefabricated concrete structure and prefabricated wall panels, for example, help to diminish these losses. Furthermore, the significant reduction in construction time also helps to increase the savings. It is important to highlight that construction companies also use other strategies, different from prefabrication, to diminish losses and reduce construction time.

2.2.4.1. Pre-fabrication in Social Housing in Brazil

Most of the advantages and challenges of prefabrication are still true when considering social housing projects in Brazil. However, several context-specific issues limit the extent of its adoption in this kind of project. It is important to mention that the government considers traditional building systems in Brazil as those that are commonly used in the national territory and have specific performance legislation ("Desempenho Técnico para HIS," n.d.). These systems are usually comprised of ceramic or concrete blocks and may have reinforced concrete structures. Systems such as wood framing and light steel framing are considered innovative and are rarely used. Therefore, prefabrication is often associated with prefabricated reinforced concrete for structures.

Smith (2010) indicates that the inability of building officials and regulatory agencies in keeping up with all the innovations in prefabrication could bring problems in terms of municipalities delaying approval or the company having to hire third parties for special inspection. In most municipalities in Brazil, companies would not have a problem with approving projects that included entire modules produced offsite. However, when it comes to publicly funded housing, the way the funds are disbursed may be a limitation to the broader adoption of prefabrication since it is based on traditional building systems. The funds are made available depending on the completion of different stages of construction that are expected to be done in a certain order. Therefore, trying to change the system or to acquire a special licence to overcome this schedule requires the building company to invest extra resources in terms of time and people to deal with the bureaucracy. However, as more innovative technologies are introduced, and more companies apply for different approaches in building technology, the disbursement of funds, and inspection processes, this might become easier for the companies. Thus, this problem can be

considered a negative aspect particularly for the pioneers in the use of new construction approaches.

Cost of labour is another significant aspect to consider. In places where labour is expensive, "prefab methods that reduce the number of workers and the time spent in labor benefit the project more significantly than in locations where labor is inexpensive and available"(Smith, 2010, p. 51). In Brazil, labour for traditional construction is not expensive, whereas more skilled labour such as that usually required by factories is much less available and more expensive. The cost of training skilled labourers and their higher salaries over time is another factor that influences Brazilian construction companies to opt for more traditional building technologies. This is especially relevant in smaller cities and those further from the capitals. Furthermore, traditional building systems are culturally accepted, whereas innovative technologies often face prejudice. This might require investment from the company to educate the population that, for example, walls built with light steel framing can achieve the same performance as brick walls. However, this is irrelevant if considering developments for the lowest income range of the population. The families eligible for housing in these developments do not have the option of choosing to buy their unit somewhere else because they are not comfortable with the building system: they are assigned a unit by the city ("Programa Minha Casa, Minha Vida - PMCMV," 2016; Taube, 2015).

As indicated in the literature, the highest benefits of prefabrication are achieved when producing many elements on an ongoing basis. This is one of the reasons why the prefabrication of reinforced concrete elements is successful in Brazil; there is a demand by many construction companies. Knaack et al. (2012) indicate that prefabrication in housing is attractive when a large concentration of housing has to be built quickly. Regarding this aspect, social housing developments for the lowest income range fulfill this aspect of demand for high volumes of

production. For this kind of development, prefabricated reinforced concrete structure is not very often used. This kind of prefabrication brings advantages in cases in which there are high loads, like apartment buildings. However, social housing developments aimed at the lowest income range of the population are usually either single-story houses or buildings with a maximum of four flights of stairs to avoid the need for elevators (Serapião, 2016); therefore, lower costs can be achieved using other kinds of structural systems. Prefabrication that is currently used for this kind of development includes: prefabricated concrete panels, concrete and ceramic panels and, more recently, wood framing panels. All of these reduce the lead time and costs for building this kind of development ("Desempenho Técnico para HIS," n.d.; "Programa Minha Casa, Minha Vida - PMCMV," 2016; Silva, 2013).

However, it is important to highlight that the housing units in this kind of development are very small. Therefore, especially in developments of house units, it is expected that the families will start making changes and expanding their units mostly through self-building (Rufino, 2015). Even though the developments built using traditional construction usually do not consider adaptability of the units, some of the prefabrication technologies could make it even harder for the families to make changes to their homes. This is the case of the prefabricated concrete and concrete and ceramic walls. As well as being load-bearing (Silva, 2013), these walls would be very difficult and more expensive for the families to break through to change the layout of their unit or access plumbing and electrical wiring. Families are more likely and better able to make these changes using the systems they are familiar with. Thus, systems that require several layers of different materials to achieve the minimum standard of acoustic and thermal insulation, such as the wood framing panels, would make it also more difficult for families to make changes. Furthermore, the

materials for building in such systems are not easily available to these families and their attempts to make changes could result in diminished performance of the original unit.

For the use of prefabrication in social housing in Brazil, location plays a vital role regarding the availability of labour, machinery, materials, manufacturers, and acceptance of the proposed building system. Any of these factors could lead to the development being a success of savings and sales, or to require extra investment to make it work, thus, significantly reducing the savings. Furthermore, especially when considering housing for the lowest income range of the population, the use of prefabrication should consider how these housing units will be used and changed in the future. This includes considering potential increases in cost to carry out changes resulting from the choice of prefabricated system.

2.2.5. Interaction with customers.

As mentioned before, mass customization is primarily a customer-centric approach; therefore, the interaction with customers is essential for its success. In this regard, Gilmore and Pine (1997) have indicated that there are four different approaches to mass customization: collaborative, adaptive, cosmetic, and transparent. In collaborative customization, it is the collaboration with the customer that helps them identify and articulate what they need. In adaptive customization, the standard product offered can be customized by the users themselves even to perform differently on different occasions. In cosmetic customization, a standard product is presented differently to each customer, and in transparent customization, the customized product is sold without explicitly telling the customer that it was customized for them. Although subsequent authors have categorized mass customization with several different approaches, this approach demonstrates different ways in which the customer can be involved in the decision-making process; from almost not involved as in transparent customization, to completely involved

as in collaborative customization. However, it is the customer involvement in the specifications of the product that is most often associated with mass customization (Gilmore & Pine, 1997; Khalili-Araghi, 2017).

To offer individually customized products, it is necessary to know what the individual wants. However, achieving this is not as simple as asking since the individuals themselves often do not know exactly what they want. Furthermore, the customer's true preference may be different from the expressed preference used to customize the product, or they may have an overall idea of their preference that becomes lost in the confusion of having too many options (Franke, Keinz, & Steger, 2009). Therefore, these problems of the relationship with customers have led to great amounts of research addressing whether and to what extent customers prefer customized products, as well as how to elicit their preferences without overwhelming them.

Through controlled experiments, researchers have found that in general, customers do find benefits in having a customized product. However, the extent of this benefit depends on several factors, including their level of insight into their own preferences, the ability to express their preferences, and how relevant the product is to the customer (Franke et al., 2009). Furthermore, having a greater fit to the customer's preferences is only one of the aspects that increase the value of a customized product to the customer. Another aspect that has become increasingly relevant is the value that customers attribute to products they feel were originated by themselves, self-designed or co-designed. That is, often customers are willing to pay more for a product they feel was originated by them even if their needs are satisfied to the same extent as another product which they did not take part in the design. Franke, Schreier, & Kaiser (2010) indicate that the perceived benefit of self-designing is higher when the preference fit achieved is higher and when "the customer feels that she has contributed more to the result" (p.137). However, there is a limit as to

how much contribution is beneficial beyond which it is perceived as only effort (Franke et al., 2010). Often allowing the customer to co-design their products is enabled through the use of a mass customization toolkit.

2.2.5.1. Mass customization toolkits.

Mass customization toolkits are described by Blazek (2017) as software applications that give "users a configuration space where they can design a product to their specific needs" (p.40); these are also often called product configurators or co-design systems. These configurators have become increasingly popular, especially online. Through them, many products can be configured to the customer's specific needs and preferences. However, several authors indicate that, although more complex configurators usually mean the customer can achieve a better preference fit, these configurators cannot be too complex to the point of negatively affecting the mass customization process, and that how much is too complex varies from one customer to another (Blazek, 2017; Dellaert & Stremersch, 2005; Randall, Terwiesch, & Ulrich, 2005). Therefore, how the options are presented to the customer and their enjoyment of the process is an important aspect for the success of the mass customization operation. Researchers suggest not only balancing complexity and utility but also customizing the customization process to allow each user to take the most advantage of it (Blazek, 2017; Dellaert & Stremersch, 2005; Kreutler & Jannach, 2006; Randall et al., 2005).

Randall, Terwiesch and Ulrich (2007) indicate two main approaches for presenting the options to customers: needs-based and parameter-based. In the needs-based approach, the customer indicates their needs for the product, and the manufacturer translates those into the available parameters, suggesting a final product that satisfies those needs. In the parameter-based approach, the customer chooses directly from the available parameters. The needs-based approach yields better results for customers that do not have much expertise regarding the technical aspects

of the product, while the parameter-based approach allows more expert users to achieve a higher fit to their needs. Referring to the problems that customers may have in using mass customization toolkits, Randall et al. (2005) indicate principles of user design and actions to be taken to avoid the problems, as seen in Table 2.

Table 2 Main problems with customization systems (Randall et al., 2005)

Problem	Principle	Action
Some consumers have more knowledge about the product than others	Customize the customization process	- Provide novice consumers with needs-based interface - Provide expert users with parameter-based interface
Not all consumers are interested in fully exploiting the potential of customization	Provide starting points	- Provide multiple access points for customization
Customizing a product is a cognitively challenging task typically requiring many iterations	Support incremental refinement	- Allow consumers to bookmark their work - Allow for side-by-side comparison - Provide shortcuts through "attribute space"
Since customized products are tailored to a specific consumer, the consumer typically must order a product before having seen or tested it	Exploit prototypes to avoid surprises	- Provide rich illustrations of the product - Provide increasing levels of fidelity in prototypes as the customization process progresses
Consumers know very little about the options available to them as well as how these options are useful in fulfilling their needs	Teach the consumer	- Provide "help buttons" leading to meaningful information - Explain the product attributes and how they map to design parameters - Show the distribution of design parameters and product attributes across the consumer population

However, it is important to note that the product itself and how it can be customized also influence the options that can be presented and how complex the configurator will be. Blazek (2017) shows six types of configurators that influence how the product is configured and how complex the configurator will be to handle those attributes. In select-to-order and pick-to-order configurators, the complexity is low. In both cases, the customer picks the components of a product and either there are no component dependencies or the customer "takes care of the dependencies themselves, without support of the configurator" (p. 40). For assemble-to-order and configure-to-order configurators, the complexity is considered medium. In assemble-to-order, "The configurator matches prefabricated components, taking into consideration components dependencies" (p. 40). Configure-to-order is based on a modular system in which the configurator supports the customer in the selection of the components that will fit together. Make-to-order configurators are considered by Blazek (2017) as being of medium-high complexity in which "the configurator allows the customer to define specific parameters based on product rules. Manufacturing takes place after the order" (p.41). Engineer-to-order configurators have a high level of complexity with high freedom for configuration, possibly needing new components and rules to fulfill the customer's needs (Blazek, 2017).

The representation of a product within the configurator is also considered an important aspect to reduce the burden of choice for the customers since they will not be able to see the actual product before purchasing it. Avella and Albano (2017) consider that "the complexity of the visualization system adopted is directly proportional to the complexity of the configurator" (p. 48). Therefore, low complexity configurators such as the select-to-order and pick-to-order types may only need orthographic projections or perspectives, and may not even need orbital rotation and zoom depending on the product. The more complex the product and configurator, the more options

for visualization may be needed, and rendered versions of the representation, augmented and virtual reality can be useful visualization tools. These authors point out that in make-to-order configurators, the product is not limited to predefined modules, and the user may alter geometric or dimensional parameters, thus, adding complexity and requiring that parameterization functions be visible on all views(Avella & Albano, 2017).

In some cases, it may be possible to combine physical elements with the digital configurator to facilitate certain visualization or manipulation aspects. Winder and Larson (2017) have demonstrated the possibility to facilitate interactive sessions with stakeholders using a system that combines computation with physical models. Their system is composed of tagged objects that are placed on a table equipped with sensors, which allows the computer to read how the objects are being placed. The information is then processed, and light is projected back onto the table, adding layers of information for the users to manipulate the objects further. This example demonstrates the possibility of manipulating physical models while the validation is processed digitally. in a different approach, Cuperschmid, Ruschel, and Monteiro (2015) used augmented reality with physical markers that were manipulated on a map while visualized in three dimensions on-screen with the intent of facilitating the participatory design of open spaces in Brazil.

Regarding the use of product configurators in housing what is usually available to be changed are things that do not affect the geometry such as surface materials and finishes (Kolarevic, 2015). Geometric or dimensional customization, in which the changes of the customer could be automatically validated and sent to production as with other products, is technologically possible. However, to offer a configurator with the possibility of geometric customization requires much greater effort and resources in an initial stage. Therefore, this kind of approach is only feasible if the operation is large enough that the initial efforts can be recovered after

implementation (Benros & Duarte, 2009). The use of this kind of configurator has great potential to diminish costs from the design stage since even some examples of mass customization in housing today, still require several meetings between the company and the client to, in collaboration, determine the specific options.

Several studies have demonstrated the possibility of using this kind of approach for the geometric customization of houses and apartments with varying complexities. Khalili-Araghi and Kolarevic (2016) propose a framework for a dimensional customization system in which the architect creates the parametric design and establishes the constraints for the dimensions. The customer can then interactively and numerically manipulate the dimensions exploring different solutions while ensuring design validation. The interface used for this manipulation allows the design to be viewed through 2D and 3D representations.

In another approach, Lo, Schnabel, and Gao (2015) propose a platform based on gaming methodologies to facilitate the interaction between architects and occupants in the design of mass housing buildings. In this case, the architect sets the parameters, and the occupants then manipulate the design of the units to suit their needs and budget. It also provides a component for conflict resolution between the occupants of different units. The authors point out that the process is simple enough that no prior design knowledge is needed in order to use it stating that "the users will only need to drag the room types, make the connections, and the plan will appear immediately" (Lo et al., 2015).

However, Kolarevic (2015) indicates that the reasons why geometric mass customization is not more widely adopted are mostly social and cultural. It refers to people not having the confidence or enough knowledge to take responsibilities for their own housing designs, especially given that it is much more expensive than most other products and is often a once in a lifetime

purchase. Franke and Hader (2014) suggest that these configurators should be viewed as learning tools given that the customers can gain better insight into their own preferences through interacting with them. They also hint that this interaction may even change the customers' preferences.

In the Brazilian social housing context considered for this research, homeowners engaging in the design of their own houses is something that already happens when they change and expand the units, a configurator could be used as a learning tool aimed at exploring and avoiding the problems of such designs. Many of these problems result from the homeowner's lack of technical knowledge and the inability to visualize the expansion before starting it. Therefore, being able to visualize and interact with the design in a way that the inappropriate situations would be pointed out before making changes could significantly improve these designs. However, it is also essential to consider that families of the lowest income range in Brazil face greater challenges to access digital technologies. For example, even though internet access has been increasing over the past years for this population, it is still more difficult than for higher income ranges of the population (Centro Regional de Estudos para o Desenvolvimento da Sociedade da Informação, 2019). This difficulty of access to digital technology by the families could limit the use of a mass customization toolkit in this context. Therefore, for the implementation of such a toolkit intended specifically for use by this low-income population, careful consideration must be given to the kinds of resources that the user will need to access the toolkit, what kind of devices and internet connection, for example.

2.3. Housing Adaptability

Several authors have studied housing adaptability and offer strategies and guidelines for design. Friedman (2002) states that housing adaptability can be interpreted as "Providing occupants with forms and means that facilitate a fit between their space needs and the constraints

of their homes either before or after occupancy." He also considers that housing adaptability means being able to change the environment to suit new circumstances. Although Schneider and Till, (2007) differentiate between the terms 'adaptability' and 'flexibility', they use 'flexibility' with the same broad meaning as Friedman (2002, 2013) uses 'adaptability', encompassing all kinds of changes that can be made to the home to better suit new circumstances. Thus, in this study, these terms are used with this broad meaning without differentiating between them.

It is important to highlight that there are different aspects of adaptability that can be considered. One relevant distinction is between initial adaptability and continuous adaptability. Initial adaptability is when the occupants are offered choices or can make changes to the design before moving in, and continuous adaptability is when changes are facilitated while the people are living in the dwelling (Brandão, 2011; Digiacomo, 2004; Friedman, 2002). Another aspect refers to how the unit will be changed, for example, rooms that can be used in different ways – such as a bedroom or living space that can become an office or business space just by changing the furniture – or the possibility of physically changing the rooms themselves, through expanding or moving walls (Schneider & Till, 2007). Both these possibilities of how the unit can be changed are relevant in the context considered in this study. Given the small size of the units, the residents often expand them and change the original unit to better suit their needs. Likewise, rooms in the original unit are often used for other purposes than that for which it was originally planned, such as bedrooms being used for business. Therefore, it is relevant for the initial unit design to consider these adaptability aspects.

Describing the concepts for residential Open Building, Kendall & Teicher (2000) advocate that there should be a physical separation between the supports – which includes the structure, façade and common building services – and the infill, which includes everything that belongs to

each dwelling and should afford maximum control by the occupants. Leupen (2006) considers this aspect of separating what is permanent from what can change as an important aspect of adaptability considering the ‘frame’ as the permanent, which defines the space, in which change can occur. This author shows five layers that perform different roles in the building: structure, skin, scenery, services, and access. If each layer is separated completely, then one can be changed without affecting the others. In this case, some of the layers could work as permanent frames, while others can be changed. Leupen (2006) indicates that any of the five layers can be designed to serve as a frame.

Friedman (2002) indicates that the reasons for spatial change in housing include family transformations, fitting new technologies, and affording in stages. These reasons coincide with those identified in social housing post-occupancy studies in Brazil. Therefore, although housing adaptability is relevant for all housing construction, it is further examined below as it relates specifically to social housing in Brazil.

2.3.1. Housing adaptability in social housing.

Family transformation refers not only to the changes in a family that take place over time but also to the different configurations of families that have become increasingly more diverse over time (Friedman, 2002). Given that the housing units in the social housing context considered in this research are usually all equal and small, it is unlikely that they will satisfy the needs of the diversity of families they are aimed at. It is prevalent in this context to have extended family living in the same house and, in some cases, the housing programs prioritize specific configurations of families such as families with a single mother head of the family or families with an elderly dependent. Furthermore, it is common for the family´s needs to change over time; for example, as the children grow and marry and continue to live in the same house, relatives move in or out, or

family members start a business. In this context, moving is seldom an option. Therefore, this diversity of families and changes in the families over time are important factors to be considered in terms of housing adaptability.

Similarly, the aspect of affording in stages is an important factor in this context. Friedman (2002) indicates that builders can plan ahead, leaving some unfinished spaces or room for expansion, making the unit cheaper initially. He indicates that considering this aspect in the design "will facilitate the growing process, whether it is inward or outward" (Friedman, 2002, p. 12). In the social housing context, this aspect is especially relevant since the programs start from the premise that these families cannot afford adequate housing. Therefore, the units built are subsidized by the government, aiming to provide housing to the maximum number of families possible, thus keeping the cost of each unit to a minimum. Although this usually results in units that do not have room for internal growth – such as unfinished basements or attics – the adoption of strategies to facilitate external growth in house units could significantly reduce the costs of future expansions.

Many of the situations that have been identified as problematic for allowing families to adapt their units in the social housing context considered here, have been addressed in previous housing adaptability studies. For example, Rufino (2015) identifies that load-bearing walls are used too often in these social housing enterprises and that this makes it difficult for homeowners to adapt the units to their specific needs. Friedman (2013) considers that floors without load-bearing divisions and large square-shaped compartments allow for better adaptability in the future. In a study specific to social housing units in Brazil, Brandão (2011) made similar recommendations regarding the shapes of rooms and the use of walls that are not load-bearing. These authors also make recommendations for the initial design regarding the dimensioning and placement of utilities,

circulation, position of openings, and roof configuration. These aspects are particularly important to allow for easily expanding in the future, as well as to guide the direction to which the house should grow (Brandão, 2011; Friedman, 2013). Digiacomo (2004) considered twelve different aspects which should be considered for the adaptability of house units in social housing developments: (1) conception of equipment, installations and furniture; (2) altering room layout; (3) form of circulation; (4) neutral space and polyvalent use of space; (5) conception of structure; (6) conception of facades; (7) number and placement of accesses; (8) changes to useful floor area; (9) architectural design; (10) standardization of components; (11) instruction manual; (12) roof design. For each of these aspects, she proposed several strategies to be adopted to facilitate the adaptability for future occupants. Building on these strategies Brandão, (2011) proposes thirty-one guidelines, divided into nine groups, for the adaptability of house units specific to Brazilian social housing developments, a summary of these guidelines can be seen in Table 3.

Table 3 Guidelines for adaptability for house units in Brazilian social housing developments (Brandão (2011).

Group	Guideline
Spatial arrangement regarding shape and dimensions of rooms	1) Provide neutral rooms without size extremes 2) Provide multiuse rooms 3) Provide for the possibility of a new position for the bathroom door 4) Provide, if possible, larger meal space in the kitchen 5) Study the options of having corridors inside the unit or not
Spatial arrangement regarding the direction of expansion	6) Make the direction of expansion clear 7) Provide room to add a garage or business space 8) Position the bathroom in a strategic place
Openings and frames	9) Position the openings in each room strategically 10) Avoid variation in the size of windows 11) Provide for the possibility of additional communication between rooms 12) Adopt additional door or panel-window system
Roof	13) Set the height of the ridge suitable for expansions 14) Allow the creation of new roof slopes without affecting the functionality
Structure	15) Separate, if possible, structure from walls 16) Prepare structure to receive one or more floors 17) Prepare structure to receive stairs
Services	18) Dimension water pipes providing for an increase in flow 19) Provide permanent hydraulic walls 20) Place septic tank and seepage pit adequately 21) Dimension tubes for electric wiring providing for new circuits 22) Avoid centrally placed lighting 23) Place electric switches and outlets adequately

	24) Add sink outside the bathroom
Division of rooms and furniture	25) Use moveable and/or collapsible partitions 26) Avoid excess of built-in furniture 27) Use furniture to divide environments
Site and typologies	28) Provide setback which allows expansion to the front 29) Adopt broader front for individual lots, if possible
Support to user	30) Provide designs of possible expansions 31) Create a user manual

Although it is acknowledged that following these guidelines could result in units that are more expensive, Brandão (2011) points out that this added cost considers only the initial construction. This difference is quickly recovered by the families when the changes are cheaper to implement in an adaptable unit. This author further indicates that when social housing is subsidized, as is the case for the lowest income range, these subsidies could cover higher initial costs as a strategy to guarantee future expansions. Furthermore, for several of these guidelines – such as making the direction of the expansion clear and positioning the bathroom in a strategic place – their implementation does not necessarily result in a design that will be more expensive to build. However, when compared to using a standard pre-approved unit, using the guidelines means adding effort in a design stage, and this could be the reason why they are not more widely used in the social housing developments.

The building system and typology are two important aspects to consider in regard to implementing adaptability strategies in housing aimed for the lowest income range of social housing programs. Although the building system itself does not determine how adaptable the housing unit will be, how it is implemented can influence the overall adaptability of the unit. For example, in hollow brick construction, the walls are usually implemented as load-bearing, not separating the structure even when concrete beams are present, thus limiting the adaptability of the unit. Some of the innovative building systems, currently used, limit the potential for adaptability even further, as is the case with systems that use concrete walls (both in-place moulded or

prefabricated). This system makes it very difficult should the changes require destroying parts of the existing walls or accessing embedded systems such as water pipes and electrical wiring.

For innovative building systems, further aspects should also be considered, such as how future changes are likely to be made. Families are more likely to make changes successfully using construction techniques they are familiar with. Thus, building systems such as light steel framing and wood framing, which require the use of layers of different materials to achieve the minimum standards of acoustic and thermal insulation, could make it difficult for the family to carry out future changes. Furthermore, such materials are not easily accessible to the families, who may not feel comfortable in building with such materials. This could result in poorly executed changes that may diminish the performance of the original building. Families might carry out the changes using the building system they are familiar with, thus combining two systems. Further evaluation of current, innovative building systems and other adaptable systems should reflect how compatible they would be with the systems considered traditional in this context, as there is a higher chance of future changes using these traditional building systems.

The typology chosen for the houses also influences how adaptable the units will be. From the literature, there are examples of adaptable housing units of different typologies. However, considering the house units in the Brazilian social housing context, the typology influences which of the guidelines proposed by Brandão (2011) would be of higher priority to be implemented. For example, the priority to prepare a structure for adding floors is higher in developments of higher density (Digiacomo, 2004), which is usually the case in neighbourhoods of row houses.

2.3.1.1. Previous cases that considered adaptability.

Several housing initiatives in South America considered the adaptability of the units in the project. One approach that was common in previous housing programs in Brazil gave the families

a very small often unfinished unit, called “embryo” unit, which had a reduced number of rooms. Sometimes only the bathroom was separated by walls, and the rest was one large room. The expectation was that the families would start expanding and improving on the units (Digiacomo, 2004; Larcher, 2005; Malard, Conti, Ferreira De Souza, José, & Campomori, 2002; Palermo, 2013). An example of such an embryo unit meant for expansion in four directions can be seen in Figure 2.1. It consists of a unit of 20 m² with bathroom, kitchen and living room; the image also shows possibilities for the expansion for the first two bedrooms (Brandão, 2011).

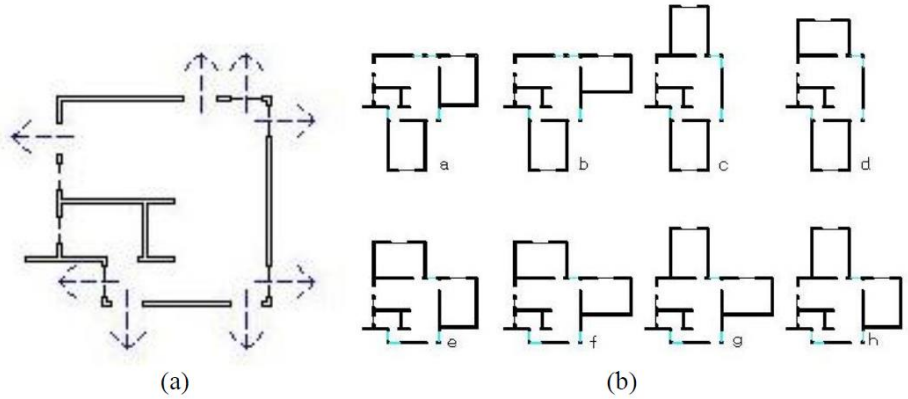

Figure 2.1 Embryo unit (Brandão, 2011)

Although this approach allowed the units to grow, they needed significant investment by the families immediately, both for expanding, due to the small size of the units, and finishing. Given that this approach was meant for the lowest income range of the population, many families could not make such a substantial investment and, thus, were left to live in inappropriate conditions. Furthermore, the families often did not have support regarding how or where to expand their unit, leading to several problems with the expansions. The program MCMV, does not allow this kind of approach and sets strict rules regarding the number of rooms and their uses. Although this means the houses are usually larger than those considered embryo units, these rules make it

even more challenging to offer diversity and adaptability within the developments (Rolnik, Pereira, Lopes, et al., 2015).

However, this kind of approach still is used in private non-profit social housing initiatives and other local initiatives. One example can be seen in Figure 2.2; it is called Casa Prisma and was designed by Cassius Baumgarten. The house shown in Figure 2.3 was built by the architect following this model in partnership with the city of Pelotas, following a fire that destroyed the owner's previous home in 2016. The house is composed of combined equal modules of the wooden structure, one of which can be seen in the top left image of Figure 2.3. The structure is then closed with sheets and roof tiles made from recycled Tetra Pak cartons, which also received ceramic tiles in the bathroom. The initial unit, in this case, measures 24.20 m^2 and is meant for expansion to the back, reaching 53.56m^2 with two bedrooms, as shown in Figure 2.2. However, the unit could continue to grow to the back and the front beyond the two bedrooms shown.

It is important to highlight that this house was not built within the MCMV program. Despite this program allowing new innovative building systems, the process for approving such new material is lengthy and costly. The building system used for this house is not currently within the approved systems for this program. However, the unit could be built with other materials that are already approved. Furthermore, given the way the unit is meant to expand, continuing along a side corridor, the initial unit could be built already with two bedrooms falling within the rules of the program and still being able to expand further.

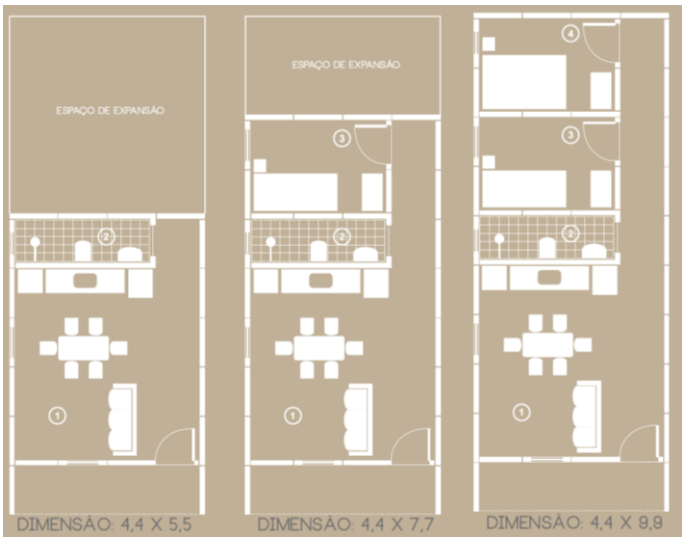

Figure 2.2 Casa Prisma floor plan: embryo unit (left), unit with one bedroom (centre), and unit with two bedrooms (right). Images courtesy of Cassius Baumgarten

Figure 2.3 Casa Prisma: during construction (left), and finished house (right). Images courtesy of Cassius Baumgarten

An initiative that also considers the possibility of expansion is Quinta Monroy, which was built in 2004 in Iquique, Chile. The designers intended to include the homeowners from early

design stages, considering their cultural, behavioural, and social backgrounds. They also aimed to keep the population in the same area in which they were already living informally, in a central region of the city. Initially, equal mass-produced units (two types of units) were built. However, these were only half the house, which would later be finished in a customized way by the homeowners (Aravena, Montero, et al., 2004). The two unit types consisted of one occupying level 1 and with growth predicted also on level 1. The other unit occupies levels 2 and 3 and allows growth also on these levels. The initial units built measured 25m² and 36m², and the provided space for growth allowed the units to increase to 72m² and 70m², respectively (Drexler & El khouli, 2012). Figure 2.4 shows the initial units built on the left and, on the right, the units after some expansions were made. Figure 2.5 shows the floor plans of standard units in Quinta Monroy.

Figure 2.4 Quinta Monroy original units and with expansions (Aravena, Iacobelli, Montero, Cortese, & de la Cerda, 2004)

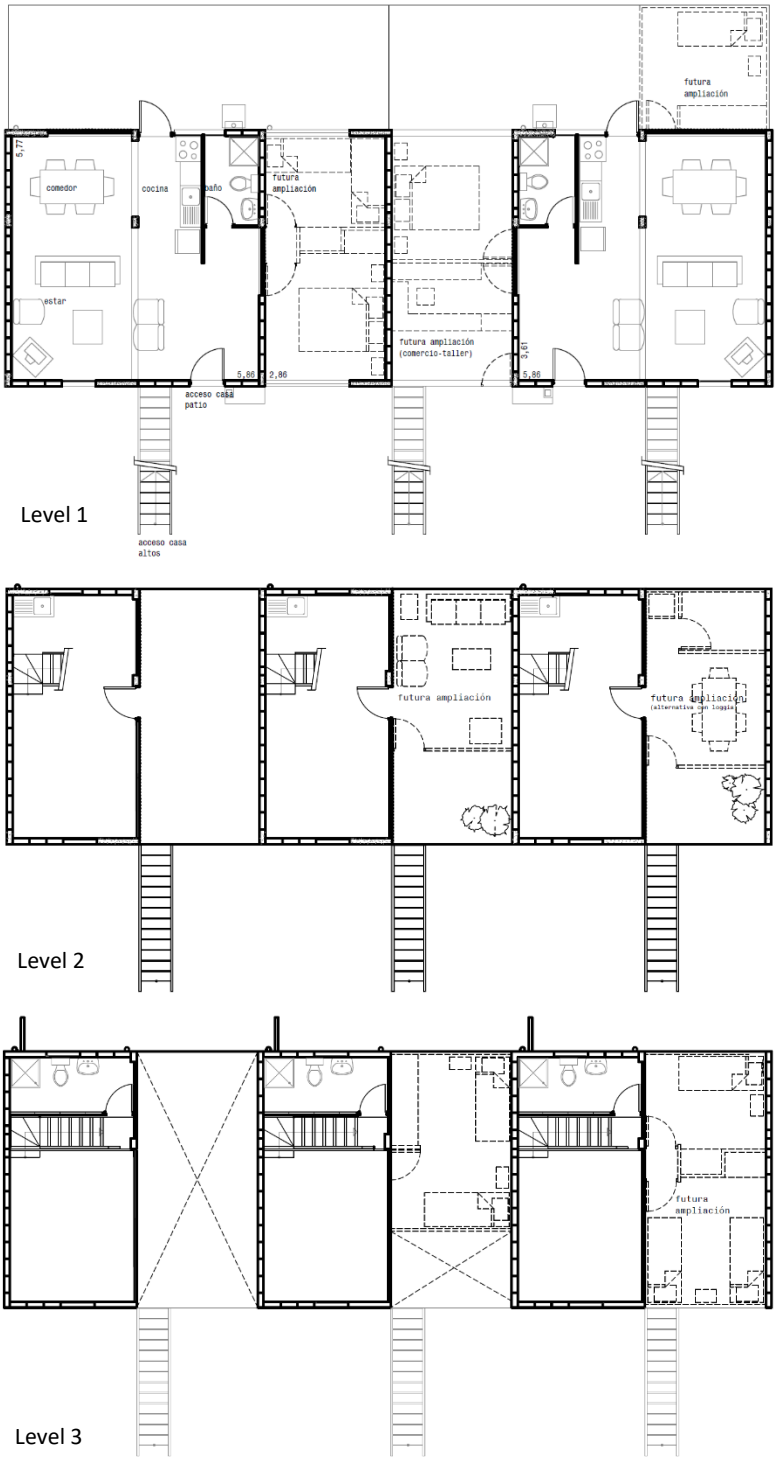

Figure 2.5 Floor plan of standard housing units in Quinta Monroy. Modified from "Elemental" (2004).

One of the advantages of Quinta Monroy, when compared to other such housing neighbourhoods, is that it provided a specific place to expand. This prevents, some of the problems identified in other cases such as illegal expansions and the immediate expansion onto the common public space. However, even the half of the house initially built was unfinished, which meant that the units needed immediate construction work once the families moved in. The possibility of leaving the unit to be finished by the homeowners is not considered as a good option in the studies specific to social housing in Brazil. One of these studies shows that several years after moving into a development that used such a strategy, some families still were having problems because they had not finished the walls, ceiling or floor (Digiacomo, 2004). Furthermore, this approach is not allowed within the current main housing program, MCMV. It is also important to highlight that this typology of housing brings up some of the same issues of multi-family buildings regarding ownership when considering expansions by the families. For example, the top floor units can only expand to the back once the lower floor unit has done so. These issues become even more difficult to resolve when many families from different backgrounds, coming from different areas in the city are assigned to a new neighbourhood by the social housing program, as is often the case in Brazil. This could be one of the reasons this typology is not used more often for social housing developments in Brazil.

In a different approach, Instituto CASA (Convergence of Art, Society and Architecture), ETH Zurich Master of Advanced Studies in Urban Design research and design laboratory, and Fundação Vale, through a technical cooperation agreement, developed an Urban Quality Label (UQL), a set of urban design best-practice guidelines for social housing (Eskes & Vieira, 2016). Some of the guidelines include ensuring architectural diversity (unit designs cannot be repeated more than 40 times) and designs adapted to specific climates, prioritizing public squares, urban

integration and community participation in the design, among others. The Pilot project using these guidelines is being built in Parauapebas, in the north of Brazil, using different unit designs that allow changes to include an extra bedroom or small business inside the original unit. However, it usually costs more to achieve the goals of such initiatives: “compared to an average MCMV project, pilot schemes such as that in Parauapebas demand more time and requires the involvement of a much larger number of stakeholders in the process” (Eskes & Vieira, 2016). It was possible in this case because Vale guarantees the funding and higher profit margins to the developers if they follow the guidelines. The floorplan of some of the unit designs used in the Parauapebas project can be seen in Figure 2.6. It is important to highlight that although these units were designed to allow the creation of one more room inside the units, this does not necessarily mean that they applied other adaptability strategies. However, some strategies that are often not used when thinking only about expansions outside the original unit were used in this case, such as the strategic placement of windows, which can also facilitate external expansions.

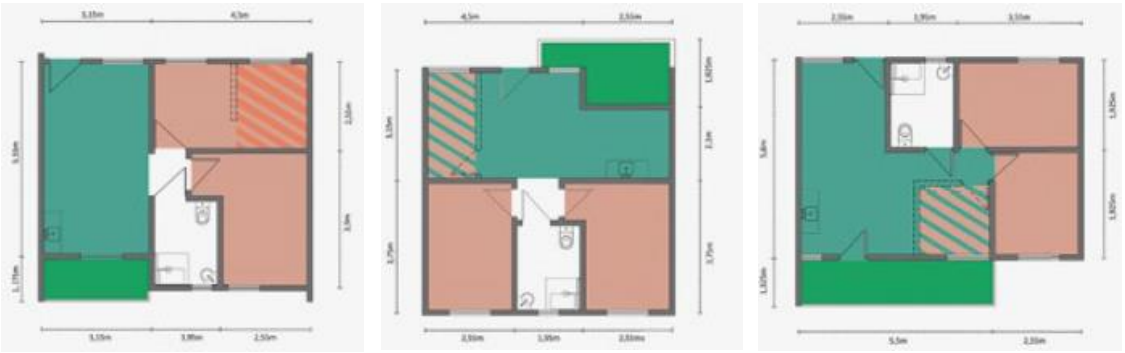

Figure 2.6 Floor plan of housing units in Parauapebas (Eskes & Vieira, 2016)

All the examples shown are from South American cases for low-income populations. These examples show that implementing adaptability strategies in social housing developments aimed at the lowest income range of the population is possible. However, several factors must be

considered. First, several local factors – such as location, typology of the development, the culture of the population, among others – can be decisive to determine what adaptability strategies are most important or relevant to implement for the specific development. Furthermore, the specific regulation of the housing program or funding agency is also a factor that can influence how the strategies can be adopted in each case.

Chapter 3. Social Housing in the Lowest Income Range

This chapter outlines the processes involved in the provision of social housing and in the post-occupancy period. It seeks to understand the ecology of the social housing system for the lowest income range including its pre- and post-occupancy processes, with a focus on the design aspects of the units. The current regulation discussed in this chapter refers to overarching social housing legislation, and to the specific program Minha Casa Minha Vida (MCMV) since it is the current main program and has produced significantly more units than any other social housing program in recent years. Furthermore, particular attention is paid to the enterprise sub-section of MCMV as it is through this division that markedly more housing has been built. From 2009 to 2019, MCMV Enterprise delivered 1,094,698 housing units for the lowest income range, while all the other urban housing avenues within the program collectively delivered 183,904 units (Ministério do Desenvolvimento Regional, 2019). However, it is important to note that unit design and many processes in the MCMV program are similar to those of prior programs for this income range. The needs of the inhabitants and, thus, the changes made post-occupancy in house units are also consistent with previous programs. Therefore, the analysis of the changes made to the units include several post-occupancy studies from developments built through different programs at different times.

While the overall process of provision of social housing and post-occupancy is very similar in different regions of Brazil, there is some variation for each specific development regarding local legislation, the building company and its processes, the specific location of the development, among others. Therefore, at the end of the chapter, a local example of social housing development

is shown outlining its specific processes and solutions. This location is also used in subsequent chapters to demonstrate the application of the proposed processes.

3.1. Legislation

Currently, in Brazil, two main laws regulate how federal funds can be used for social housing purposes: Lei nº 11.124 from 2005 and Lei Nº 11.977 from 2009. The first law is referred to as the Social Housing National System – translated from Sistema Nacional de Habitação de Interesse Social (SNHIS) – and centralized the funds from different federal sources to be used for social housing purposes. The second law refers to the creation of the program My House My Life – translated from Minha Casa Minha Vida (MCMV). Both laws have been updated several times (through the approval of other laws) since they were first published. This section outlines what is valid today considering those updates while referring to the original laws' numbers and names.

While adequate housing is a focus of the SNHIS law, it also refers to and provides funding for several different actions that are included in bringing about adequate housing such as sanitation and infrastructure projects that do not necessarily include housing units. Furthermore, different ways of housing provision are allowed under this law, such as providing lots with infrastructure, acquiring existing dwellings, renovating, or upgrading existing dwellings and building new housing units. As well as ownership by the families, this law outlines several mechanisms to transfer the right to live in and responsibility for maintenance of the dwelling to the family, while the municipality or state maintains ownership. A typical scenario is for there to be a contract transferring the housing rights to the family for fifty years, renewable for another fifty years, which can also be inherited by heirs of the original family member who signed the contract. In these cases, the family lives in the housing unit without paying rent as if the unit were theirs; however,

they cannot sell the unit or rent it to third parties. Nevertheless, illegal sales, transfers and rental are common (Interviews 1, 2, and 3).

The funds used under the SNHIS law are applied in a decentralized manner (Ferreira, Calmon, Fernandes, & Araújo, 2019). The states and municipalities have authority over how the funds will be applied and are responsible for proposing and managing the specific actions to be taken using the funds. In this sense, the law requires that municipalities must have a social housing plan to be able to access the funds. While this law is still valid and several local programs still operate with its funds, Ferreira et al. (2019) highlight that one of the immediate consequences of the creation of the program MCMV was the reduction of funds provided for the provision of social housing under SNHIS. Its investments were now mainly concentrated in urbanization actions and institutional development.

The program MCMV created by the law Lei Nº 11.977 has as the main focus the production of new housing units for ownership by the beneficiary families. Different from the funds managed under the SNHIS law, the main focus of MCMV is to finance homeownership with varying percentages of subsidies depending on the family's income. Its creation was an economic response to deal with the financial crisis started in 2007. It was meant to benefit large construction companies, in order to boost the economy, as much as provide housing for those in need (Cardoso, Mello, & Jaenisch, 2015). Worried about agility in approval of projects and the interests of entrepeneurs from the construction industry, this program breaks free from SNHIS and its social representations and sustainable urban development concerns (Cardoso et al., 2015; Ferreira et al., 2019). MCMV is divided into two main streams: rural housing and urban housing. For this study, urban housing is considered.

The law Lei Nº 11.977 establishes how different existing funds can be used within the MCMV program. Each of these funds has their own set of rules that must also be followed. A set of social development funds can be accessed through this program only for the lowest income range. The other ranges of the program are financed through other funds. This law also establishes that it is the bank Caixa Economica Federal (CEF) that will manage all funds for urban housing within this program.

Regarding the use of funds, this law establishes that for the lowest income range of the program, the beneficiary family must live in the housing unit during the ten years of the financing process in order to receive the subsidy. If the family wishes to settle the remainder of the debt beforehand (to sell the unit, for example), then they must pay the total that is still owed without receiving the subsidy (which can be up to 90% of the total cost of the unit). However, illegal sales do still happen (Interviews 1, 2, 3, and 4).

In regard to urban and architectural aspects of the developments, this law establishes that new housing developments are acceptable within the existing urban fabric or in areas of urban expansion. This is different from previous programs that only allowed developments within existing urban fabric such as those that fall under SNHIS law. MCMV law also indicates that the executive power will establish the minimum standards and regulations for the housing units. This has been done through ministerial ordinances and updated several times since 2009. After the establishment of these minimum standards, all other housing programs that use federal funds were updated to require the same minimum standards.

Currently, the ministerial ordinance Portaria Nº 660 (Ministério das Cidades, 2018b) regulates and establishes guidelines for new projects as well as the minimum standards for housing units and urban parameters for projects within the MCMV program. Regarding the urban

parameters, the regulation refers to local urban legislation stating that new developments must comply with those. However, it also sets some minimum and maximum parameters for cases in which the local urban legislation is less restrictive. These include things like the maximum area and length for a new city block and minimum street dimensions. Some rules apply for all new developments, such as the maximum number of housing units per development, which varies according to the size of the city. Some guidelines are shown to be considered for all developments and applied whenever possible, such as incorporating bicycle lanes.

Regarding the housing units, Portaria Nº 660 (Ministério das Cidades, 2018b) outlines the minimum standards for many different aspects such as materials for walls and finishes in each type of room, number of electrical outlets in each type of room, roof standards, sizes and materials for elements such as doors and windows, among others. It also specifies the minimum standards in terms of size and height of rooms and of the unit itself. For house units, it establishes a minimum of $36m^2$ when the laundry area is outside the house and $38m^2$ if it is inside the house. Every housing unit must have at least two bedrooms, a kitchen, living room, bathroom and laundry area. However, the legislation does not establish a minimum size for each room type; instead, it indicates the minimum furniture that each space must hold and the furniture's minimum size. It also indicates 2.5m as the minimum ceiling height as long as local legislation does not require a higher ceiling. For the bathroom a height of 2.3m is acceptable. However, this legislation states that the minimum standards of the local building code must be observed; thus, these are the minimum for when the local building code does not establish such minimums or establishes lower minimums.

It is important to highlight that while the program's legislation requires compliance with local urban policies and building code, in many cases this does not happen. The lower requirements of the program itself are used as a way to pressure local authorities into approving new

developments with reduced standards in relation to the local legislation. Thus, several cities made changes in urban policy, urban perimeters, and local construction rules. These changes were made to allow the construction of urban developments in rural areas, with reduced requirements of green and public spaces, reduced unit requirements, and reduced taxes for the construction companies (Ribeiro et al., 2017; Rufino, 2015).

For the lowest income range, the law that establishes the MCMV program identifies some parameters for ranking the families for receiving a housing unit. These include prioritizing families currently living in risk areas, families for which a woman is the main person responsible, families that have a disabled person among its members. However, this legislation also allows for state and municipal authorities to include their own parameters (through approving it as legislation) for ranking the families according to their local specificities.

It is also the role of the executive power to establish and regularly update the maximum amounts of funding for each development, including the maximum per housing unit. Although the federal government sets this amount, it is done considering the different regions and city sizes, acknowledging that the cost to build and develop is different across Brazil. Furthermore, it also considers the typology. For example, considering only the South region, the maximum funding for the capitals is 85000 BRL per housing unit for houses and 88000 for apartments, while for other cities with a population of 250 thousand or more the maximum is 79000 per housing unit for houses and 82000 for apartments. Usually, the smaller the city, the smaller the maximum amount per housing unit though some consideration is also given to the regional importance of the city.

Regarding the local legislation, usually, two main documents, which are approved as law by the cities, regulate what, where and how things can be built: the city Master Plan (translated from Plano Diretor) and the building code. However, other laws complement locally the law of

the program, such as those that establish the local parameters for ranking families. Further national and local regulations are also considered for the approval of developments such as compliance with fire code and local sewage regulation, for example.

The city's Master Plan regulates the aspects related to urban planning and territorial development. Every city with a population higher than 20 thousand should have this document. However, what is in this document and how it is organized varies from one city to another. It is usually through this document that cities establish zones of special social interest. These are areas in which the development of social housing is especially encouraged and usually has lower requirements, for example, allowing smaller lots than in other areas of the city.

The building code of a city usually refers to construction site aspects and those of the building itself such as types of rooms and their minimum standards in terms of size and proportions, minimum window size in relation to the room's floor area, percentage of the lot that must remain permeable to rainwater, among many others. In some cases, it is also this document that outlines the process for approval of a project in the city. It is important to highlight that while the city establishes some standards, there are individual national technical standards for many different aspects that must also be followed. These include aspects such as minimum performance of materials, accessibility standards, fire prevention installations, among others. Municipalities usually do not check the compliance to these national standards for the approval of projects as these are the responsibility of the professional technically responsible for that aspect of the project (architect or engineer). However, some of the municipal agencies that require separate approval of the project may check for compliance to the standards pertaining to that agency, such as the fire department, the municipal water and sewage company, and the environmental and conservation agency.

Every social housing development, regardless of the program that led to its implementation, must include funds for social work with the families. The ministerial ordinance Portaria Nº 21 (Ministério das Cidades, 2014) governs this social work. It outlines the processes and documents necessary for the planning and execution of the social work with the families of new developments both before and after they move to the new homes.

It is also important to consider the law Lei Nº 11.888 from 2008, which establishes that low-income families should have free technical assistance in the design and construction of housing. Among the several objectives of this legislation are the objectives of optimizing and qualifying the use and rational use of the built space and its surroundings, as well as the human, technical and economic resources, and formalizing the process of building, renovating or expanding housing before the municipal public authority and other public bodies (Lei Nº 11.888, 2008). This law also indicates where the funding for its application will come from being most of it from federal funds. However, municipalities and other entities have been struggling to access these resources, and as a result, there are still very few cases of the actual use of the funds from this law. More recently, some entities, such as CAU (architecture and urbanism professional council), have been mobilized in facilitating and disseminating the enforcement of this law.

In sum, the legislation surrounding social housing developments is vast and involves different levels of government. The regulation around how funds can be used for social housing is mainly federal, governed by federal law complemented by standards set by the federal executive power. However, regarding the construction itself, where and how things can be built, the regulation is more disperse. All levels of government have some say in this matter, sometimes with diverging focuses. For example, given the current design of the MCMV program in which the construction companies can propose the developments and location, the federal government must

establish some minimum standards for the proposal of new developments. Knowing that each municipality has its own legislation regarding urban planning, for example, what is in the federal regulation of the program is very broad in order to encompass all municipalities. However, this broad regulation is often used by the developers as a way to get around the more restricted local legislation. They pressure the municipality to approve new developments that comply only to the federal regulation, often being successful in changing the local regulation for all future developments.

Furthermore, because of this often disconnected chain of authority, the approval of new developments can take a long time and lead to the same kind of pressure for approval outside the regulation of a specific agency. For example, a development that does not quite comply to state environmental regulation may be approved so that the city does not lose the already approved federal funding for the development. Thus, while there are many regulations, these are not always followed, especially local regulations, and the approval of funding and projects is often also dependent on the political abilities of the stakeholders involved.

For the customization of housing units in this context, the national regulation of social housing programmes can be seen as posing barriers to mass customization considering the spatial aspects. Although it is considered a broad regulation, in order to allow the specificities of every municipality to be encompassed, it is also restrictive. When considering customization in terms of space, the prescription of which rooms the units must have and what furniture these rooms should fit limits what can be customized and how it can be customized. For example, a couple with no children would not be able to customize their unit to have a larger living room and only one bedroom because the regulation states that the units must have two bedrooms. Similarly, the way that the limited funding is directly tied to number of housing units, and also capped per housing

unit, usually results in all units being the smallest possible permitted within the programs. The extremely limited size of the housing units can also be seen as a barrier to the mass customization of spatial aspects of the unit. There is not much that can be customized in terms of space when the space is so restricted and regulated.

3.2.Stakeholders

There are four main stakeholders involved in the decisions, approval and construction of social housing units: the federal government, the bank CEF, private developers, and the municipal authorities. Another relevant stakeholder to consider is the families who will receive the housing units; however, in most cases, these families' role in the process does not go beyond providing documents to prove their eligibility. It is only in the post-occupancy period that their decisions become important; this is addressed in section 3.4. The state government can be involved in the process, particularly in providing matching funds or in cases when specific state approval is needed, such as in some cases which require state environmental approval. While these stakeholders are consistent across many different programs, their roles and responsibilities are described below for the MCMV program as it is the main current program.

The federal government is responsible for providing most of the funds and outlining, through regulation, minimum standards required to access the funds. These include requirements in terms of organization of the program and other stakeholders as well as requirements for the final product itself in urban, architectural and technical terms. It is also the role of the federal government to establish the national demand and goals deciding how much funding will be destined for each region, state and even municipalities. However, because of the current design of the program which requires the initiative of private developers, the release of funds for a certain region often does not follow the established goal resulting in some cities or regions receiving extra

funding while others receive much less than was the goal for that region (Cardoso et al., 2015; Ferreira et al., 2019).

The bank CEF is the primary agent responsible for financial operations. In this regard, there are two main streams of action that are under CEF's responsibility. First, the management of funds for the construction of the development and, second, the financing process for acquisition of the housing units with the families.

Regarding the management of funds for construction, it is the role of this bank to verify if the developers are capable of completing projects under the program. Hence, before proposing the specific project, the construction company must provide a series of documents to CEF to prove their experience, legal standing, technical capacity and financial capacity (Lei Nº 11.977, 2009). Once this process is completed, the company is enabled to produce a certain number of housing units with a pre-established typology (Cardoso et al., 2015). Later in the process, CEF is responsible for approving the specific project in relation to the requested funding. This approval refers to budget aspects and compliance of the project to the program's regulation. After the approval of the project, it is also CEF that manages this funding, releasing monthly funds based on the company's monthly construction completion report. In some months, CEF inspectors visit the building site to verify the construction progress. For the lowest income range CEF acquires all the housing units on behalf of the existing fund used to finance the construction, and then establishes a financing contract with each beneficiary family. The housing units remain as the property of the fund during the ten years of the financing contracts with the families (Interview 7).

Concerning the beneficiary families, CEF receives a list of the selected families from the city and determines their eligibility to finance a housing unit. CEF requests financial information from the family and the documentation that proves their stated financial situation. It is the

responsibility of CEF to cross-check the information provided by the family, including tax and banking information (Lei Nº 11.977, 2009). It is important to highlight that this often can be difficult given the informal work arrangements of the candidate families (Interview 7). Once the family is approved, CEF is responsible for determining the amount of the subsidy and charging the monthly payments until the end of the contract.

Several authors indicate that within the MCMV program, the private companies are the main promoting agents, it being their role to take the initiative to propose new developments (Cardoso et al., 2015; Ferreira et al., 2019; Rufino, 2015). As such, in most cases, the decisions regarding where the new development will be, and the typology of the units is made by the developer. It is their responsibility to develop the project and send the required documentation for approval by the city and CEF. Once approved, it is the responsibility of the developer to build the new development within the timeframe established in the project and to provide any documentation requested by the other stakeholders during inspections of the site and within periodic construction reports. Requesting the permit to inhabit once the construction is concluded is also under the responsibility of the developer.

Similar to any development project, the municipal authorities are responsible for checking the compliance to technical and urban legislation and approving the project. However, when it comes to social housing, there are several specific regulations that the city is responsible for establishing. This includes setting local parameters for ranking the beneficiary families, establishing zones of special social interest in which social housing developments will be encouraged, and establishing regulation to give social housing developments a priority character within the municipality. The law (Lei Nº 11.977, 2009) states that one of the criteria to prioritize which developments receive funding is for cities that implement tax exemptions for the

construction of social housing units. Other actions to prioritize social housing developments can include establishing an expedited process for approval of such developments, donating land in well-located areas of the city for social housing purposes, and others.

Different from other social housing programs, it is not the role of the municipal authorities to design new developments. The municipality can, however, decide where the development will be through donating the land. While this does happen, in most cases, the developer acquires the land. Although the city approves the final design of the development, it is difficult for the municipality to demand quality in design, considering that they cannot deny approval if the project is within the legislation (Cardoso et al., 2015). This was corroborated through interviews with city workers who state that the role of the city in regards to the design is limited to checking if it complies to the legislation (Interviews 1, 2, and 3). Cardoso et al. (2015) criticize this aspect, considering that the legislation was highly simplified to facilitate the fast approval of projects, and they state that within this program, in practice, the municipalities are expected to release barriers and facilitate the action of the private sector.

The other major role of the municipal authorities is to register the families and rank them based on national and local criteria. This registration of families is done on an ongoing basis and is based on the federal criteria for eligibility. It is what both the city and the federal government use to determine the demand for social housing in the city. Once there is a new development being built, the municipal authorities rank the eligible families according to national and local criteria to determine the list of which families will be sent to CEF for receiving a unit in that development. It is also the role of the municipal authorities to lead the social work actions with the population of the new development.

It is essential to highlight that these two distinct roles performed by the municipal authorities – (1) approval of projects and (2) social housing management and involvement with the families – are most often carried out by distinct departments within the municipal administration. Furthermore, the approval of projects can also require the involvement of more than one department, such as for urban and architectural, sanitation, electric, and environmental approvals.

Although each stakeholder has the main aspects of their role defined in legislation, how they carry out that role can vary significantly from one city to another and even within the same city from one project to another. Much of how the provision of social housing happens is subject to individual subjective judgement of the many actors involved in the process, and to the political will of politicians and institutions. Thus, this process is susceptible to the capacities, operational standards and will of those who carry out the process. Cardoso et al. (2015) suggest that the definition of the role of each stakeholder should not be treated as static, thus, being updatable and negotiable when put into practice.

3.3. Process of implementation of social housing developments

This section explores the process for the implementation of social housing developments, considering the roles of each stakeholder. It outlines the process from the intention of implementing a new development until the families move in. The post-occupancy processes are discussed in a separate section. The purpose of this section is to identify the processes and the rules surrounding them. It also seeks to identify if there are opportunities for change in certain aspects of this process that could bring significant benefits in the post-occupancy or in facilitating mass customization but remain within the current capabilities of the stakeholders. The process outlined in this section focuses primarily on the MCMV program since it is the current largest provider of

social housing units. However, many of the processes and relationships between stakeholders described here are common to different programs. Furthermore, the interests and motivations of the stakeholders are also maintained across different programs. Most importantly, the design solutions, both urban and unit design, are also consistent across several different programs which means that they result in similar issues and ways in which the families deal with them in the post-occupancy.

It is also important to highlight that the process described here is the overall process containing characteristics that are common to most cities. One aspect which is particularly susceptible to this variation is how long the processes take. There are some guidelines around the maximum time specific steps of the process can take, particularly for federal agencies such as CEF. However, in some cases, these processes are done much faster, while in many cases, these guidelines are not followed at all, taking much longer than expected. An example of this is seen in the Anglo case, which started its process in 2006 and only delivered the housing units in 2014, having had several delaying factors during its implementation. Further details about this case are shown later in this chapter.

The process of implementation of new developments is outlined below in chronological order highlighting important aspects during each stage. To outline this process, several sources were used: previous studies that describe it or parts of it in different cities; current legislation; the interviews carried out with different stakeholders involved in this process including representatives from CEF, city architects and urban designers, engineers, social workers, and developer. Figure 3.1 shows the overarching structure of steps for implementing a new development considering the main stakeholders. Although there may be some variations from city to city, especially regarding how much time each phase takes, the overall process falls within this structure for most cities.

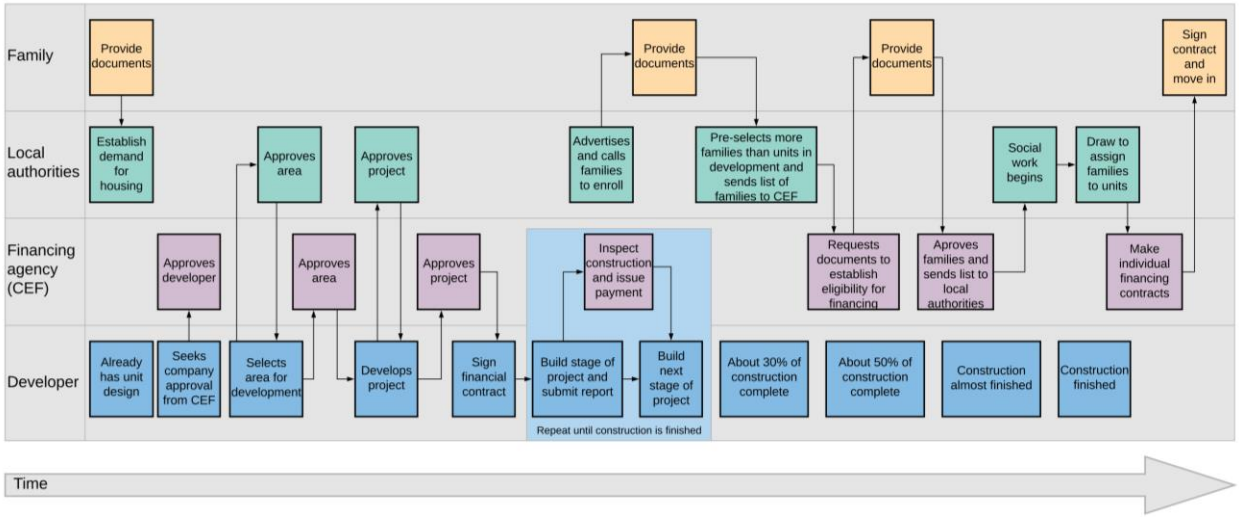

Figure 3.1 Overarching steps for new development.

The first phase refers to registering families who are eligible and interested in receiving a social housing unit. The city's housing department usually does this on an ongoing basis. At this point, the families indicate their interest in being contemplated with a social housing unit and provide the necessary documents to show their eligibility. The local authorities assist the families in registering in the federal government's social programs system (Cadastro Único). This system compiles the information from all families seeking social assistance from any of the social programs funded on a national level. The information kept within this system includes identification of each of the family members, their work condition, the family's income, their living conditions, among others (Ministério da Cidadania, 2015). Information regarding the family's current living conditions is collected during this meeting both to establish their need for housing but also to determine where within the city they currently live. The location of eligible families is used by many cities to encourage development close to where there are many eligible families or to use as part of the ranking process to determine which families will receive units in a

certain development or both. However, in most cases, this is not enough to ensure that families get a unit close to where they used to live. In most cases, the families selected to receive a unit come from various locations in the city, often far away from the new development (Interviews 1, 5, 6, and 10). The interviewees highlight that this combining of families from different areas and backgrounds poses a challenge for creating a sense of community and mutual respect among neighbours in the new development. This lack of community awareness can manifest in many ways, including conflicts related to unit expansions and occupying public space.

To initiate a new project, two distinct possibilities have been identified. One possibility is for the city to provide the land for the new development and call for interested developers to develop a project. In this case, the land is considered as a significant part of the city's matching fund. However, the most common scenario is for the city to wait for a developer to show interest in producing housing for this income range. In this case, the developer proposes to the city where they intend to build the new development. The city's matching funds in these cases can be the commitment to build new schools in the area or other necessary public equipment. At this stage, the process only keeps going if the city authorities approve the proposed land for the new development. This may seem like an opportunity for the cities to have greater control over where developments get built, however, because the cities are dependent on having developers interested in building for this income range, they are often pressured into approving developments in inconvenient areas.

When the developer proposes to build a new development for this income range, they usually already have pre-approved unit designs for varying sizes of lots and different typologies (Taube, 2015; Interviews 1, 2, and 10). In the early stages of MCMV program CEF even made some standard unit designs available through their website. An example of these standard designs

for house unit is shown in Figure 3.2. Later, after receiving much criticism for encouraging standardization, these designs were no longer announced as being available through presentations and links on other government sites, but are still available on CEF's download section of the website. The practice of using the same unit design throughout a development and across different developments continued. Moreover, there have been no actions to encourage a different practice towards the unit design either by the program on a national level or by most cities on a local level.

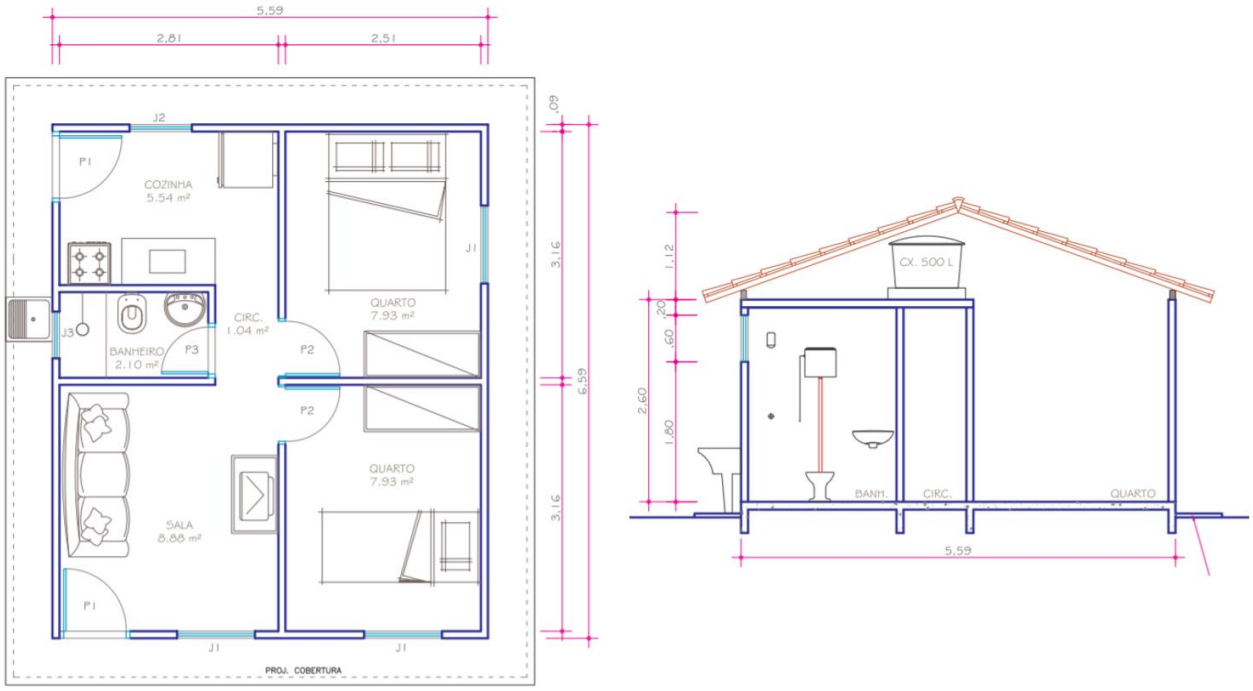

Figure 3.2 Example of house unit floor plan and section. ("Caixa Economica Federal," n.d.)

Another initial step taken by the developer is to consult CEF to determine if there is funding available for social housing developments for the chosen municipality. Furthermore, they also seek pre-approval from CEF as a capable company to build within MCMV. This involves submitting a series of documents to CEF to prove their legal standing and capabilities, as described in the previous section. As this can be a process with several barriers, it tends to benefit the large

construction companies with dedicated employees to deal with the bureaucracy and quickly circumvent possible barriers, thus, it eliminates smaller construction companies from access to these funds (Cardoso et al., 2015). However, this is also understandable when considering how the payments for the construction are made. The developer must first build the stage of the construction with their own capital, after which CEF will verify if that part is up to their standard to then pay for that part of the construction. Thus, considering the scale of these developments, a large amount of resources is needed to start the process and keep construction going.

These initial steps of the company's pre-approval, consultation of whether there is funding with CEF, and seeking approval of the proposed land with the city can be taken in varying order as they are independent of each other. However, they must all be completed before moving forward in the process. The interviews also indicated that CEF keeps a record of the developers that have previously worked within social housing programs and that CEF considers "easy to work with." CEF often contacts these developers when funds are made available by the federal government for this kind of development, thus, keeping most contracts within the same group of developers for a given region (Interviews 7, and 9).

The municipal authorities approve the area in regard to its urban characteristics and zoning within the city, determining that it would be possible and desirable, and that the city is interested in a new social housing development in that area. With this approval, the developer then has to seek approval for the proposed area by CEF, which refers more to the legal standing of the area. Once the location has been approved, the company develops the project for that area and seeks further approval from the municipal authorities. This includes infrastructure, land division project, and the selected pre-designed housing unit.

These projects are developed following the city's urban and building codes as well as state and federal regulations. However, often the developer will seek special approval for aspects of the project that do not fall within the local regulation. The arguments used to get this kind of special approval usually involve highlighting the benefits of the new development to the city and demonstrating that the development is only feasible if that aspect is approved. The benefits outlined usually refer not only to housing more people but especially the economic aspects such as creating jobs locally and increasing sales of the construction sector in the region.

The approval of the project with the city authorities often involves seeking approval of several different agencies and departments within the city such as urban and architectural, water and sewage agency, and environmental agencies. Thus, this proceeding can involve a long process of resolving interdependencies and going back and forward between the different agencies to receive all the necessary approvals and permits. However, in many cases, the city's architectural and urban department gives an initial approval for the overall project, which can be used to continue the funding process with CEF, while the approval from other agencies is still being sought or the specific plans developed. This can result in the initial project needing many updates and changes after its initial approval by the city (Interviews 2, 3, and 9).

At this point in the process, the city must also make a demand report. This report outlines the demand for public equipment and services in the area of the project. It demonstrates the capacity of the existing public infrastructure to absorb the demand that will be created by the new development. If the existing equipment and services are not enough to absorb the demand created in the area, the city must commit to build and enable the required equipment and services. This report and commitment is viewed alongside the project for approval by CEF. Despite this commitment, in many cases, the services are not enabled in the area, which leaves the families to

travel long distances to access schools and health services, among other amenities. The interviews exposed cases where the new development was very far away from the nearest school, and public transportation was not available. In some cases, parents had to choose between having the children in school or working due to the time demand to transport them (usually by bicycle) to and from school. Cases of children that dropped out of school once the family moved to the new development were also reported (Interviews 1, 4, and 5).

Once the developer has city approval, they submit the project for approval with CEF. This stage of the approval is usually not done only by the local CEF branch but also by the regional superintendence of CEF. Different from the approval from the city, CEF analyses the proposed budget for the project and if the percentages of the total funding designated to each stage of the project are within the permitted standards. Once CEF approves the project and the contract between CEF and the developer is signed, then construction can begin.

It is important to highlight that the total amount paid for the development is capped based on the number of units. Therefore, one way to maximize profits is to save as much as possible on aspects of the budget that are not determined by quantity, such as the amount designated to design development. Furthermore, having the cost of the land as part of the financing process also benefits the developer since they receive this amount from CEF at the start. Often developers negotiate to pay the previous owner in instalments over time, therefore, leaving a significant portion of the amount received for the land to be used to start construction (Interviews 2, 3, 7, and 9).

During construction, the developer submits monthly progress of construction reports in order to receive payment for each stage of the construction from CEF. Inspectors from CEF also make regular (usually not every month) site visits to confirm the progress of construction and if it is up to the standard required. Many reasons can lead to delays during construction. An example

includes an inspection determining that a particular stage of the construction is not up to the standard required, and some aspects need to be re-done. This means that the construction company will not receive the amount designated to that stage until it is re-done. Depending on the company's resources, this can mean all the rest of the construction stops until they receive that amount. There are cases in which the resources necessary to bring the construction up to the established standard was so much that led the company to bankruptcy. In these cases, construction stops for longer, until another company can be hired to finish construction, usually with an updated cost estimate, which brings up the final cost for the development. If the same company has to re-do parts of the construction, this brings down their profits since, in these cases, they do not get paid for the part that was not done up to standard, nor for demolishing it. Construction can also be delayed for other reasons that are not under the control of the company, such as public authorities requiring that construction stops to review specific permits and taking longer than usual to review them. In such cases, if the prices for construction change significantly, the company can apply to update the cost estimate. Thus, it is not uncommon for this kind of development to end up costing much more than the original budget (Interviews 2, 3, 7, and 9).

When construction is about 30% complete, the city's social housing department starts the pre-selection of the families (Taube, 2015). In this process, the city publicizes the new development location calling interested families. These families return to the social housing department to express their interest and update their registration within the federal system. At this point in the process, the social workers may use different means – such as interviews with families and visits to their current home – to make a social report. With this, the city ranks the families according to national and local criteria and selects the families to continue the process to receive a unit in the specific development. The number of families selected to continue the process is equal

to the number of units the development will have, plus 30% (Ministério das Cidades, 2013). The city sends this list of pre-selected families to CEF. The interviews indicate that pre-selecting this significantly higher number of families than units available is necessary for several reasons. It is common for families to lie to the social workers and mask their work and financial conditions. This aspect can be better evaluated by CEF later in the process, thus, eliminating several of the families the city pre-selected. Another significant reason to select more families is selection and construction taking a long time. Therefore, by the time the families are called to sign the contracts, several of them may have changed their eligibility conditions, sometimes even having moved to a different city (Interviews 2, 3, 4, and 5). These challenges in selecting the families significantly limit the chances of attributing a specific unit to each family early in the process, as would be desirable for mass customizing the initial housing units.

CEF receives the list of pre-selected families when construction is about 50% complete (Ministério das Cidades, 2013) and does their own analysis of the documentation to determine which families are eligible for financing. With this updated list of eligible families, the city informs the families that have been selected to receive a unit. At this point, the families have not yet been designated to a specific unit.

By knowing which families will live in the development, the pre-occupancy social work with the families can begin. This consists of working with the families to prepare them for formal housing and living in the new community. Most often, the families selected for a development come from different areas around the city. The social workers help them create a community association and carry out educational actions regarding things like how to deal with their garbage, how to save energy, what is acceptable or not in public spaces of the neighbourhood, among others.

Preparation and support are also given for the families to apply to other social programs, when that is the case, and things like finding and enrolling children in a new school (Interviews 4, 5, and 6).

When construction is practically finished, in some cases after it is finished, the city calls the families for the draw of units. This is a draw to establish which family will receive which unit. The updated list of families with their designated unit is then sent to CEF, who makes the individual contracts of the financing process for the families to sign. Although each family signs their contract individually, cities often wait until all the families have signed the contract to give the families the keys to their unit all on the same day in a highly publicized event.

3.3.1. Innovative technology for housing

Considering that mass customization in construction is often associated with pre-fabrication and other construction technologies considered innovative in Brazil, it is relevant to understand how such innovative technologies can be used within the context of social housing programs. Currently, the federal government considers two categories of building systems: traditional building systems, and innovative building systems. The traditional systems are commonly used in the national territory, the components of which have specific performance legislation in Brazil. These systems are usually composed of ceramic or concrete blocks and may have reinforced concrete structures. An innovative building system is any other system that is not traditional. Some technologies considered innovative in this context include light steel framing, wood framing and concrete and ceramic panels ("Desempenho Técnico para HIS," n.d.).

The construction companies can use innovative building systems in the construction of social housing units produced with federal funding. However, the company must go through the process for approval of innovative building systems called SiNAT (national system of technical evaluation of innovative products). SiNAT is part of the Brazilian program of quality and

productivity in habitat (PBPQ-H), which aims to organize the construction sector to improve the quality of habitats as well as to modernize productivity (Ministério do Desenvolvimento Regional, n.d.; Interview 8).

This system, SiNAT, works in a decentralized manner, including several institutions throughout the country that are responsible for testing new technology. Through a series of tests, the new technology must show adequacy to the national performance regulations. The performance is evaluated regarding the finished components and its compliance to minimum performance criteria in terms of structural integrity and comfort, for example. Another aspect that is evaluated during this process is how the components are made and its compliance to the national standards, including, for example, the health and safety of those involved in the fabrication. Once the evaluations are completed, the new technology receives approval through a document of technical evaluation (DATec), which is valid for two years but can be renewed if no changes are made to the technology. Likewise, even within the initial validity of the DATec, the new technology may require re-evaluation, and the DATec can be suspended (Ministêrio do Desenvolvimento Regional, 2019; Interview 8).

This process usually takes between five and nine months for the evaluation of the technology (Costa, 2015). Furthermore, this process can also be expensive for the construction company since they are responsible for all the costs with tests and the evaluation of the technology done by the local institution (Interview 8). The coordinator of SBPQ-H within the federal government highlighted that a process like this is necessary to guarantee construction quality, and that foreign technology is adequately adapted to the Brazilian conditions. However, she indicates that sometimes construction companies find a way around this system. An example of this is the extensive use of concrete panels for social housing construction. There is national legislation

regarding one specific kind of concrete panel. The existence of this legislation is used to approve social housing developments using concrete panels without going through the SiNAT process. However, the panels used are usually not the same as the one approved in the legislation, often resulting in problems such as condensation inside the rooms of the unit (Interview 8).

Considering the use of the housing units after construction, these technologies are often not understood by the populations who live in them. This can lead to misuse, lack of adequate maintenance, and difficulties with renovations (Interviews 2, and 9). Therefore, although there are systems in place to allow the use of innovative technology, it can be discouraging for the construction company, given the time and costs associated with approving such new technologies. One of the interviewees indicated having had problems with a development built with innovative technology for the lowest income range. He explained how the required maintenance was explained to the families, and the company even had an on-call employee to assist the families for several months after they moved in. Still, lack of maintenance and the many illegal, poorly built additions to the units led the development to deteriorate much faster than those built with traditional building systems (Interview 9). From a different perspective, these innovative technologies sometimes allow construction in less time with less waste, for example. These processes, when applied on a large scale, can be more profitable for the construction company making up for the initial cost and effort to approve the new technology.

3.4.Post-occupancy processes

This section shows the post-occupancy processes that happen in social housing developments of the lowest income range. It focuses mainly on the changes made to the housing units over time. However, it also addresses social work carried out with the families, either mandated by the funding agency or through other programs and non-profit organizations. Post-

occupancy studies from several developments of varying ages were used to understand how these neighbourhoods evolve over time. Furthermore, interviews with stakeholders involved in this process were a significant source of information to determine the reasons for some of the actions or lack of actions taken by the public authorities, this includes city architects, social workers, and representatives from other organizations that work in these neighbourhoods.

3.4.1. Social Assistance

Current legislation guarantees that a minimum of 2.5% of the total amount of federal funds given to any social housing project must be used for social work with the families. This social work begins before the families move into the new development, as explained in the previous section. The social work team that works within a given development is usually hired (a private company) specifically to work on that project. This team works with and is overseen by the municipal housing social work department, which is locally responsible for coordinating social actions related to housing (Ministério das Cidades, 2018a; Interviews 2, 4, 5, and 6).

The work regarding educational actions and community support, which started pre-occupancy, continues in the post-occupancy. Pre-occupancy the social workers collect the families' interest regarding which workshops they would like to have regarding activities to generate income. Once the families move in, the social workers hold regular meetings in the community and organize the workshops. These workshops are aimed at providing the inhabitants with a skill that will provide a source of income to the families. Usually, between three and six workshops are offered, depending on their cost, as part of the mandatory post-occupancy social work. Popular workshops include beauty-related skills, such as nail styling and makeup, preparation of baked items to sell, and fixing mobile phones (Interviews 2, 3, 4, 5, and 6). Some of the interviewees from the same city reported a case where they started a community vegetable

garden as part of these social work actions. However, they highlighted that this was the only case in which this kind of collective initiative in the neighbourhood worked (Interviews 2, and 4). Other cases of collective actions that were attempted and failed were also reported during the interviews. The primary perception in this regard, stemming from the interviews that addressed this aspect, is that the families have an individual approach. Thus, it is challenging to engage them in any action that depends on the community's collective efforts.

In many cases, the social workers have designated on-call days in the neighbourhood, for example, once every two weeks. During that time, the social workers either check-in by going to each unit or stay at a designated place where families can seek their support, such as the community center. The families can bring up any concerns they have, and the social workers try to articulate with the rest of the public services network to solve the problem or forward the family to the appropriate service. Concerns that emerge vary greatly and refer to many different areas, including things like having difficulties enrolling children in school, health concerns, difficulty in scheduling health exams, and wanting to enrol in other social assistance programs (Interviews 4, 5, and 6).

In some cases, the municipality was able to seek further funding for social work specifically within social housing developments, to continue the post-occupancy assistance beyond the year mandated withing the funding for the development itself. In other cases, further assistance that was specific to a housing development was offered through non-profit organizations or university outreach programs.

It is difficult to outline a sociodemographic profile of the beneficiary families, given the vast differences in situations from one city to another and even between developments within the same city. It is common to have in a development many different family arrangements, such as both parents with children, one parent with children, one parent with children plus a grandparent,

the beneficiary family plus extended family living in the same unit (two families in the same unit). It is also common to have, in the same development, families from different housing backgrounds. For example, half of the families that were removed from an informal settlement in a risk area, and the other half coming from various places in the city with different previous living arrangements.

3.4.2. Renovation processes

3.4.2.1. The need for change

This section outlines why the families feel the need to make changes to their unit in these social housing developments. It is important to highlight that the changes being considered refer to the spatial aspects. Specifically for this social housing context Brandão (2011) indicates that the following aspects frequently appear in post-occupancy studies as motivators for change: aspects related to function such as the layout and size of the rooms; the size of the housing unit; aspects related to visual and auditive privacy; aspects related to personalization and definition of territory; changes in the family such as the size of the family, economic and educational level. Thus, most reasons for making spatial changes in this context fall under the categories identified by Friedman (2002) – family transformations, fitting new technologies, and affording in stages – and, thus, are similar to other contexts. However, how these aspects appear and motivate changes to the housing units is specific to this context.

The initial size of the housing units is a crucial factor perceived by the families as needing change. In a study regarding the perceptions of the users in three different social housing developments Bonatto, Miron, and Formoso (2011) indicate the main reason for wanting to leave the development was the inadequate size of the unit. However, in the only development of house units out of the three, the possibility of expanding was seen as a positive factor. The aspect of fitting new technologies is identified often in relation to the size of the unit. This does not

necessarily mean that the technologies changed since the unit was initially built, but often, the initial unit did not consider the technologies available at the time it was built in order to minimize costs and the size of the unit. This is a common complaint by the families concerning washing machines, for example (Digiacomo, 2004; Jorge, Medvedovsky, Santos, Junges, & Silva, 2017). Although it is not a new technology, most of the social housing developments do not include a space in the unit for this equipment nor the necessary plumbing to facilitate its use. Families make similar complaints in relation to space and electrical outlets available in the kitchen.

The aspect of family transformation is also a significant motivator for spatial changes to the unit. This occurs with the normal changes to the family through time but, similar to the technologies factor, the family does not necessarily need to change for the original unit to become inadequate. In many cases, as a result of the standardization in design, the original unit already is inappropriate for the size or arrangement of the family when they first move in. In a post-occupancy study, Jorge et al. (2017) identified that 40% of the units had six or more people living in it and 30% of the units had extended family living in the same unit. Another important factor to consider regarding adapting the unit to changes in the family refers to the work conditions of the families. It is common for the family members to have informal work conditions, that is, unstable sources of income. Thus, initiating and running a small business from home is common in these developments, and even is encouraged in the workshops provided as part of the social work. This kind of activity often requires space beyond the original unit and is a significant driver of spatial changes.

Affording in stages is also an important aspect to consider in this context. While it is not a reason for the change, it significantly influences how change happens, as discussed in the next section.

3.4.2.2. How change happens

In house units, it is expected that the families will make changes and expand their unit after moving in. The possibility of an expansion even is required by current legislation (Ministério das Cidades, 2018b). Furthermore, many of the interviews done for this research with architects, engineers, and social workers, included similar statements saying that for house unit neighbourhoods, it is unavoidable that the families will expand the units even when it is not allowed. However, because the units are not built with adaptability in mind, it is even more expensive and difficult for the families to make these changes (Rufino, 2015). Most of the changes are carried out illegally by the homeowners themselves. This includes planning what to change and the construction itself.

It is common for the family to start buying construction materials in small quantities from local, often small, building materials stores and building the extension themselves, a small portion at a time. This process continues over time until all the intended expansion is complete. Thus, it is common in these developments to see partially built rooms such as the outline of the room built to only half the height, or a space with one wall and the roof, which is used as a veranda until the other walls can be built. It is also common to use temporary materials, such as plastic and plywood, as parts of the walls until they can afford a more permanent solution. Another common scenario is for the family to buy all the necessary materials over time, storing it until they have enough to build the entire intended expansion and then building it very quickly. The storage of materials is usually done in the garden or in front of the house on the street, which can contribute to losses due to weather or theft. Often neighbours, family and friends help with the construction. Hiring a resident of the neighbourhood who works with construction is also seen in some cases. Therefore,

the aspect of affording in stages does not only refer to expanding when they can afford it but also to dividing an intended expansion into stages distributed over time.

Several post-occupancy studies have demonstrated the changes that families make to their housing units in social housing developments (Brandão, 2011; Digiacomo, 2004; Jorge et al., 2017; Marroquim & Barbirato, 2007; Palermo, 2013). These studies categorize not only the changes made but also why they were made. Marroquim and Barbirato (2007) identify four main reasons associated with the changes made by the users: safety, such as building a wall and adding bars to windows; family need, such as building a pantry or new bedroom; size, such as adding or increasing the area of rooms like bedroom, bathroom, and kitchen; finishing, such as changing the windows and the wall finishes like substituting paint for ceramic tiles. In that study, the 'needs' of the family and 'size' account for similar changes, referring to spatial changes, and in some cases, appear together. These authors indicate that most changes are made due to dimensional inadequacy of the spaces to their functions and the domestic needs of the occupants. This is consistent with findings from other studies. Digiacomo (2004) indicates that for social housing, even though other kinds of changes are also present, the most pertinent kind of change are expansions. This author analyzed several social housing developments, indicating the following changes as most frequent:

- Intervention on the façade including building a wall;
- Adding a garage;
- Increasing the area of the kitchen;
- Creating or increasing the area of the laundry;
- Creating a separate space for business, studies or hobbies;
- Creating more bathrooms;
- Creating more space for storage;

- Changing the relationship between kitchen, area for meals and living room;
- Adding one more room.

These changes are consistent with those that appear in other post-occupancy studies in Brazil (Brandão, 2011; Jorge et al., 2017; A. E. F. Lacerda, Marroquim, & Andrade, 2011; Larcher, 2005; Marroquim & Barbirato, 2007; Palermo, 2013). However, some regional characteristics also appear as reasons and determining how the spatial change was made. For example, studies by both Digiacomo (2004) and Palermo (2013), carried out in the south region show a significant number of changes made to include a wood-burning stove, given the cold weather and the cultural significance of that element in some areas of the region.

An important consideration that is consistent across many post-occupancy studies refers to the order in which changes to the units are made. Changes that are made immediately after the families move in are more related to demonstrating territoriality and differentiating themselves from the neighbours. These include placing significant objects in the front of the house, planting a garden, and changing the colour of the façade. These being the first changes made is understandable given the importance of the feeling of ownership towards the unit and also the low cost involved in making them. Other changes that are often made before spatial changes in the unit are related to safety, such as building walls around the lot.

Regarding spatial changes, the studies indicate that increasing the area of the kitchen is often a priority, and usually, it involves increasing the area of the unit. Expansions of other spaces or adding other spaces to the unit appear as the second change made or the second most frequent first change. Several studies highlight the significant amount of cases in which hydraulic walls (such as the bathroom and kitchen) had to be demolished and rebuilt elsewhere making the changes more difficult and expensive than necessary and highlighting the need of carefully placing these

elements in the original unit design (Jorge et al., 2017; Marroquim & Barbirato, 2007; Palermo, 2013).

Another important consideration is the need for working at home. Several post-occupancy studies indicate that most of the units have some form of work activity carried out within the unit. This is reflected in the significant number of cases in which a room for business was added to the units. Likewise, adding a garage is very frequent in cases where it is possible to expand to the front or side of the unit. In these cases, the garage and business sharing the same space is common.

It is important to highlight that while the categories of expansions are consistent across many different developments, the solutions for the expansions (for example, where the expansion is built) vary considerably. Not only dependent on the original unit design and where there is room to expand, the solutions also vary within the same development of identical units. For example, when adding a bedroom within the same development, there are cases of the new bedroom being added to the back, detached from the original unit, and on a second floor. Furthermore, even in cases in which an expansion plan was provided, there were many cases of the families not following such a plan. Some of the reasons for this include the plan not meeting the needs of the family or for economic reasons (Larcher, 2005).

Another important aspect to consider is how long after moving in the changes are made. Several studies made up to five years after the completion of the development already show significant changes made to most units. In the Anglo neighbourhood, which was completed in two stages, four years and two years before the data collection of the post-occupancy study done by Jorge et al. (2017), 80% of the units already had changes made. Even in an older neighbourhood studied by Marroquim and Barbirato (2007), the authors show that most changes (70%) were made within the first three years after moving in. However, it is still relevant to consider that older

neighbourhoods present more expansions, and this shows that there is continual transformation of the houses over time.

3.4.2.3. Problems with changes

In most cases, the families perceive the changes as beneficial and an improvement in their living conditions. However, these changes often result in inadequate situations such as dangerous proportions of stairs, blocking off of windows, lack of ventilation and lighting, opening windows directly onto the neighbour's lot, inappropriate routing of rainwater, and encroachment onto the public space. These inadequate situations can result in negative consequences not only for the families but also for the city, such as increasing health problems and the cost to provide health care, and limiting the city authorities' access to public services such as public lighting, provision of electricity, water and sewage for example. An example of this can be seen in Figure 3.3, which shows an older neighbourhood in the city of Pelotas. Due to extensive construction onto the public space, currently public access to most of the public lighting and distribution is difficult because the electrical network posts are now inside people's houses or locked gardens. Similar situations were reported during the interviews with city workers from two different cities. In both cases, the families built expansions over the water drainage system, which resulted in frequent flooding inside the houses due to lack of maintenance to the system (Interviews 3, and 11).

Figure 3.3 Social housing neighbourhood in Pelotas, originally duplex units. (Google Maps, 2011)

Referring to self-construction in informal settlements, Estevão and Medvedovski (2017) indicate the inadequacies related to humidity as one of the main factors in which the housing environment can be problematic. Self-construction in formal social housing neighbourhoods show several of the same risk factors. Several authors highlight the lack of natural light and ventilation as a frequent problem resulting from the expansions in social housing neighbourhoods (Jorge et al., 2017; Marroquim & Barbirato, 2007; Palermo, 2013). Such a scenario aggravates health problems resulting from humidity such as respiratory and skin problems (Estevão & Medvedovski, 2017). Furthermore, it often leads to a lack of thermal comfort, which, as well as aggravating existing conditions such as hypertension (Estevão & Medvedovski, 2017), can lead to excessive use of energy to mitigate the condition.

Another factor indicated by Estevão and Medvedovski (2017) refers to situations of risk to the physical safety of the inhabitants. These authors indicate that the inappropriate proportions of stairs and the use of the area on top of ceiling slabs as a habitable extension of the house are responsible for an unimaginable number of serious accidents. These situations are also common

in self-built expansions in social housing neighbourhoods. An example of inappropriate proportions of stairs can be seen in Figure 3.4.

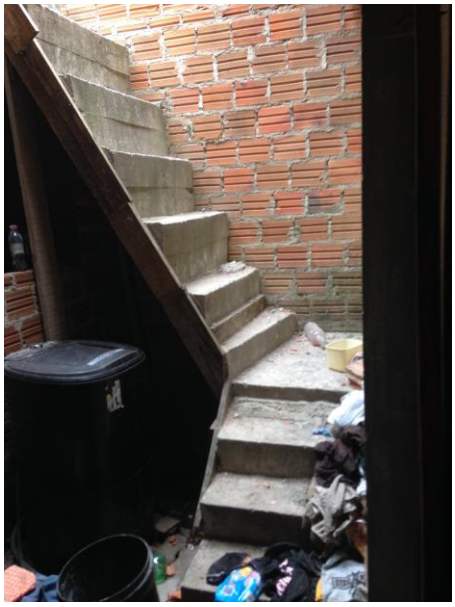

Figure 3.4 Stairs in the Anglo neighbourhood in Pelotas. Image courtesy of NAUrb-UFPel.

Although most stakeholders expect the families to make changes to their units in these neighbourhoods, most of the changes made are illegal. Furthermore, many of these changes bring problems beyond the family that lives in the unit. However, very rarely are any actions taken to support the families in making better decisions in their expansions or to discourage problematic situations. Many municipalities have in place legislation with mechanisms to allow the municipal authorities to notify, fine and in some cases, demolish illegal constructions such as those that encroach onto the public space, but these mechanisms are seldom used. Giving a notification when this kind of illegal construction is identified is the action most used; however, these are usually ignored, and no further action is taken. When questioned about this scenario, several of the stakeholders interviewed attribute it to political will. They highlighted that, as well as costs

associated to such actions, local politicians fear looking bad for allowing more severe action to be taken ‘against’ this vulnerable population.

Given the opportunity to receive assistance for these expansions, often, families will seek it. However, there are very few organizations that provide it free of charge for these families. An example of such organizations are the university outreach services called “Model Offices” (Escritórios Modelo in Portuguese), which are present in some architecture schools. There are several benefits for the families in having their houses legal within the municipality, one that is immediately perceived by the families is the possibility of being able to apply for financial assistance for further construction. The benefits which the families themselves might not see immediately, such as avoiding health issues, are equally important and in the best interest of the city as a whole.

This need to assist low-income families in design was recognized by the federal government in 2008 when specific legislation was approved stating that they should have such assistance without being charged for it. However, there are few examples of municipalities and other entities that provide such assistance. This is understandable since the costs for professionals to work individually with each family are high, and the funding is limited. Moreover, in cases where such technical assistance is available, it is usually only for families living in informal settlements and not for families of such social housing neighbourhoods. This is understandable since the latter are considered as already adequately housed, and it would not make sense to spend limited public funds twice on the same family when there are others in need. However, there are significant funds destined for social assistance specifically for these social housing neighbourhoods. Thus, if costs could be reduced from having a professional work individually with each family, it would be feasible to provide such design assistance for the expansions as part

of the initial funding for the development and other social assistance programs that take place within these neighbourhoods.

3.5. Anglo Neighbourhood

This section uses the Anglo neighbourhood to exemplify some of the specific processes that take place in social housing neighbourhoods, especially in the post-occupancy period. Furthermore, the location and limits present for this case are also used in subsequent stages of the research to demonstrate the possibilities of the proposed processes to a specific case. This neighbourhood was chosen because of the significant amount of previous studies available regarding its implementation and post-occupancy processes. Furthermore, data from post-occupancy studies detailing the changes to the units were made available to me by the research group NAUrb/UFPel (Research Centre in Architecture and Urbanism) from the Federal University of Pelotas (UFPel).

The Anglo neighbourhood is in the city of Pelotas in the southernmost state of Brazil, Rio Grande do Sul (RS). This area was occupied informally at the end of the 1990s as a result of the bankruptcy of the slaughterhouse Anglo which had existed in this area since 1914. Thus, with families occupying the land by the canal, it became an irregular precarious settlement, and many families were considered as occupying a risk area. In 2007 the contract for funding from the federal government was signed to develop this area. This was part of the program of growth acceleration PAC (Programa de Aceleração do Crescimento) of the federal government within the line of urbanization of precarious settlements (Medvedovsky, 2014). Therefore, this project started before the creation of the MCMV program and included funds for sanitation and infrastructure as well as for building 90 housing units.

The project design for this area was done very quickly by the department of housing and cooperatives (SEHAB) of the municipal government under the responsibility of two architects and a civil engineer (Medvedovsky, 2014) to respond to a call made by the federal government. There was no participation by the inhabitants of the area; SEHAB had only a list of the families that lived there (Medvedovsky, 2014). Following the initial design for the project, its execution was managed by the city's project management unit (UGP), which is a separate department within the municipal government. Medvedovsky (2014) details a timeline of the occupation of this area which I used to create a flowchart outlining the process of implementation of the Anglo neighbourhood within the social housing program from 2006 when the design was made. This flowchart can be seen in Figures 3.5 and 3.6.

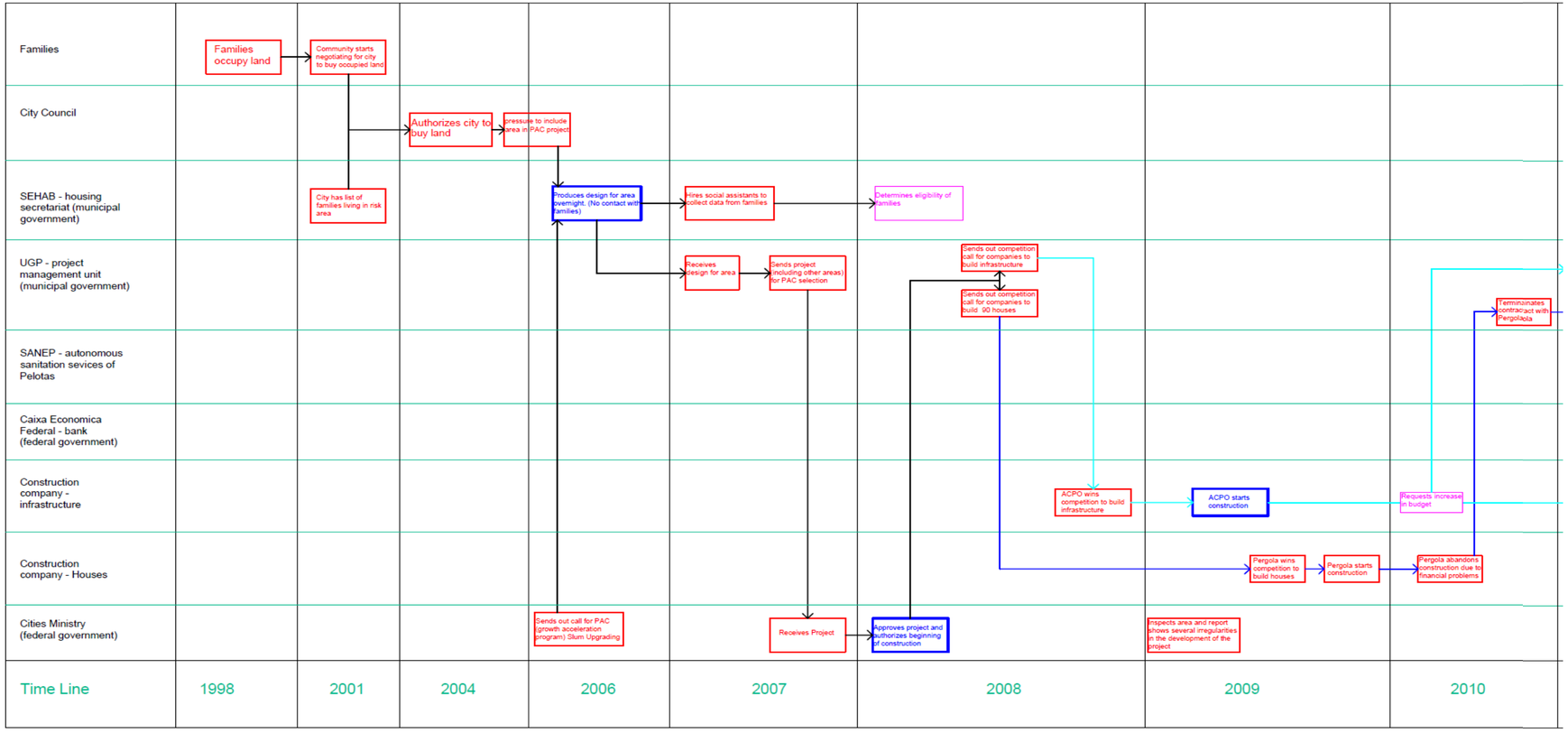

Figure 3.5 Flowchart of implementation of Anglo neighbourhood part 1

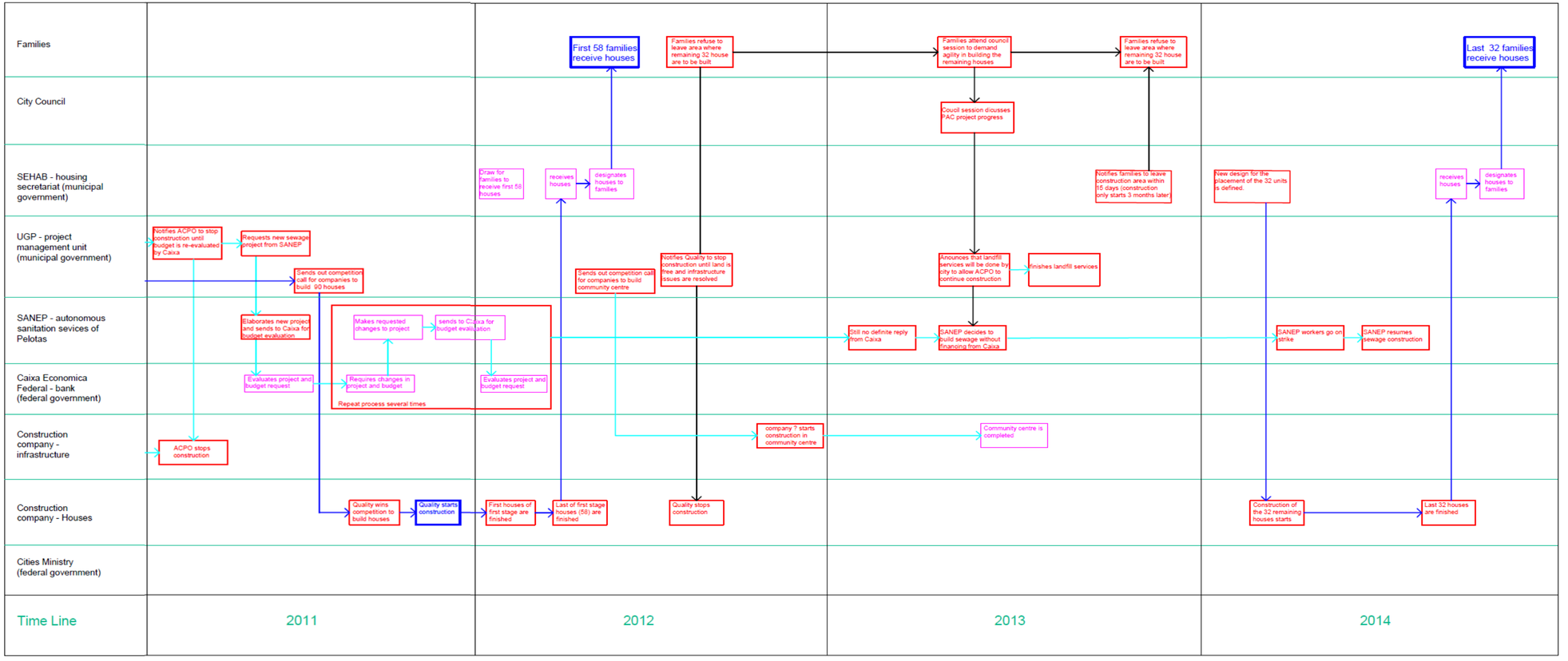

Figure 3.6 Flowchart of implementation of Anglo neighbourhood part 2

This case illustrates some of the many reasons that lead this kind of project to be delayed, such as the slow processes for decision making from some stakeholders and financial problems that can lead the developer to stop construction. This project was meant to be finished in 2009 but the first housing units were only completed in 2012 and the last 32 units only in 2014 (Medvedovsky, 2014). This situation of delayed projects is common not only in cases like this, in which the public authority is responsible for the design and management but also in cases mostly managed by private companies through the MCMV program.

It is important to highlight some of the specific aspects of the Anglo neighbourhood. First, the inhabitants of this neighbourhood were already part of a relatively organized community that was able to pressure the city to buy the land they were occupying. Thus, in this case, the families were kept where they already lived. This area is well located, being adjacent to a well-established area of the city and close to one of the federal university's campuses. It is within walking distance of the city centre, being only 1.7km from the city hall.

Regarding the implementation of the project, as shown in the flowchart, separate companies were hired for the construction of infrastructure and for the construction of the houses. Furthermore, the construction company responsible for the housing units had to be changed during the process due to the incapacity of the first company, regarding financial capabilities, to complete the job. Within the city administration, two departments were mainly involved in the process: the social housing department which was responsible for the design, selection of families and supervision of the social work with the families, and the project management unit which was responsible for managing the construction, including hiring companies.

Furthermore, SANEP (the autonomous sanitation services of Pelotas) also had a significant role in this case since the project involved significant sanitation improvements. The delays in approving further funding for sewage led this company to take charge of parts of the sanitation construction itself to make the continuity of the project feasible. However, due to their limited funding and internal processes, part of the sewage project was never built – the elevation station – and the families complain of frequent sewage smell in the neighbourhood (Medvedovsky, 2014).

Regarding the families that live in the neighbourhood, data from a post-occupancy study carried out by NAUrb/UFPel shows that 60% of the families earn up to the minimum wage as a family per month. 15% of the families earn up to half the minimum wage per month. This demonstrates that in this case, most families are on the lower end of what is considered low income. Furthermore, 12.5% of the housing units have five inhabitants, and another 40% have more than five people living in the unit (Jorge et al., 2017). The post-occupancy study was done only two years after the completion of construction, and 80% of the families had already done renovations to their unit. Of the units that had renovations, 84.8% were carried out by the members of the family, and another 6% had help from the neighbours (NAURB-UFPel, n.d.).

The housing units are of row house typology built with traditional building methods of ceramic brick load-bearing walls and some reinforced concrete elements. Figure 3.7 shows the site plan of the neighbourhood with an indication of the 90 housing units built through the social housing project. Figure 3.8 shows the floor plan of the original standard unit and its insertion in the lot, Figure 3.9 shows a section of the original standard unit, and Figure 3.10 shows the front of a unit that did not have changes made to the façade.

Figure 3.7 Site plan of Anglo neighbourhood with indication of the 90 housing units. (Medvedovsky, 2014)

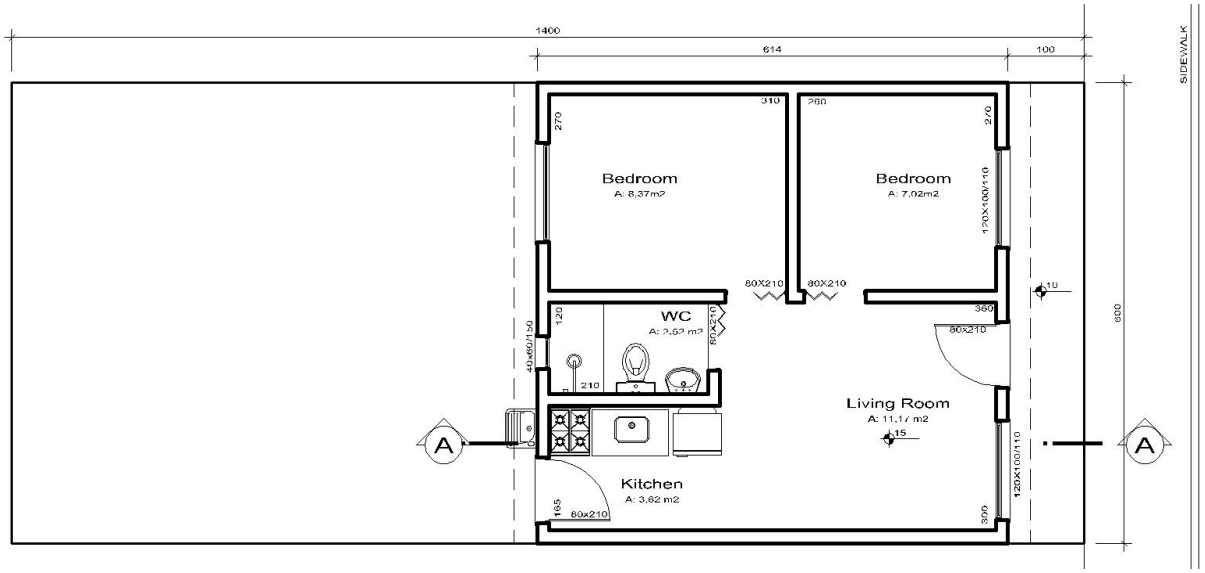

Figure 3.8 Original housing unit floor plan

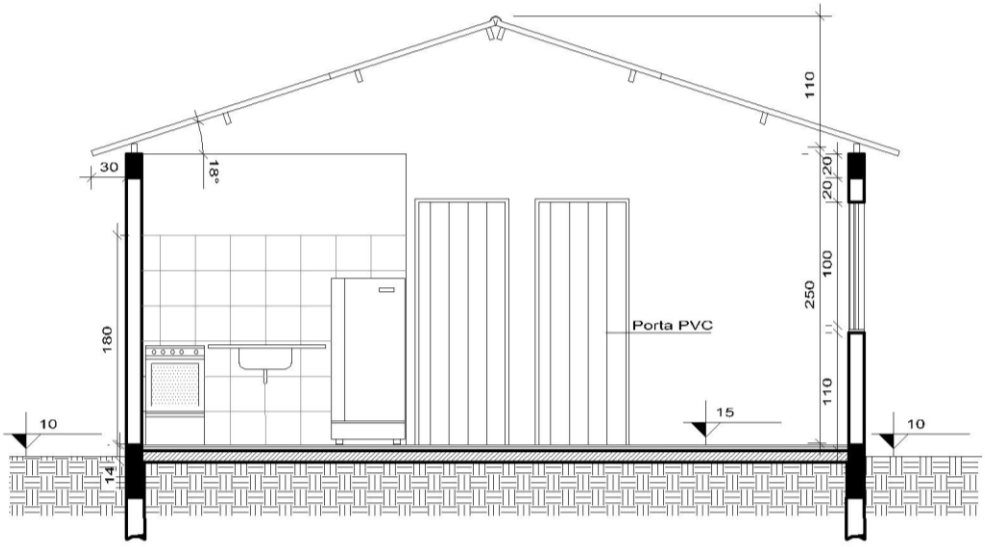

Figure 3.9 Original housing unit section

Figure 3.10 Front of housing unit without changes. Image courtesy of NAUrb-UFPel.

After construction of the houses was underway, the social housing department of the city recognized that they should have consulted the families. They acknowledged that the families do not like the row house typology (Medvedovsky, 2014). Furthermore, the original design demonstrates that no consideration was given to the possibility of future expansions of the units. This has resulted in complications in the expansions. Due to the proximity of the original house to the front limit of the lot (1m), expansions to the front, often for business purposes, encroach onto the public space, as can be seen in Figure 3.11. Furthermore, the typology and position of the windows make it difficult to expand to the front without compromising the natural light and ventilation of rooms from the original unit.

Figure 3.11 Example of expansions encroaching onto the public space. Images courtesy of NAUrb-UFPel.

Furthermore, the placement of the bathroom and kitchen within the unit made it difficult to expand the kitchen without needing to rebuild either the kitchen or the bathroom in a new place. This makes the expansions more difficult and expensive for the families. Consistent with other

post-occupancy studies, the expansion of the kitchen was done in many cases in the Anglo neighbourhood. Four examples of how this was done, including a corner house which also expanded to the side, can be seen in the floor plans in Figure 3.12 in which the colour red indicates the demolition of walls, orange indicates social areas, green indicates intimate areas, blue indicates business areas, and purple indicates service areas. It is essential to highlight that while all of these cases in Figure 3.12 show an increase in area for the kitchen combined with adding other rooms, each of them has a different solution for those changes. However, all four solutions needed to rebuild areas that required plumbing. The two cases on the right moved the bathroom to different locations on the lot, and the two cases on the left moved the kitchen either to one of the existing rooms in the house or building a new room. This variety of different solutions for the same kind of expansion is seen throughout the neighbourhood and is often associated with more than one type of change. This variety indicates that the way different families relate to space and perceive their needs are different. Thus, having only one standard solution for each type of change may not be enough to satisfy this variety of needs. For example, as seen in this case, some families were happy in maintaining a small kitchen as long as it was separate from the living room. In contrast, other families preferred a larger space that could be separate from the living room.

Figure 3.12 Examples of housing units that expanded the kitchen. Images courtesy of NAUrb-UFPel.

As can be seen on the bottom images in Figure 3.12, some expansions include areas with independent access from the original housing unit. This strategy was used in several cases, often to allow separate access to a place of business as on the bottom right image. The case of the image on the bottom left the independent access is to a place of religious gatherings. The two examples shown in Figure 3.13 created the independent access to accommodate another family. Having more than one family living in the same place is typical and in the Anglo neighbourhood it was the case in 17.5% of the houses (Jorge et al., 2017). A differentiating aspect seen in these two units was the possibility of access through the side or back. The image on the left shows a corner unit that allowed access to the side; the image on the right shows a unit adjacent to a green space on the back, which allowed access from this direction. It is important to highlight that the expansion of

the unit illustrated on the right goes beyond the limits of the lot and on to the area designated as green space of the neighbourhood. However, the green space was not developed as such and looked like leftover space, which may have induced the families to build there. Other units that had their back to this space also started occupying it, as can be seen in Figure 3.14, which shows this unit on the right and the neighbouring unit also occupying this space.

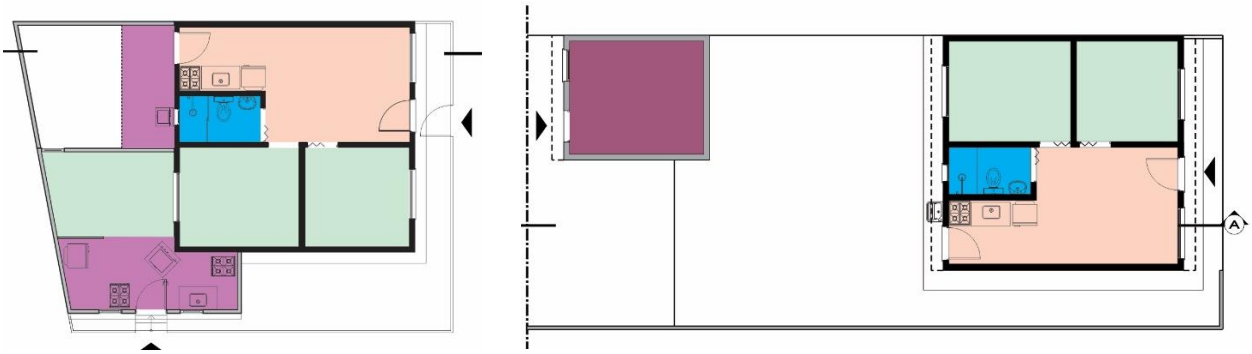

Figure 3.13 Floor plan of housing units with independent access for second family. Images courtesy of NAUrb-UFPel.

Figure 3.14 Construction encroaching onto public space. Images courtesy of NAUrb-UFPel.

In another approach, several of the housing units built a second floor. However, in this case, none of the units destroyed the roof of the original unit. All the families that built a second floor did so over an area that was itself expansion. However, in several cases, it looks like the second floor was planned from the beginning of the expansion and not that it was added later as a second expansion. This indicates that the expansions were planned in their entirety, even if the construction was done in parts. Furthermore, it shows the families' awareness of construction aspects and intent in having the expansions done in the easiest way possible, thus requiring minimal demolition from the original unit to build the second floor. This can be seen in the examples in Figure 3.15, which also shows the new bathroom and kitchen space, and Figure 3.16, in which the family uses the first floor of the expansion as a shop.

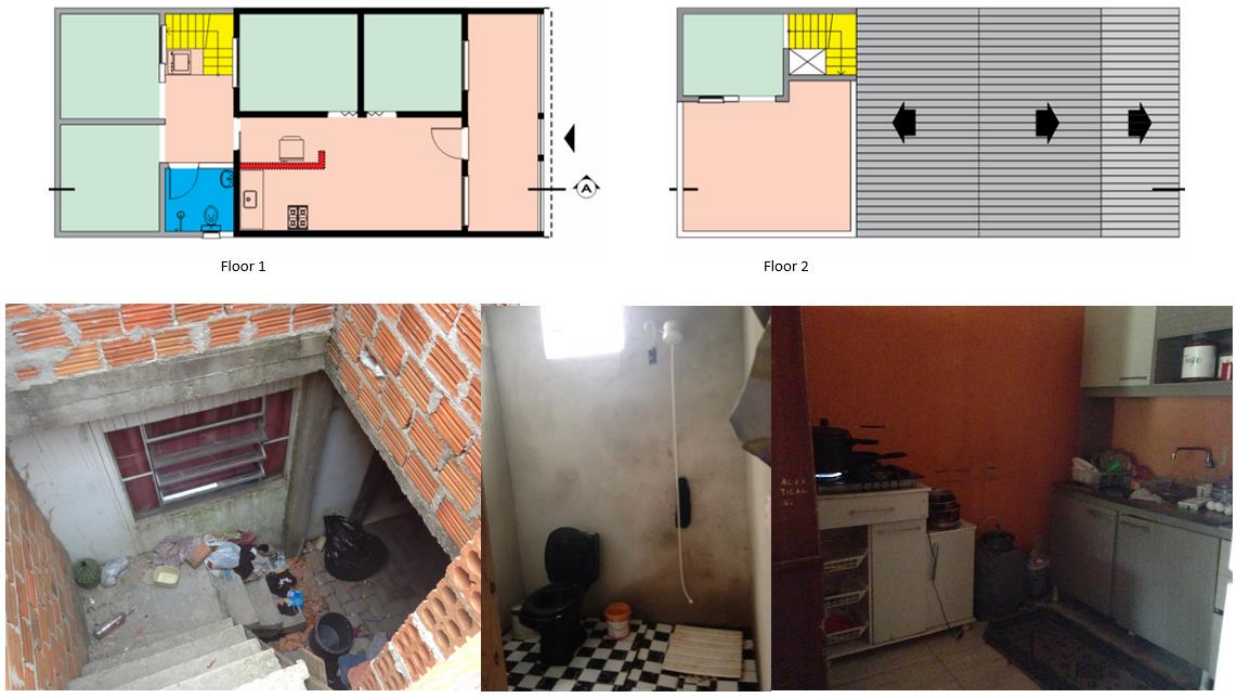

Figure 3.15 Example of housing unit with expansion on two floors. Images courtesy of NAUrb-UFPel.

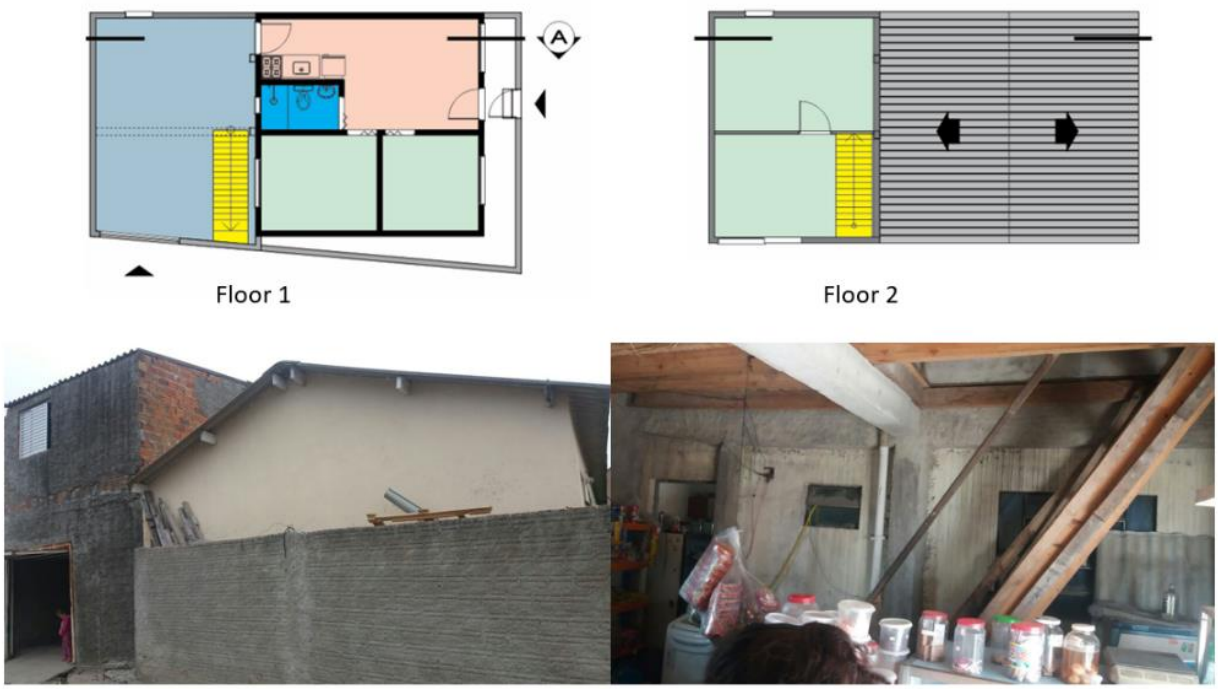

Figure 3.16 Example of housing unit with expansion on two floors. Images courtesy of NAUrb-UFPel.

Jorge et al. (2017) indicate that in some cases, the expansions reproduce the logic of precarious housing in which the families lived before, for example, building rooms or walls with temporary materials or accommodating a second family on the same lot without a bathroom. These authors highlight how these practices create a cycle that threatens the condition of a healthy environment and increases the risk of disease contamination. However, it is possible to notice that despite the families' low-income situation, many of them have invested significantly in expanding their units in a permanent way.

Finally, it is important to highlight that the changes that were made and how they were made is consistent with what is shown in post-occupancy studies in other cities and built through

different programs. Many of the challenges faced during the development of the social housing project were also similar to those reported in many other cases.

3.6. Discussion

This section discusses the implications of some of the exposed processes in conjunction with the possibilities of mass customizing the housing product. A vital consideration is how the public authorities view social housing production. Through legislation and practices, it is clear that the initial housing unit is seen as the final product. All the legislation regarding the production of social housing units refers to the process as finished once the construction of the unit is complete. The post-occupancy social work is the only thing that goes beyond the finalized construction of the initial unit, and its legislation does not consider further construction. The legislation regarding technical assistance in housing design is broad enough that it could include social housing developments, but it is not seen in practice as applicable in these cases. Pre-occupancy construction, post-occupancy renovation, and technical assistance are organized and seen as completely separate processes. Thus, one happens without any consideration of the other. However, when considering the limits of the initial production of social housing and the needs of the families over time, it becomes clear that for social housing developments, it should all be seen as part of one continuous process, including for funding purposes.

This is particularly relevant when considering mass customization for this context. Previous studies have indicated that small changes in the current process of provision of social housing could create opportunities for mass customization of the initial units (Taube & Hirota, 2017). However, when linking mass customization to provision of social housing and to the post-

occupancy processes, it is possible to indicate that customizing the initial unit may not have lasting results in terms of satisfying the families' needs and avoiding problematic situations over time.

An important consideration is that mass customizer companies usually profit by attracting more customers with customized products, gaining their fidelity, or taking advantage of their willingness to pay a premium for a custom product (Pine, 1993). These options are not available in this social housing context. The amount that the company can receive per unit is capped, and the families do not have a choice of developer. Stakeholders from different spheres of government are more interested in a higher number of units built than higher quality in design. This appears in all publicity, and even official program websites state that priority will be given to proposals that reach a higher number of families ("Caixa Habitação Urbana - Minha Casa Minha Vida," 2019). Therefore, developers still would not be motivated to mass customize, even if the added effort and cost were only marginally higher.

Furthermore, regulations around the numbers and types of rooms that the units must have, combined with the restricted floor area to keep the costs low, mean that there is very little that can be customized in terms of the families' space needs. Although these regulations are necessary to establish a minimum standard, they can be a barrier to mass customization. Investing in flexibility could be a way to allow for the families to satisfy their needs after occupancy better, while still building all equal units within the regulation. However, the way the families currently change and expand their units also leads to problems for themselves, the neighbourhood and the city. Thus, providing assistance for the families in this renovation process is necessary.

It is also important to highlight that the needs of the families change over time. Thus, having a strategy to customize the initial unit and not addressing this as a process over time could

still lead to the same problems, especially with the expansions. Therefore, it would be more feasible and have a higher potential for bringing significant benefits over time – not only for the families but also to the city and other stakeholders – if a mass customization strategy were applied with post-occupancy differentiation.

Therefore, it is also relevant to consider the current post-occupancy processes to maximize the potential of such an approach to bring benefits over time. For example, distributing the costs of construction over time and being able to self build to save even more money are important aspects to be maintained. This has direct implications regarding construction and operation aspects for the mass-customized product. For example, pre-fabricating entire rooms to be combined on-site would not be a feasible solution. Pre-fabricating panels that can be combined, allowing families to build at their own pace as well as using materials that are familiar to them, would be more feasible. The next three chapters discuss how such a mass customization approach could be implemented in this context.

Chapter 4. The Mass Customization System

4.1. Introduction

This chapter and the next two chapters discuss how mass customization approaches could be used in the lowest income range of social housing programs to improve the environments of these neighbourhoods as they evolve over time. These chapters consider the whole ecology of the system, highlighting important aspects and discussing different possibilities regarding how they could be approached and how barriers could be overcome. These chapters examine the roles of various stakeholders and their capabilities within the social housing processes as well as technical and technological aspects.

From the analysis of the social housing context in concert with the tools and approaches of mass customization, it is possible to indicate that such approaches and tools could contribute to improving the living conditions in social housing environments in Brazil. However, as shown in the discussion in chapter 3, it would be more feasible and have a higher potential for bringing significant benefits over time if the strategy were applied focusing on post-occupancy differentiation of the units.

It is relevant to emphasize that the focus of this proposed mass customization system is on the different needs of families in terms of space: how much space, how it is organized, and how it is used. Although other aspects, such as choice of surface materials and other finishes, that would not affect the spatial organization, are also acknowledged as relevant, it is the needs in terms of space that are considered most important in this context since these are the changes that need most investment and can result in problems later. Thus, it is the spatial aspect that is addressed in these

three chapters. This includes aspects that influence how the space can be changed such as the materials of the building system.

Moreover, it is important to highlight significant differences between what is being proposed for this social housing context and what is usually highlighted when discussing mass customization. The most significant difference refers to the agents who choose to mass customize. Most of the literature on mass customization, as well as how the term was first conceptualized, refers to companies as the main agents of mass customization. It is the company that provides the customized product to each client while maintaining or even increasing the company's profits. While most of the concerns, tools, and strategies that companies use are still valid in this social housing context, it would be difficult for the developer to be the main agent for mass customization. It would require significant changes not only in legislation but also to the way cities and other levels of government operate for mass customization to be profitable enough for the developers, leading them towards such a mass customization approach for the lowest income range of social housing programs. Furthermore, in most cases reported in the literature, the company is selling a product directly to a customer who knows what their needs are, which is not the case in this context since the end user is not known before completing construction. In this case, other stakeholders are considered as possible main agents in the mass customization process, especially the local authorities. Therefore, the proposed processes are not seen as a business strategy for bringing profit to the agent that provides mass customization.

The framework for mass customization, first outlined by Salvador et al. (2009) and further explained by Piller and Wang (2017) and by Piller (2019), is used to organize the different aspects to be considered for the mass customization system in this social housing context. This framework

proposes three main capabilities for mass customization: solution space development, robust process design, and choice navigation. The following sections of this chapter refer to solution space development and the following two chapters address process and choice navigation. In each of the chapters, I make overall considerations and recommendations, which can be applied to future social housing developments in this context. To demonstrate possible solutions for a specific development, I present a counterfactual example using the real context of the Anglo neighbourhood. The example demonstrates how the mass customization system could have been applied in that case, but considering current legislation and stakeholder capabilities. Feedback about all parts of the mass customization system, received through interviews, is discussed at the end of Chapter 6.

4.2. Solution space development

Compared to the way that families currently change their units, one of the main advantages of a post-occupancy mass customization approach is that there would be an established 'solution space' for the housing product. Solution space development refers to identifying the attributes of the product on which the customers diverge most in terms of choice, and defining what the company will offer, the solution space (Piller, 2019). In this case, this development must identify what types of changes the families make to their units, and outline what can and what cannot be built to avoid the problematic changes.

To identify the divergent needs customers have for a product, Piller (2019) suggests different forms of formal market research or "following one's own need" (p. 33). In this social housing context, post-occupancy studies carried out in such neighbourhoods have identified the spatial changes that families make to their units. Furthermore, most post-occupancy studies also

identify the rationale families have for making the changes that they do. These studies are a valuable source not only for understanding the needs of the families but also what kind of spaces these people understand as satisfying those needs. Thus, it is possible to propose a solution space based on the needs and divergences identified through post-occupancy studies.

Additionally, post-occupancy studies show that in most cases, the changes expanded the total area of the house or added elements outside the initial unit, such as walls. Very few units had only changed the space internally. However, expansions affect the spatial organization of the original unit. For example, if a wall is destroyed to expand the kitchen, the original space of the kitchen is also changed, not only the added portion. Therefore, the focus of the solution space should be on adding built area to the unit. Still, for validating the new design solutions as appropriate, the unit as a whole should be considered, not only the new portion.

This section is divided into two main sub-sections to organize the different aspects to be considered for the solution space. First, the section 'initial unit' outlines the aspects to be considered in the development of the initial unit to facilitate changes in the future and the success of the strategy. It shows relevant considerations regarding different aspects (unit design, typology, and building system) of the initial unit, which are shown in further sub-divisions of the section. Then, the second sub-section, 'expansions,' shows the relevant aspects that should be part of the solution space regarding the expansions, and what will be offered for the differentiation of the units.

4.2.1. Initial unit

For the development of the initial unit, it is necessary to consider the current post-occupancy processes in order to maximize the potential of the strategy to bring benefits to the

social housing neighbourhoods over time. If any proposed strategy implies significantly changing the way the families currently build, they may not be willing to comply with those changes. Similarly, considering it is the low-income range of the population, attention must be given to how they can afford the changes they make to the units. In many cases, families distribute costs and construction over time. Distributing the costs and being able to self build are essential aspects to be maintained. How the families currently build and how they afford what they build are considerations that have direct implications in what is possible for future expansions. These possibilities for the expansions directly affect what is needed from the initial unit to facilitate those changes. Thus, this section considers several aspects of the initial unit as it affects how differentiation can occur post-occupancy.

4.2.1.1. Unit design

An important objective for the initial unit is to make it as flexible as possible to facilitate future changes. A vital recommendation present in both post-occupancy studies and guidelines for flexibility (Brandão, 2011; Jorge et al., 2017; Palermo, 2013) is the strategic positioning of wet areas such as kitchen and bathroom. Because bathroom and kitchen are rooms that include plumbing and sewage and have regulations around the types of finishes they must include, these areas are usually more expensive to build than other rooms, such as bedrooms. Furthermore, these areas require more construction knowledge and skill to ensure they work properly. Therefore, the designer needs to strategically place these areas so that they do not need to be destroyed and rebuilt in future expansions. Post-occupancy studies show that families often destroy these areas if they are in the way of the expansions and that how the families rebuild them often results in inappropriate situations. While the strategic positioning of the wet areas is considered as especially

important, it is recommended to incorporate as much as possible the guidelines for flexibility proposed by Brandão (2011), shown in chapter 2. The following sections make specific considerations regarding the choice of building system and typology for the initial unit; further discussion regarding how more flexibility could be facilitated within the programs is shown in the next chapter.

Another aspect that should be considered refers to regional culture and habits that may affect the way the home is organized, and the space used. An example of this regional aspect appears in the post-occupancy studies described by Palermo (2013), carried out in different regions of the state of Santa Catarina. In one neighbourhood, 100% of the units had installed a wood-burning stove in the kitchen, as is the norm for that cold region. Furthermore, it is more common in that region for the kitchen to be the heart of the house where family members spend most of their time. This placement is different from other regions (including some which also have cold weather) that use the living room as the main area in the house. While it may be difficult to accommodate some cultural aspects within the regulations of the program, knowing how the space will be used with respect to the regional culture and needs could indicate how the unit will be changed and, therefore, facilitate incorporating these aspects in the initial unit design.

4.2.1.2. Typology

The choice of typology for the initial unit must take into account the possibilities to facilitate future expansions by considering where these expansions will be possible. This choice has direct consequences for the post-occupancy differentiation possibilities and, therefore, on other aspects of the solution space for the mass customization strategy. The considerations for choice of typology are directly linked to making space available on the lot for expansions. In this regard, we

should consider two main aspects alongside the choice of typology: placement of the unit within the lot, and which flexibility strategies will be prioritized. These considerations assume that the size and proportion of the lot itself were previously established and cannot be changed.

Where the unit is placed on the lot directly influences the most likely scenarios for expansions and potential problems associated with them. For example, families often need a space in the front of the house for business; if this space is not left on the lot (either in front of the initial unit or on the side aligned with the front), it is more likely that the expansions will encroach on the public space. Therefore, the choice of typology should consider the most frequent changes (shown in chapter 3) and predict where the families are likely to expand for those scenarios. This will give an indication of appropriate combinations of typology and placement on the lot that are likely to allow those expansions with appropriate solutions within the lot. For example, if the lots are narrow and require row-houses, then it would be desirable to place the units further back, leaving space to expand to the front as well as to the back. If the lots are slightly broader, it may be an option to consider semi-detached houses possibly on two floors to leave further space for expansions to the side.

The choice of which flexibility guidelines to prioritize will influence the choice of typology. Similarly, the choice of typology influences what guidelines should be prioritized. In this regard, Palermo (2013) indicates that semi-detached typology is the best option for these social housing developments. This solution balances saving urban soil with freeing space on the lot for expansions. Furthermore, it does not add living expenses for the families, such as condominium, as is usually the case in multi-family developments. Therefore, this typology is considered as ideal.

To allow this typology, an initial flexibility guideline that should be followed refers to adopting a broader front for individual lots, however, it is not always possible.

In the case of narrower lots, row-houses may be a more feasible typology. In this case, it would be more difficult to make significant expansions without compromising natural light and ventilation of the original unit. Thus, preparing the structure to receive another floor gains importance to allow appropriate solutions for the expansions, but it could increase the costs for building the initial unit. If preparing the structure to receive a second floor is recommended, it may be a better option to build the initial unit on two floors as the reinforced structure would cover less area than if it were a single floor. Similarly, the initial expenses with the roof could also be smaller. Moreover, the space left on the lot would be larger, making it feasible for the families to expand initially on the ground. For example, it may be a better option, for the same lot, to have two-floor semi-detached houses than single floor row-houses. There would still be added costs in this case, especially related to building the staircase itself. However, this could also prevent future problems since the inappropriate construction of stairs was identified as one of the significant problems with the self-built expansions.

Therefore, the choice of typology should prioritize leaving as much space as possible ready to receive expansions, either vertically or horizontally. In this regard, typology should be considered along with other aspects of the initial unit (such as flexibility strategies, dimensions of the lot, and placement of the unit within it) to balance what is possible in terms of budget with leaving as much space as possible for expansions.

4.2.1.3. Building system

The choice of building system for the initial unit affects not only how flexible it is but also the strategy for post-occupancy differentiation, depending on its compatibility with other systems. In this regard, I make some considerations regarding both traditional and innovative building systems.

Although pre-fabrication has been considered in previous studies as an important enabler of mass customization in housing, it implies the use of building systems considered innovative in Brazil and which may not be the best option for this specific social housing context. Depending on the system used, it may make expansions more difficult and expensive for the families, as is the case with concrete panels and concrete and ceramic panels. Where the prefabrication will occur is also a relevant aspect to consider. Costs with labour and transportation could also significantly increase the price of prefabricated elements for the families. Furthermore, going through the process to approve innovative technologies could also delay and further increase the costs. Prefabricated solutions might become more feasible if these innovative building systems become more popular in Brazil. Furthermore, the families must be able to buy the materials a little at a time and to self-build. Thus, some prefabricated systems would not be compatible with the system that will be used for the expansions. The initial unit should, whenever possible, be built using the same system that will be used for the expansions.

In some cases, it may be feasible to use pre-fabrication in the original unit, even if it will not be used in the post-occupancy. For example, depending on the design of the initial unit, new rooms could be added without needing to break existing walls. This would allow the initial unit to be built using concrete walls, for example, and the expansions to be made with a traditional

building system. However, this approach would significantly limit the expansions because of the limited number of extra openings that can be included in the initial unit.

The use of prefabricated panels, such as wood-frame panels, would be a more feasible solution to allow both the initial unit and expansions to be built using pre-fabrication. In this case, the panels for the expansion would have to be light enough to enable the families to self-build. However, this may still limit the families' capability to buy the materials for construction. Currently, they often buy one component at a time until they have all that is needed. With a prefabricated panel, they would have to pay for all the components that go into fabricating the panel at once. If these panels could be small and cheap enough to allow the families to buy only a few at a time, this solution would be more feasible. However, it is also relevant to consider that many of the families may not feel comfortable building with an unfamiliar system. This could lead the families to reject the mass customization strategy altogether, opting to build in their own way.

Therefore, when choosing the building system for the initial unit, it is important to allow for the expansions to be built with a system that is as familiar as possible to the families. In this regard, the possibilities may differ depending on the cultural aspects of each region. For example, in the west of Santa Catarina, wooden houses are just as common as brick houses. The tradition of building wooden houses can be traced back to when the region was colonized, and it remains a common choice, especially for low budget house construction. Thus, it is normal for the families in this region to know how to build wooden houses and enjoy living in them, even though they often do not achieve the standards of comfort required by social housing programs. It is more likely that families would be willing to live in and make the expansions using prefabricated wood-frame panels in this region than in a region where wood-frame construction is not as widely accepted.

The use of traditional building systems could also be a feasible solution. In her studies, Rocha (2011) demonstrates some possibilities for improving mass customization strategies while still using traditional building systems. The possibility of using traditional building systems has a higher chance of being immediately accepted by the families since the current practice of acquiring materials over time and self-building could be maintained. Similarly, it would not require them to learn a new way of building.

4.2.2. Expansions

Depending on the initial unit, different solutions will be possible for the expansions. This section considers what should be prioritized for the expansions and how much diversity should be made available. The recommendations made in this section are based on the priorities the families demonstrate when changing their units and how they make these changes, as shown in the post-occupancy studies discussed in chapter 3. Two main aspects are considered: the type of expansion, and where the expansion can occur relative to the initial unit. Furthermore, this section also considers how the different options for changes can be presented to the users.

Regarding the type of change, the possibilities for expansions should include:

- Expand kitchen;
- Separate kitchen from living room or join kitchen and living room;
- Add room (bedroom, room for business, room for hobbies);
- Add garage;
- Add/expand laundry area;
- Add second bathroom.

For each of these options, the family should be able to choose where to expand relative to the initial unit. Depending on the space available on the lot these options can include to the front, back or side of the initial unit, detached from the initial unit (at the back of the lot for example), or on another floor. An option for independent access to the expansion should also be available, if possible, since this requirement is often seen in post-occupancy studies, especially when the expansion is for a space of business or to accommodate another family on the lot. Furthermore, there should be an option to change the organization of the initial unit along with the expansions as this also frequently appears in post-occupancy studies. For example, when a bedroom is added, two smaller bedrooms from the original unit may be combined to create a larger one.

To present the possibilities to the families, I propose that a solution for each of the combinations possible for the site should be made available in the form of a pre-defined design. Furthermore, there should be an option to allow more than one expansion at the same time, for example adding two rooms at the back or expanding the kitchen to the back and adding a room at the front. This would allow the families to visualize a complete solution after selecting only a few options regarding their needs, such as what type of room they need and where they plan to build it. It is also essential to allow some freedom to modify the pre-defined designs regarding the exact size and position of rooms and openings. This is necessary not only to achieve a better fit to the family's spatial needs but also as it impacts the cost of building the changes.

I argue that presenting the range of solutions in a parametric manner, in which the family can manipulate the design within previously defined ranges, is ideal to allow such freedom for the changes while maintaining the solutions within the acceptable parameters. With such approach, for each parameter minimum and maximum values are established and the solution to be built can

be somewhere in between. For example, if the length of a new room can have a minimum of 2.5m and a maximum of 4m, the family could choose to have their room with 2.8m of length depending on their need and budget. The establishment of these constraints should be based on the city's urban and building code parameters, and further restricted by the parameters of the building system and design. For example, if prefabricated panels are being used for the expansions, the available sizes of panels, and how they can be combined, will limit the choice of length in the previous example to increments of that particular panel. If the new room is under the slope of the roof its length will be limited by the roof reaching the minimum height at the end of the room.

Windows can also have options for different sizes and proportions but, similar to the size and position of the room itself, the possibilities will be governed by the city's urban and building code and the parameters of the building system. Therefore, compiling the code and constructional parameters is a relevant part of solution space development. An example of how the urban and building code parameters can be compiled, as well as an example of design solutions, can be seen in the following section.

4.3.Anglo Example

Through a counterfactual design exercise, this section demonstrates how the aspects discussed in this chapter could be applied to the Anglo neighbourhood in Pelotas. It considers the neighbourhood's specific location, neighbourhood layout, lot size, the city's regulations, and the specific processes adopted in this city. However, it also incorporates recommendations made in the previous sections as if the development were being built new. Therefore, when considering different ways in which the development could have been implemented, the current legislation and

programs are taken as a starting point for what is or is not possible. Furthermore, the current capabilities of the stakeholders are considered.

It is important to note that certain aspects of the solution space can encompass more than just one development to avoid having to develop a completely new solution space for each neighbourhood. However, the specific parameters that refer to the location still must be input for each development. For example, the parameters from Table 4 and Table 5 can be used for several developments, however, if the numeric values permitted in other places are different, then those values would be changed. If the same unit design is used across different developments, the pre-defined solutions of changes can also be maintained. Table 4 and Table 5 show the compilation of current parameters from the local urban legislation and building code for the location of the Anglo neighbourhood. Any intended changes to the housing units need to be validated for these parameters. No changes should be allowed to elements identified as structure.

Table 4 Parameters per type of room.

Parameters for Validation per Room Type					
Room type		**Area**	**Height**	**ventilation and lighting (windows)**	
Living spaces (e.g. living room, bedroom, work space)	bedroom	minimum area for first bedroom - 8m^2 all other bedrooms minimum area - 6m^2	minimum 2.4m	Must have windows directly to outside; Minimum area of window = 1/6 area of room.	all windows used for lighting and ventilation must be at least 1m away from any wall it faces, 1.5m away if facing a wall belonging to another unit (must be 1.5m away from division line of lot on sides and back)
	other				
	kitchen	minimum area - 5m^2; area must allow the insertion of a circle of diametre 1.5m.			
Transient spaces	Corridors	minimum width of 0.9m.	minimum 2.2m		
	bathroom	Minimum area= 2.3m^2. If lavatory is external, minimum area = 1.8m^2.Must allow the insertion of a circle of diametre 1.1m. Must have free circulation space with width of at least 0.6m; Minimum shower space must allow the insertion of a circle of diametre 0.8m.		Minimum area of window = 1/8 area of room. Can have window opening to another compartment in which case that room must include this area in the calculation of its window.	
	others				

Table 5 Additional parameters.

Other Parameters for Valitation			
Stairs	minimum width= 1m	minimum ceiling height at every step = 2m	Formula for dimension of steps: 2h + b = 0,63 to 0,64m; h=height of step; b=depth of step; maximum h=0.18m; minimum b=0.27m.
Walls	Mininmum height = 1.8m	maximum height = 3m	walls to the street (front of lot) must have 70% permeability beyond the height of 1m.
General	nothing can be built past the limits of the lot.	maximum height of building = 10m	

In order to incorporate many of the recommendations made in the previous sections it was necessary to re-design the initial unit since it was not up to the current standards of the federal housing programs or the city's regulations, which were both updated since 2006, when the Anglo development was approved. Two options for the proposed initial unit are shown below. The first one consists of two-story semi-detached units. It is an option that considers more of the recommendations, leaving more available space on the lot and having stairs included in initial construction. However, this option would be more expensive to build initially, and thus may be less feasible under the current federal programs. The second option sought to balance, as much as possible, the need to facilitate expansions while not costing more for initial construction. It consists of single-story semi-detached units. Considering the availability of labour, factories, and regional culture, a traditional building system was chosen for both cases, composed of concrete structure with brick infill. Both options allow several combinations of type and location of expansion.

4.3.1. Option 1

With this house unit all the expansion possibilities indicated in section 4.2.2 are possible and should have pre-defined designs available to the user as previously explained. The possibility

of combining two or more of these solutions should also be available. All the combinations shown in Table 6 are possible. Some examples of combinations are shown in Figure 4.3 to Figure 4.7. For this option, adding a room on the second floor is only available when combined with expanding on the ground floor.

Table 6 Pre-defined combinations of changes – option 1.

Type of Change:	Can be combined with:								
	Separate kitchen from living room	Expand living room to side	Expand kitchen to back	Expand kitchen to side	Add laundry room	Add room to front	Add room to back (can include extra bathroom)	Add garage	Add room on second floor
Separate kitchen from living room									
Expand living room to side									
Expand kitchen to back									
Expand kitchen to side									
Add laundry room									
Add room to front									
Add room to back (can include extra bathroom)									
Add garage									
Add room on second floor									

Possible combination

Combination possible, can include independent access to one of the rooms.

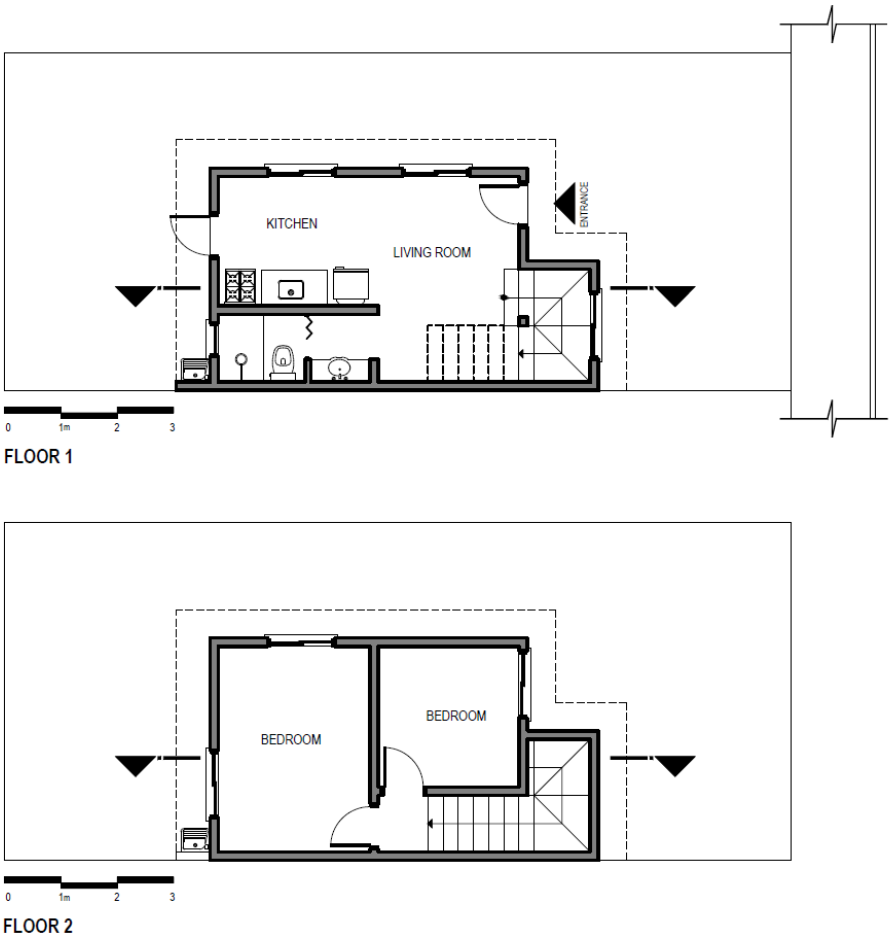

Figure 4.1 Floor plans inserted on the lot – option 1.

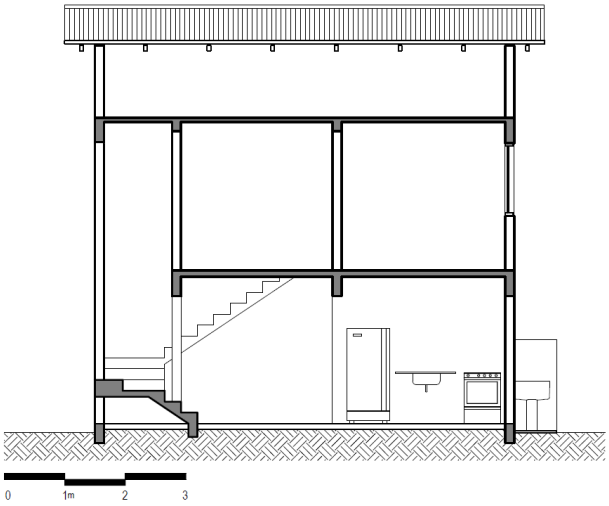

Figure 4.2 Section – option 1.

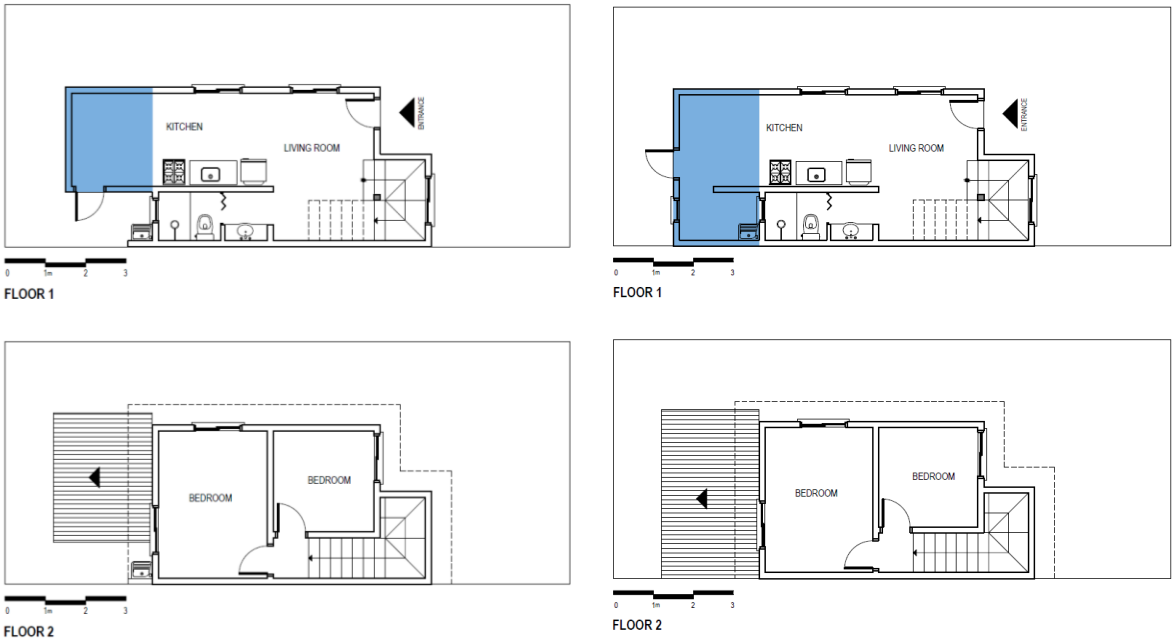

Figure 4.3 Expand kitchen to back (left) + add laundry (right)

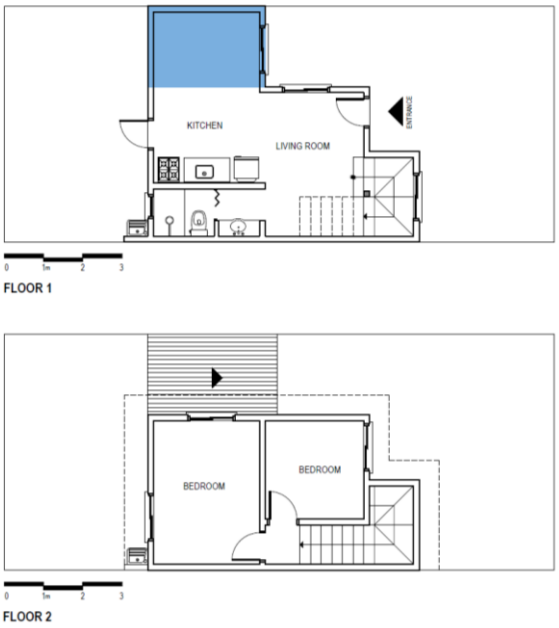

Figure 4.4 Expand kitchen to side (left).

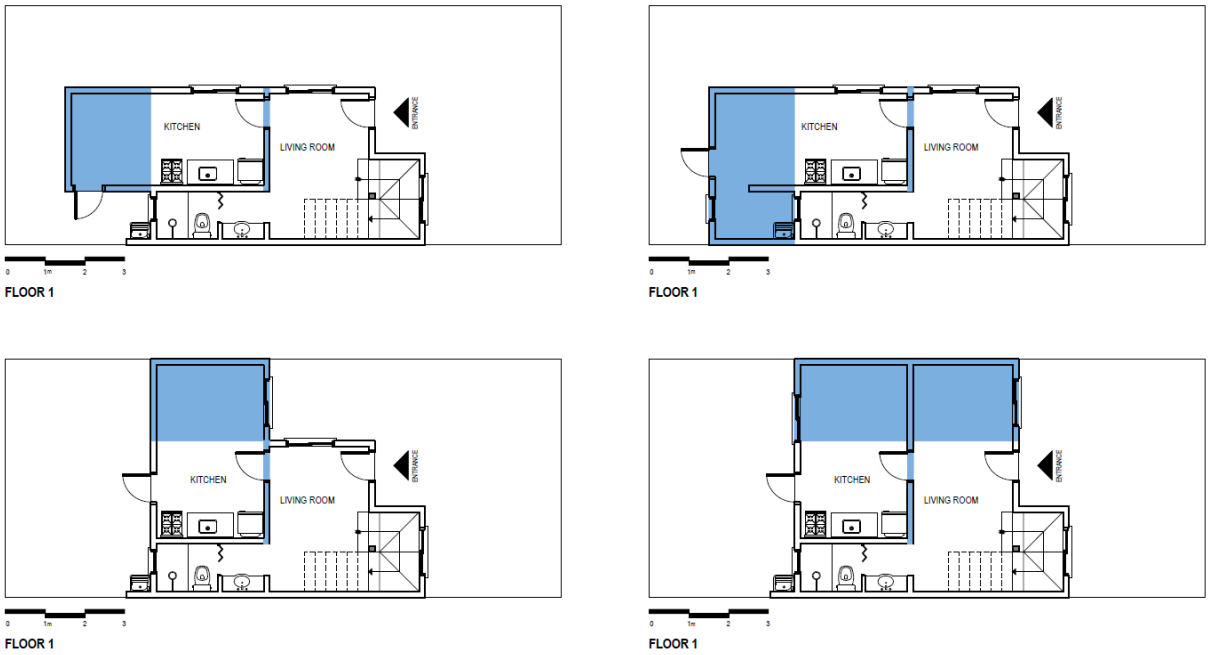

Figure 4.5 Expand kitchen and separate from living room (left) + add laundry (top right) or expand living room (bottom right).

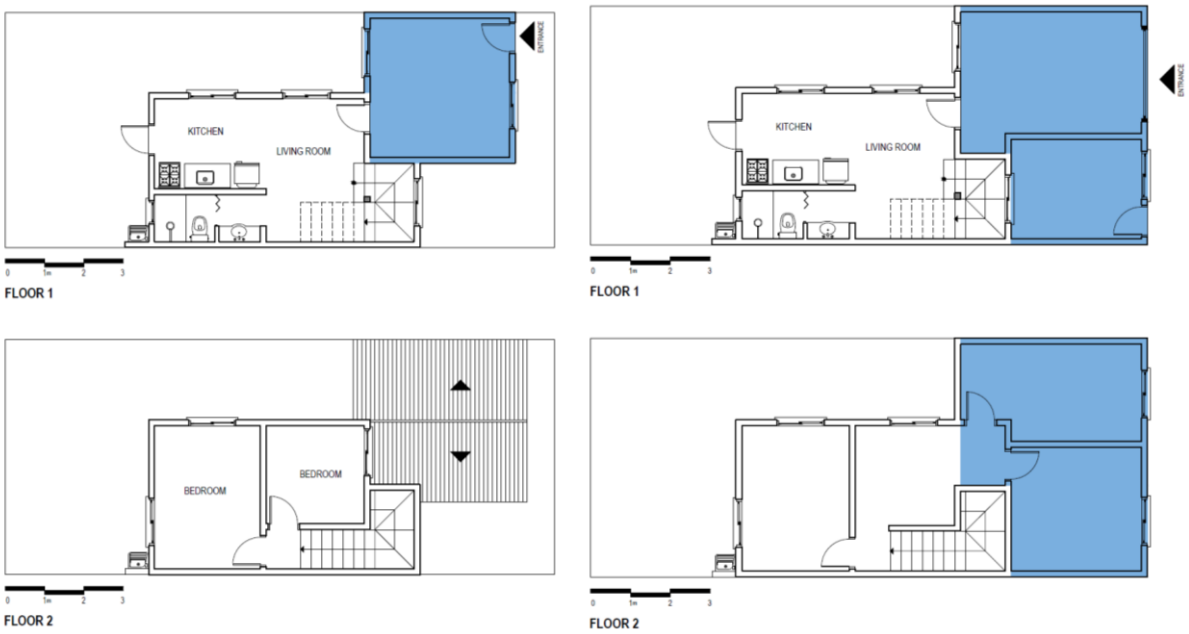

Figure 4.6 Add room to front (left) + add garage + add rooms to second floor (right).

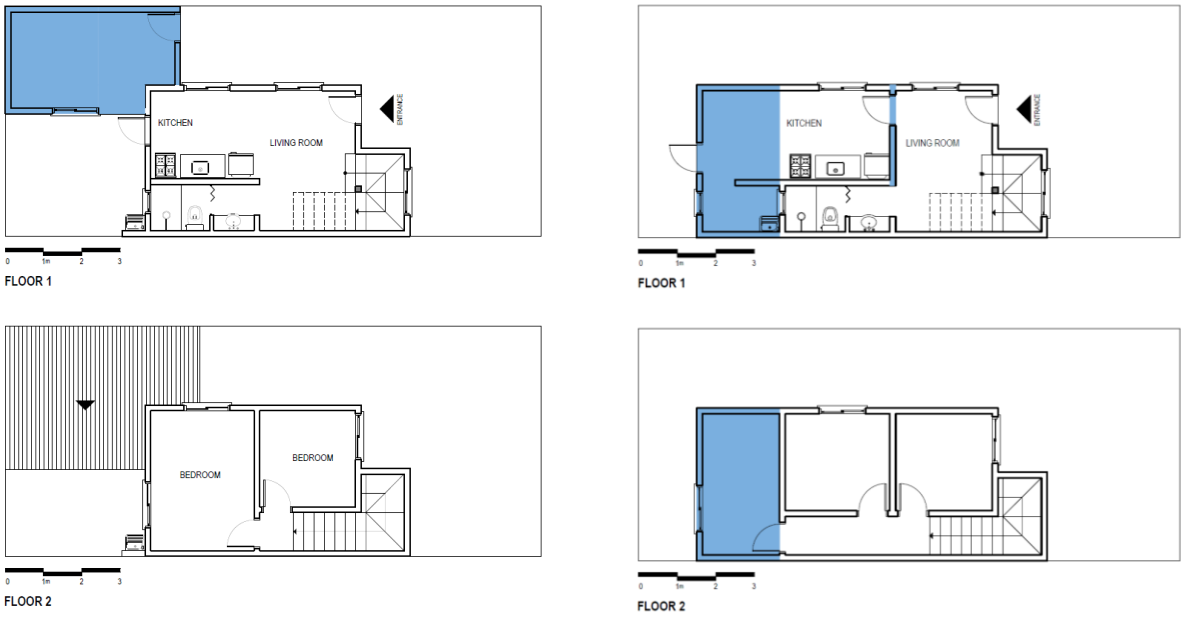

Figure 4.7 Add room to back (left); expand kitchen to back + add laundry + add room on second floor (right).

4.3.2. Option 2

This option for the initial unit allows most of the changes indicated in section 4.2.2 to be made with adding a garage being the only one not possible. It consists of single-story semi-detached units. All the combinations of changes shown in Table 7 are possible and should be available as pre-defined solutions. Figure 4.10 to Figure 4.16 show the individual pre-defined solutions and Figure 4.17 and Figure 4.18 show some of the combinations of these solutions. For this option, separating the kitchen from the living room is only possible when the kitchen/living room is expanded.

Table 7. Pre-defined combinations of changes – option 2.

Type of Change:	Can be combined with:							
	Separate kitchen from living room	Expand kitchen/living room to front	Expand kitchen/living room to side	Expand kitchen/living room to front and side side	Add room to front	Add room to back (can include extra bathroom)	Add laundry room	Add second floor (can include extra bathroom)
Separate kitchen from living room								
Expand kitchen/living room to front								
Expand kitchen/living room to side								
Expand kitchen/living room to front and side side								
Add room to front								
Add room to back (can include extra bathroom)								
Add laundry room								
Add second floor (can include extra bathroom)								

Combination possible.

Combination possible, can include independent access to one of the rooms.

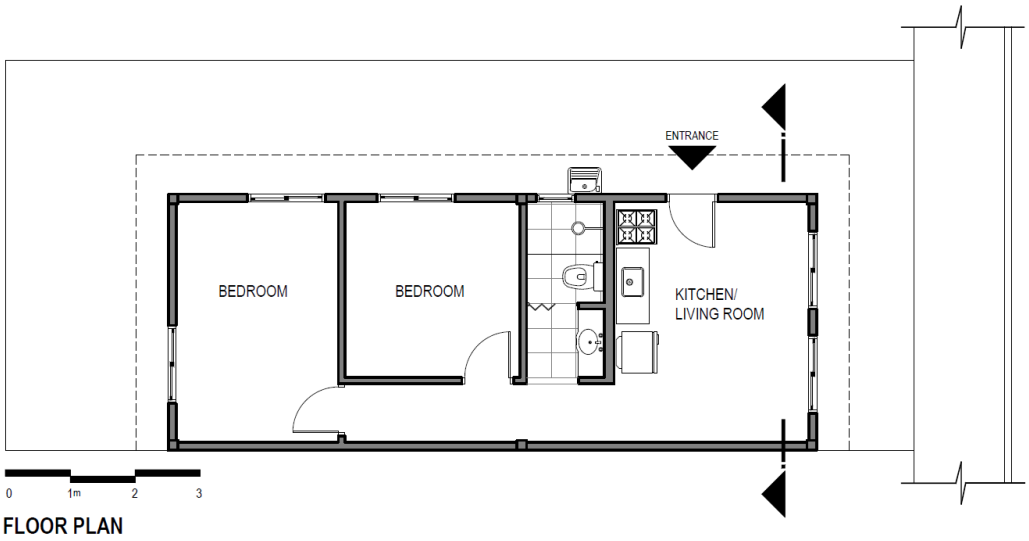

Figure 4.8 Floor plan inserted in the lot – option 2.

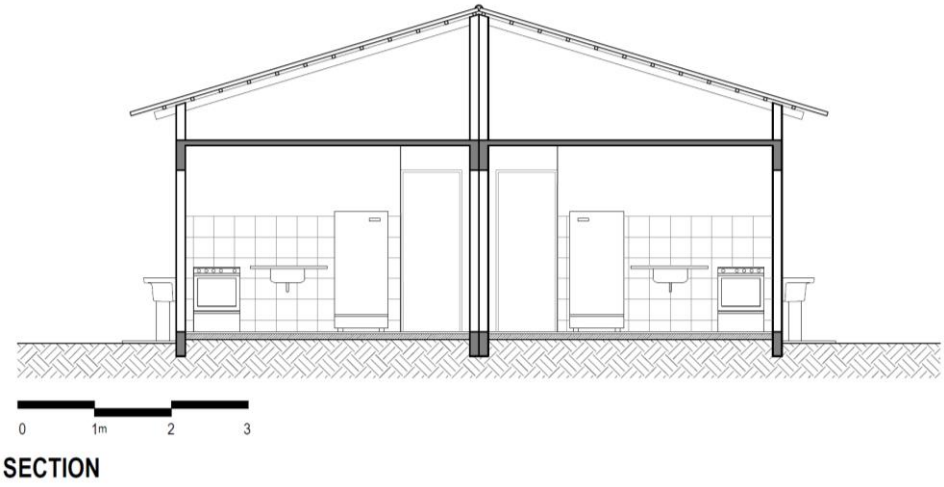

Figure 4.9 Section of two units – option 2.

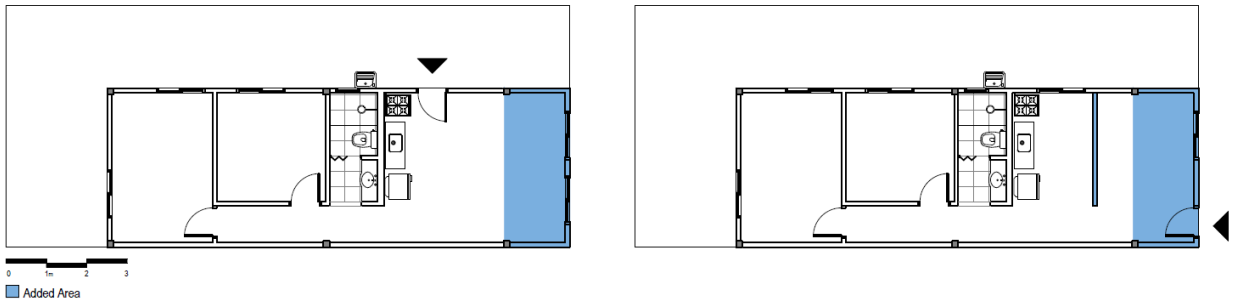

Figure 4.10 Expand kitchen/living room to front (left) + separate kitchen from living room (right).

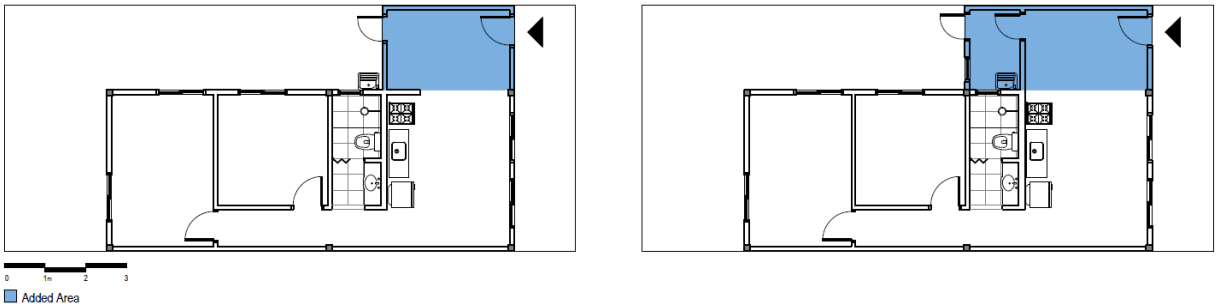

Figure 4.11 Expand kitchen/living room to side (left) + add laundry (right).

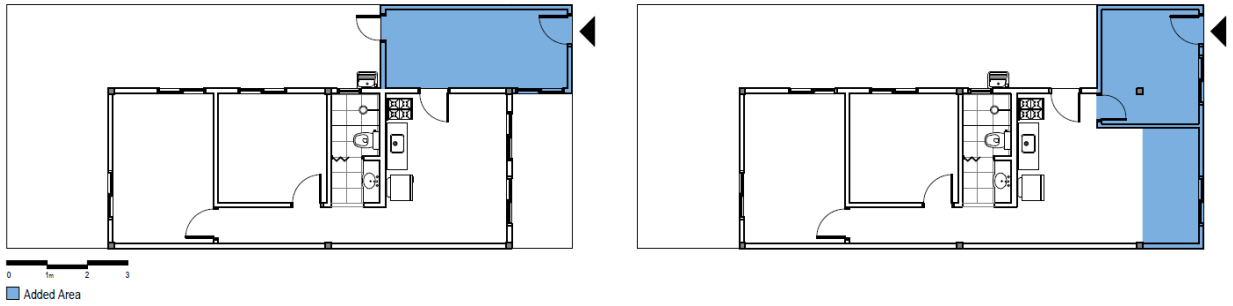

Figure 4.12 Add room to front (left) + expand kitchen/living room to front (right).

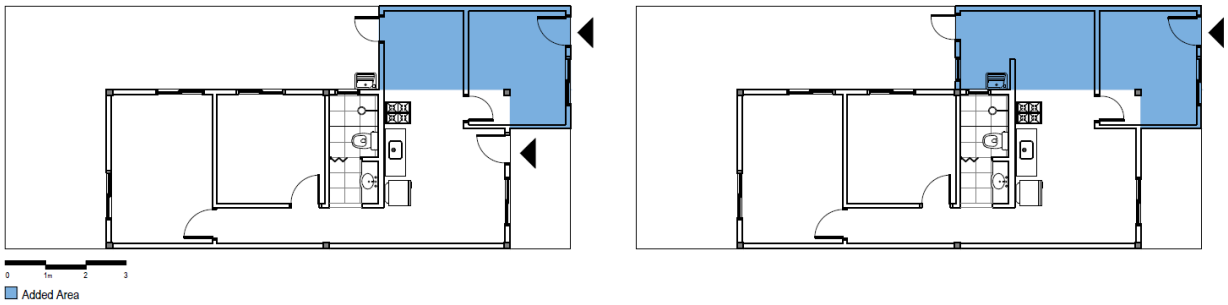

Figure 4.13 Expand kitchen/living room to side + add room to front (left) + add laundry (right).

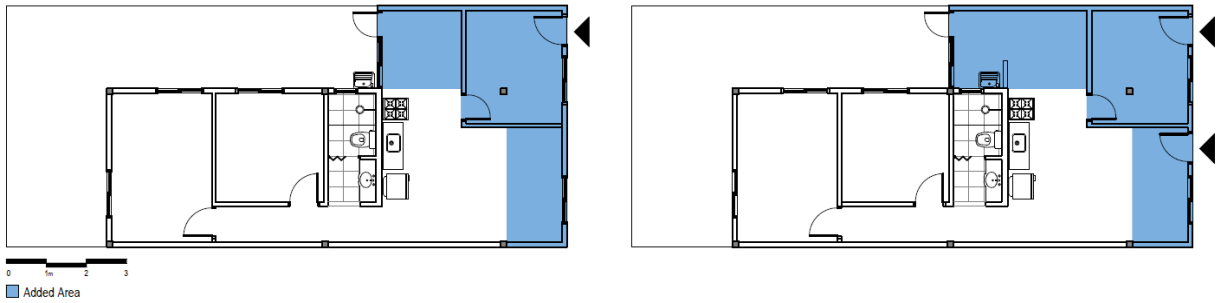

Figure 4.14 Expand kitchen/living room to front and side + add room to front (left) + add laundry (right).

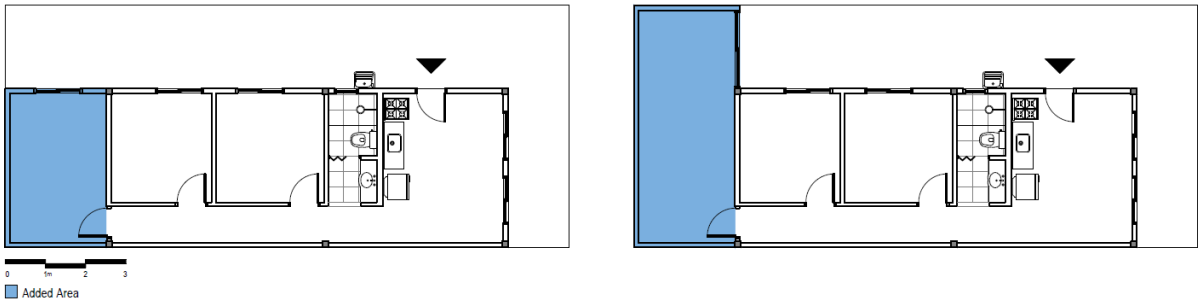

Figure 4.15 Add room to back

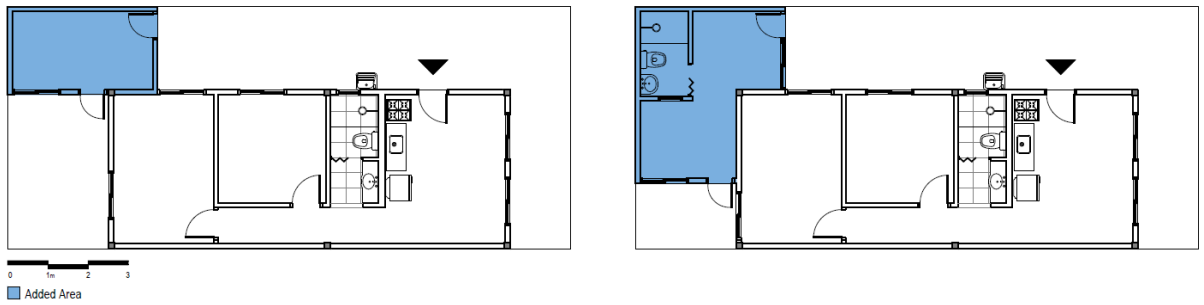

Figure 4.16 Add room to back with independent access (left) + add bathroom (right).

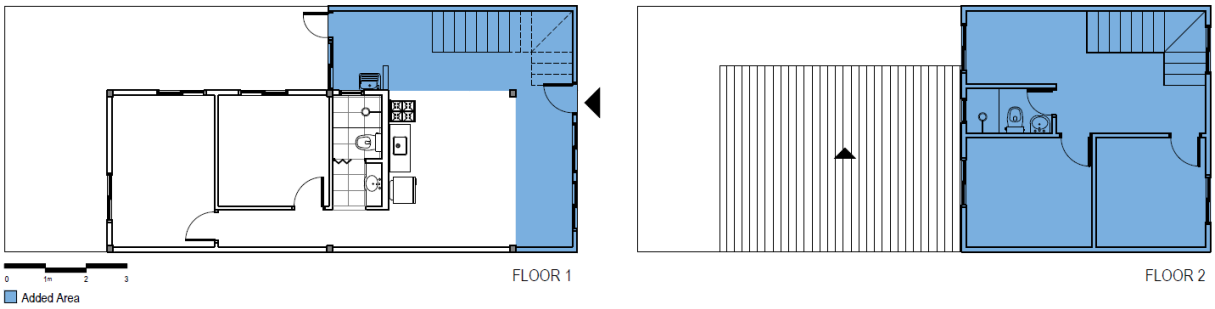

Figure 4.17 Expand to front and side + add a floor.

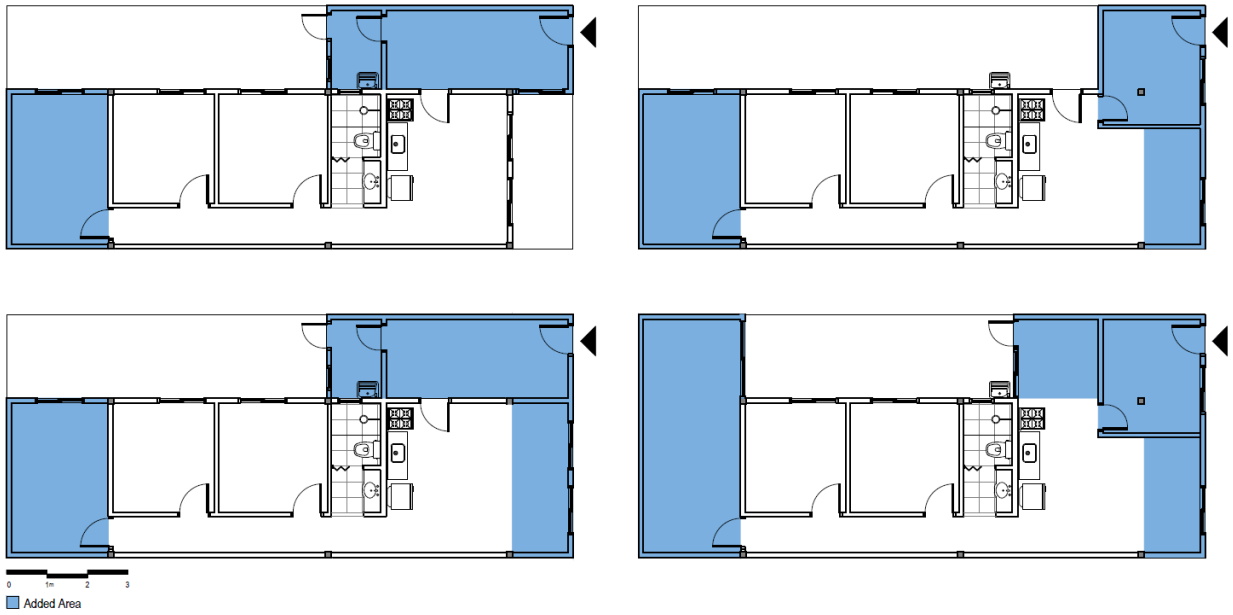

Figure 4.18 Examples of combinations of pre-defined solutions.

4.4.Conclusion

Several factors influence the creation of a solution space for the post-occupancy differentiation of housing units. It is important to highlight that differentiation post-occupancy does not happen without connection to the initial unit. Therefore, the design of the initial unit is a crucial aspect of the solution space. Ideally, the design of the initial unit should be done with this post-occupancy differentiation in mind. For the expansions, knowing the main types of changes that will likely be made is crucial. Allowing the maximum freedom possible for the families within the permissible parameters is also considered essential. Thus, compiling those parameters and their acceptable ranges is an important part of the solution space development.

Chapter 5. Process Design

This chapter refers to how the process of provision of social housing and post-occupancy processes could work, aiming for post-occupancy differentiation of the units. It considers the different stakeholders, and current policies and programs. As previously mentioned, in the context of this research, there are significant differences from the way most of literature approaches mass customization – a company as the main agent. This is also reflected in what is considered in terms of process.

I argue that differentiation of the house units should happen post-occupancy. Although the pre-occupancy processes could remain the same and post-occupancy differentiation could still occur, some changes to the pre-occupancy processes could facilitate and bring even more benefits for post-occupancy differentiation. Therefore, this chapter considers the process from the early stages of proposing a new development through to post-occupancy differentiation.

Although several programs for the provision of social housing exist, this study considers the current regulations of MCMV since the total amount of funding and number of units produced through this program has been significantly higher than all the alternatives in the last decade. Locally managed programs often use the standards and processes of MCMV as a reference, and they must comply with those minimum standards if federal funds are used.

Throughout the chapter, two overarching concerns guide the recommendations. The first concern refers to the capabilities of the stakeholders. For the strategy to be feasible, all processes should be kept within stakeholder's current capability. The second concern relates to ensuring the families' participation. Applying such a mass customization strategy could bring significant benefits to the city as well as the families involved. However, if there are too many barriers for the

families to access the strategy, they could decide it is not worth the effort and continue with their current practices, compromising the positive outcomes not only for themselves but also for the neighbourhood and the city. Thus, ensuring that the families would want to take part in the mass customization strategy is a paramount concern that imposes certain limits to how the strategy can be implemented.

5.1. Overall process and funding

This section considers how the social housing process is seen and managed by the stakeholders, as well as how funding is captured and used. It discusses changes that could be made in this process to enhance positive outcomes within the proposed mass customization system.

An approach that could bring significant benefits to how developments are implemented and designed would be to separate land acquisition and design from construction. However, this implies significant changes to the overall structure of the program. The idea, in this case, is to give the local authorities more power in decision making. This way, cities could contract the design of new developments separately from construction. This approach allows the city to decide the location of new developments. Usually, when local authorities donate the land, new neighbourhoods are much better located than when the developer chooses the land. Furthermore, separating who designs from who builds means that the funds designated for design are actually being used for design, and not being taken as profit or used to cover costs in other areas. Currently, developers often rush and reuse portions of the design, as shown in Chapter 3. This separation of roles allows the design of the development and of the initial units to be more thoughtful, incorporating more input from the local authorities. Increasing how much effort goes into the design increases the chances that the resulting design will be of higher quality and more aligned

with the priorities of the customer, the local authorities. If post-occupancy differentiation of the units is a priority, then this approach would increase the chances of the initial units being more suitable to receive this differentiation.

Although uncommon, some cities have been able to implement local policies in this regard, which allows them to select the land, call for designs for the new neighbourhood, and then have construction companies bid for the project. The capital, Brasilia, is the most famous case in which the local policies and processes allow this kind of approach ("Companhia de Desenvolvimento Habitacional do Distrito Federal," 2020). Having seen the relative success of such approaches in cities like Brasilia, implementing some policies in this regard on a national level could facilitate its implementation for all cities. However, reaching a point where this is possible on a local level requires very well-structured local housing departments, which is difficult to achieve in medium and small cities. Increasing the demand on the municipalities to manage such a process could be beyond their current capabilities. Thus, this approach is not immediately feasible for all cases.

One of the most significant changes with potential to bring many benefits over time is to reorient how the local and national authorities see the entire process. They should account for the pre-occupancy and post-occupancy aspects, which are usually only considered separately, as integrated as one. This could allow funds to be better managed throughout the entire process. For example, the city could invest more in the early stages of new developments if they knew that they would save more in the future from avoiding the problematic changes.

One approach that could be useful in this regard is to allocate some of the initial funding specifically for post-occupancy renovations. This would not necessarily make these developments more expensive for the government. Funds for post-occupancy social work are part of current

funding for such developments. Assistance in designing the renovations could be part of the social work as discussed later in this chapter. Extra funding could also be entirely or partly taken from the funds from the technical assistance law Lei Nº 11.888 (2008). Since the local authorities have the most to gain and to save from avoiding future problems, the extra funds to be applied for post-occupancy renovation also could be part of the city's matching fund. More considerations about how these funds could be applied are made in the next sections.

5.2. Design of initial housing units

This section refers to changes that could be made to current program policies and processes to allow the design of the initial unit to be more appropriate for the implementation of the mass customization system facilitating the post-occupancy differentiation.

An important focus for the pre-occupancy processes is to achieve more flexible units that allow future expansions as easily as possible. Although there are many design studies that can be applied to allow this flexibility for social housing contexts, following these recommendations adds costs to the developer. Therefore, a significant challenge is making flexibility either attractive for the developer, or required of them.

The easiest solution within the current structure of the program would be to extend the text of the existing policy around the flexibility of house units. Currently, this is regulated by the ministerial ordinance Portaria Nº 660, which has all the minimum standards acceptable to the program. In terms of flexibility, this regulation has only one line that reads: the housing unit shall be designed to enable its future expansion without loss to the lighting conditions and natural ventilation of the existing rooms (Ministério das Cidades, 2018b). Given how this regulation provides little guidance, it is usually fulfilled by showing that one room can be added. Often this

means that the unit was designed to allow only one room, in a specific place, to be added. This is not enough to satisfy the amount and variety of changes the families need. Therefore, extending this item of the regulation to provide more guidelines could result in more flexible initial units. Even changing that one sentence in the policy to, for example, 'the housing unit shall be designed to enable future expansion of at least two different rooms, would already be beneficial. However, previous studies, such as shown by Brandão (2011), provide extensive guidelines specifically for social housing units, many of which could be incorporated into the regulation, such as shown in Table 8. This would be useful not only for the developer to know what is expected, but also for the local and federal authorities to require higher quality in this regard before approving the units for the new development. As shown in chapter 3, the process of approval is often limited to checking for compliance with regulations. If there is not enough regulation around providing flexibility, then the authorities cannot require its implementation in the designs.

Since approval of developments is often limited to checking if the proposed development complies with regulation, including existing flexibility guidelines in this regulation, such as those by Brandão (2011), is not enough because many of them are subjective. For example, the guideline that suggests *setting the height of the ridge suitable for expansions* (Brandão, 2011) could be interpreted in different ways by different people since it does not say how high the ridge should be or what kind of expansions it is referring to. While leaving room for interpretation can be useful to allow creative design solutions, in this case, it could be misused to show compliance to a guideline without actually adding flexibility to the unit. Therefore, for such guidelines to be useful in resulting in more flexible built units within the current capabilities of the stakeholders, I propose translating guidelines such as those proposed by Brandão (2011), as much as possible, into

quantifiable items that are easy to check for compliance. Thus, it would also be easy for the developer to demonstrate compliance with them, as with all the other strict regulations of the program for the housing units. Table 8 shows a selection of the guidelines proposed by Brandão (2011) that would be feasible to implement within the current regulation of the MCMV program, and could be checked easily within the current process of approval. The table also shows a possible wording for the regulation such that it would be easy to demonstrate and check for within the approval process.

Table 8

Guideline from Brandão (2011)	Proposed for writing in regulation	How it could be demonstrated
Set the height of the ridge suitable for expansions	Set the height of the ridge at a height that allows adding rooms of at least 2m in length, continuing along the slope without needing to change the angle of the roof.	Include in architectural drawings a section showing the added room with the expanded roof maintaining the same angle and complying with the minimum heights within the room.
Allow the creation of new roof slopes without affecting the functionality	Allow the creation of new roof slopes without affecting the functionality	Include architectural drawings with the new roof slopes.
Separate, if possible, structure from walls	Separate structure from walls, such that the walls are non-load-bearing.	Highlight in the architectural drawing the separation between load-bearing elements and non-load-bearing elements.
Prepare structure to receive one or more floors	Prepare structure to receive one or more floors	Include the loads used to calculate the structure and foundations in the plans submitted for approval, and graphic representation of all the structural elements included to allow more floors.
Provide permanent hydraulic walls	Place hydraulic walls in such a way that the kitchen and other rooms can be expanded and that other rooms can be added without needing to destroy it.	Include drawings of the expanded rooms around hydraulic walls and of added rooms showing that it does not need to be destroyed.
Provide setback which allows expansion to the front	Provide setback of at least 2m.	Shown in drawings
Adopt broader front for individual sites, if possible	Adopt front for individual sites of at least 7m.	Shown in drawings

Another possibility that could be implemented in parallel to the previous policy change would be to implement incentives to design and build more flexible units. For example, the developer would have to demonstrate compliance to at least three of the guidelines in Table 8 in

order to receive the incentive. As it is currently, the financing agent, CEF, has several criteria that it uses to select which developments get financed. Among them is the selection of projects that propose the least cost per housing unit. This does not refer to the cheapest bid for the same project; rather, it is used to select which projects will be funded from among many proposals for different developments and even across different cities. While this is an incentive to make the whole process cheaper (from design to finished units), it also means that there is no incentive to try and incorporate things such as flexibility in the design. Furthermore, developers often use the fact that this is one of CEF's criteria for selecting projects to pressure the local authorities into approving the development without requesting improvements like added flexibility, as discussed in chapter 3.

Providing incentives for the developer to achieve certain standards in terms of flexibility is more difficult because, as well as requiring more effort in the design stage, it also requires more effort by the local authorities to evaluate for approval. The careful selection of which guidelines to include in the regulation, as well as the proposed change in wording (shown in Table 8) is essential to maintain the approval process within the current capability of most cities.

This added flexibility could add costs in implementing the development. The local authorities, as well as the families, have most to gain from this added flexibility. The improvement in the neighbourhood's environments would be directly felt by these stakeholders both in improved living conditions, as well as reducing expenses to the city, associated with problematic expansions. Therefore, it could be part of the city's matching fund to cover part of the added cost. For example, if one of the strategies is preparing the structure for a second floor, this added cost for the structure could be partly covered by the city. Similarly, if the design stage takes longer, the city could

increase the amount designated for the design stage. This approach would still be difficult for the cities given their limited resources, but it could be feasible if future expenses linked to inadequate expansions could be considered.

Another relevant consideration regarding the initial unit refers to the choice of building system and typology. As shown in the corresponding sections of solution space, some building systems and typologies are better because they make it easier for the families to self-build later, or are more culturally accepted in the region. Therefore, recommendations in this regard can also be incorporated into the regulations of the program for the initial housing units. This could be done by establishing a set of local priorities in the same way that is already done for the selection of families. The municipality indicates what building systems and typologies will rank higher, considering this discussion and other priorities the city may have. For example, if the city has environmental sustainability as a priority, they may rank systems aligned with this priority higher than other systems.

5.3. Acquisition and storage of materials

As explained earlier, I propose that the funds for post-occupancy renovation should be guaranteed as part of the funding process of the development from the beginning. In this regard, I consider two main possibilities. The first possibility considers the extra funds for post-occupancy renovation as only referring to management and assistance to the families in this process, not including construction materials. In this case, the amount of extra funding needed would be small since several parts of the process could be carried out within the existing capabilities of the stakeholders involved in the post-occupancy. In this case, the families would acquire the construction materials with their own funds as it is currently. However, as well as having assistance

in design, they could still take advantage of the possibilities for reduced costs of materials and storage, as discussed later in this section.

The other possibility refers to including in the initial funding a specific amount for each family designated for the acquisition of construction materials that can be used for renovation or maintenance. In this case, more funds would have to be captured initially, but it would be an extra incentive for families to undertake their renovations within the appropriate standards. This would not only guarantee a higher standard in design for these renovations but also higher quality in terms of materials, avoiding the replication of standards from informal settlements exposed by Jorge et al. (2017). I envisage three possibilities for payment of this extra amount for materials: (1) it could be paid by the families within the ten years of the financing process, (2) it could be part of the subsidized amount paid for by the government, or (3) it could be a combination of both.

This funding for materials of the renovations could be held in an investment fund by CEF until it was used. In this case, since each family would have a guaranteed amount for renovation, the combined amount of materials to be bought would be significant. This could be an opportunity for the city to negotiate lower prices with the suppliers of the materials. The funds would only be accessible once the renovation project for the unit was approved by the city, which could be done automatically after validation. The city would be responsible for registering the material suppliers, which could include more than one for the same kind of material. Once the family had the project approved, they would seek the suppliers to acquire the materials and then either CEF or the city would pay the provider directly on behalf of the family using the funds designated to that family at the start of the process. Currently, it is common practice in Brazil for the total amount of a purchase to be divided into smaller monthly payments, but this means that customers do not always

pay all the months, creating a high default rate. This direct payment from the housing program would serve as an extra incentive for the material suppliers to offer a good deal on prices within the program since it would reduce the default rate.

It is important to note that even within the first possibility that does not include amounts for the purchase of material, it would still be beneficial for the city to register providers and negotiate a reduction on the price of materials. The reduced prices would only be for the families included in the program, who would still buy the material themselves but at the reduced price the city negotiated. The suppliers would still benefit from having more business explicitly directed to them, and it would significantly benefit the families. In either of the two cases, the reduced price in materials would only be guaranteed for families that had their design approved. Thus, this would give the families a compelling reason to adhere to the mass customization strategy and have their design approved, increasing the chances of positive outcomes of the strategy for all stakeholders.

Another aspect that the city could negotiate is the storage of materials, allowing the families to buy in increments but only delivering when they have bought enough to build. In this way, the family would not need to store the materials. Considering that most changes are done shortly after the families move in, the storage for the families should be guaranteed for periods of up to six months. This should be enough time for them to acquire the rest of the materials necessary for each stage of the construction they have planned. Two main reasons make it relevant to avoid having the families store the materials themselves: (1) The space available to the families in the unit and the lot is small, so not having to store construction materials in this limited space is an advantage. (2) Storing materials for longer than necessary can result in loss due to weather or theft. This approach does not necessarily mean that the supplier would have to store the material from the

time it is bought until delivery, though that may be the best option in some cases. It depends on the suppliers' capacity to guarantee prices for some months as well as how much storage space they have available.

5.4. Designing the changes

An essential consideration for the success of the mass customization strategy is how the processes of choice navigation and approval of the solutions can be done. I propose the use of a digital co-design system to be used by the families for choice navigation. The families would use this system to manipulate and visualize the design of their units and receive feedback and validation for the solutions before engaging in construction. The co-design system and several aspects of choice navigation are discussed in chapter 6; however, some possibilities regarding the process and roles of stakeholders in designing the changes are considered in this section.

The validated solutions resulting from choice navigation need to be automatically approved by the city. This approval would be another significant advantage for the families and a good reason for them to use the strategy. Furthermore, it would save the city time and effort from approving those projects individually, as well as resources to deal with the illegal construction and the problems that may emerge from them. For this automatic approval to be feasible within the city, it implies using a system connected to the choice navigation system to allow automatic approval of the design. Conversely, this process may face prejudice from architects and engineers who may view it as limiting their job opportunities. However, it is rare, currently, for professionals to design renovations in this context. Currently, for any design to be approved, it needs to have a registered professional responsible for it. It is important to emphasize that this automatic approval is only possible because professionals worked on achieving a viable solution space. In this case,

the difference is that any solution within the established ranges of the solution space would have their approval pre-determined instead of individually developing each solution to then seek approval for that one solution.

The process of choice navigation itself is also a process which may require the involvement of other stakeholders. Although this process should be simple enough that the families can do it by themselves, some families may still require assistance. Furthermore, having the option of assistance and the involvement of other stakeholders could help in increasing the awareness of the families of the importance of having validated solutions and their perception that this process is worth undertaking.

Assistance could be provided as part of the social work in the post-occupancy. If funding is available specifically for the renovation process (as suggested before), then a member of the social work team could be hired specifically to address the renovations and provide this assistance in choice navigation. However, this is something that could be done by members of the social work team as they are currently composed. Within the pre-occupancy meetings with the community, the social work team could advise the families that there is support available for renovations and the importance and advantages for them of engaging in this process for renovations. Post occupancy, this can be further discussed with the families especially when the intent to build is identified.

Considering that most renovations are done shortly after the families move in, this assistance could also be provided as part of the post-occupancy social work, both the mandatory social work of the development and further social work and outreach projects carried out within the neighbourhood. Another way to allow those who need it to have assistance in using the system even after all social work activities have ended is to encourage the community members who feel

more comfortable using the system to assist others when needed. It is important to note that the family can only take advantage of design approval and lower prices for materials if they use the co-design system and have their design solution validated.

Considering the Anglo neighbourhood, which I use as an example in this study, it is relevant to note that many social projects have taken place there beyond the mandatory social work of housing projects. This is partly due to the neighbourhood's proximity to one of the federal university's campuses, as several projects were implemented in the form of university outreach from different faculties. Projects by the Faculty of Architecture and Urbanism included creating digital apps to be used with the population as an educational tool to bring awareness about ways to improve the urban environment, and teaching children and teenagers to use digital tools (including drawing tools and photo editing). Therefore, assistance to go through the choice navigation process could be part of these kinds of projects involving architecture students and extending how long such assistance would be available beyond the period of mandatory social work.

5.5.Overarching support system

Considering the large number of housing units, the variety of possibilities for expansions, and the many stakeholders involved, I propose implementing a digital support system to manage the process of post-occupancy differentiation. This system would encompass choice navigation and validation of the proposed post-occupancy changes. This section discusses the possibilities of the overarching support system, considering how it could be organized and used to support the process of expansion of the units in this social housing context. Further aspects of choice navigation are discussed in the next chapter.

The local authority should be responsible for managing this support system since it is the stakeholder that has significant roles both pre-occupancy and post-occupancy. Furthermore, the local authorities interact closely with most other stakeholders, including the families. This way, other stakeholders would be users of the system, inputting information when necessary, but the local authorities, the city, would be responsible for its management and maintenance. Many cities use digital support systems for the management of different aspects of the administration and to interface with citizens. Therefore, many cities already have the capability and personnel to maintain such a system.

Since the stakeholders have different roles and needs during the process, not all aspects to be managed in the system are relevant to all stakeholders. Therefore, the system should be composed of several modules. Each stakeholder would only have access to the modules containing the aspects pertinent to that stakeholder. The modules would be interconnected so that relevant information can be shared between them when necessary. Figure 5.1 shows the overall relationship between modules and relationships between stakeholders for the renovations.

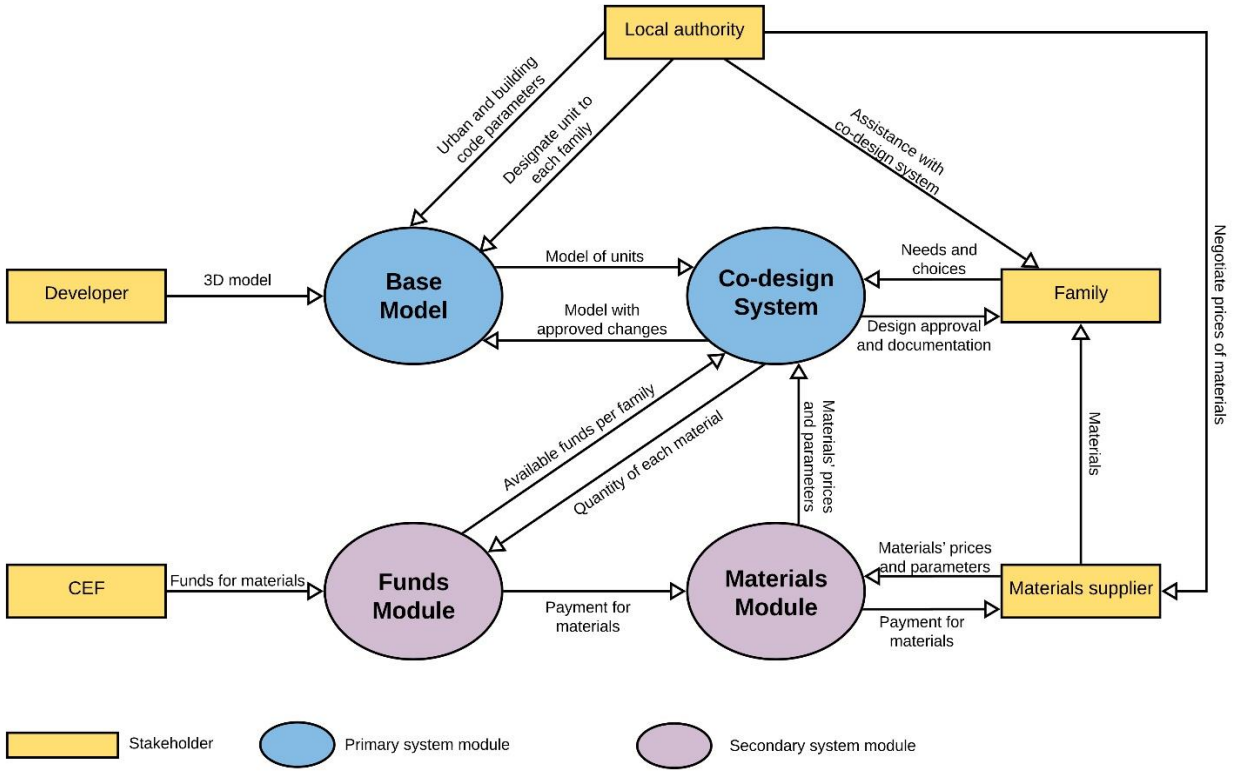

Figure 5.1 Modules of overarching support system

A first module is used for implementing the development design into the system, the base model. This should include the overall urban design of the development as well as the standard unit designs. Ideally, the developer would be required to implement the models of the development, thus, not requiring that the public administration hire someone to do this. It is also relevant to note that this implementation of the models within the system is not the same as merely uploading any file to be stored (as currently expected in some cities). It requires that the different elements of the building can be associated with their functionality, necessary parameters and interdependencies, and understood as such by the system. Therefore, this module of the system could use existing BIM formats that allow for this (Eastman, Teicholz, Sacks, & Liston, 2011).

Thus, depending on how the company developed the project, this may require a new digital model within the system's standard. The developer could also develop and model the standard expansions and implement them in this module of the system. However, this development and modelling of the standard expansions would mean an extra cost to the developer. In a different approach, generative design solutions (McCormack, Dorin, & Innocent, 2004) could be implemented for expansion possibilities, as further discussed in chapter 6.

The city could also use this module in early stages to assist in the approval of certain aspects of the project, such as the initial unit design. For example, the initial model could be automatically checked for adequacy to urban and building code parameters, in the same manner that these parameters are automatically validated for the expansions. This could make the approval process easier and faster by not requiring that someone check those parameters manually for approval, thus, saving the city funds that could be applied elsewhere in the process.

The implemented model of the new development could then be used to associate each family to their designated unit. This would be done directly by local authorities as soon as they receive the approval of the financing process from CEF for each family. Associating each family to their unit within the system facilitates record-keeping for proposed and approved changes.

Another module of this system would then be used for choice navigation with the families for the changes to their unit, the co-design system. Within this module, the family selects their unit. It is then isolated from the development but has the necessary urban and building code parameters implemented. Through a choice navigation interface, the family would engage in a co-design process indicating what they intend to build, manipulating and visualizing the design, receiving feedback, automatic validation and cost estimate, as further discussed in chapter 6. The

system keeps the validated solution as the updated status of the unit, and to authenticate its legal standing.

Another module that may be needed refers to the interface between the overarching system and materials suppliers. Depending on the building system chosen for mass customization, different companies can be associated with the development. For example, if a specific type of prefabricated panels is to be used, then the company, or a few companies, that make the panels would be associated. In this case, the system would need a module to keep track of the parameters of the panels and the associated cost. It would be the responsibility of the fabricator to input such parameters and costs. These parameters and cost would then be linked to the choice navigation module. If a traditional building system is used, then several local construction materials stores and fabricators (such as brickyards) can be associated and would also have an opportunity to input the costs associated with their materials. However, in this case, this module would not be a requirement. The parameters of the components could be input based on industry standards, and the costs could be updated based on the averages periodically released for the region. It is important to highlight that in this case, the cost estimate within the choice navigation module would not be as accurate as if the actual cost from a provider were input into the system.

If the overall strategy includes funding construction materials for each family's expansions, then a module to manage these funds also would be needed. This module would allow the management of the funds between CEF, the city and materials suppliers. The amount of funding for materials available to each family could also be shown in the choice navigation module as part of the budget. As explained in section 5.3, the payment for materials to the supplier would be made directly by CEF, using this module, aiming to reduce the default rate for the suppliers.

Chapter 6. Choice Navigation

Mass customization toolkits or configurators are used to facilitate choice navigation for many products. Within the proposed mass customization system, the use of such a configurator – the co-design system – is essential to achieve the overarching goal of allowing social housing neighbourhoods of the lowest income range to evolve over time with more adequate design solutions. Within this system, the user will still be able to self-design, to some extent, while having their solutions validated as adequate, viable and legal. Thus, even if other aspects of the proposed overarching support system cannot be implemented, the co-design system is still necessary. Not only is it an important enabler in mass customization strategies, in allowing the customers to make their own choices, but in this case, it is also a valuable educational tool, as will be further discussed later in this chapter. As I argue that differentiation should happen post-occupancy, the families would only use the co-design system post-occupancy for the expansions of their units.

This chapter discusses the specificities of the social housing context in relation to the relevant considerations regarding co-design systems shown in chapter 2. It also outlines desirable characteristics such a system should have. While the chapter makes some recommendations that could be applied in different ways, it also shows specific examples of what the system could be like considering those recommendations. For the examples, I use solution space option 2 for the Anglo neighbourhood (shown in section **4.3.2**). Initially, I discuss overarching aspects of the co-design system, possibilities, and barriers, including aspects of families' accessibility to such a system. Second, the sections 'Preparation' and 'Customization process' describe specific aspects of the co-design system regarding its use from beginning to end. 'Preparation' refers to the

elements that are managed by local authorities before the families have access to the system. The section ‘Customization process’ refers to the portion of the system that will be used by the families. The last section, ‘Further possibilities,’ discusses the potential for including in the system aspects not considered essential.

6.1. Initial considerations

When evaluating what aspects to include in the co-design system and how they should operate and be presented to the families, it is relevant to consider the following issues. First, there are significant differences between the families regarding their knowledge of design and construction and their confidence level in addressing it. Families usually know what kind of space they need but may be unaware of the different possibilities of where and how they can build that space. Second, separate families and members within the family have varying skill levels in manipulating digital technologies such as computers and smartphones. These characteristics are combined in different ways for each family. For example, a person that works in construction may have more confidence in the design aspect but may have less skill with digital technology. Still, they may have a teenage child that is very confident with the use of a computer. In another scenario, there may be a family that knows nothing about construction and has limited skills with digital technology. Thus, the co-design system should be as easy as possible to use, but still allowing as much freedom as possible within the pre-established solution space.

Another vital consideration is how users can interact with the system. As discussed in chapter 2, the use of different kinds of technologies, such as physical models and virtual reality, could help facilitate the visualization of design possibilities. However, depending on the technology, its use could require the acquisition of equipment and specialized personnel, thus

increasing the costs associated with the mass customization strategy. Certain technologies could also increase the need for assistance in the choice navigation process, further increasing the costs. Moreover, if the co-design system is only available in an assistance environment, this could become a barrier for the families to engage in the process. For example, if the only way the families can manipulate the design options is through physical models that are kept with the social workers, the families may lose interest altogether and opt to build in their own way. In other words, it should not be a requirement to use the system that the families go somewhere specific or purchase pieces of equipment, as this would significantly limit who would be willing to use it and could potentially compromise the whole strategy. Depending on the funding available for the project, it may be feasible to have different options of technologies that the families can use with assistance or extra equipment. However, this would be available as an extra option and not as a requirement for engaging in the co-design process.

The co-design system should be easy enough for the families to use independently and it should be easily available. Therefore, having digital manipulation and visualization for the system is considered a feasible option since it allows the system to be used with any digital device such as computers, tablets, and phones, which are more commonly available. A relevant concern is access to such digital technology by the lowest income range of the population in Brazil. Such access has been increasing over the past years. For example, research shows that in Brazil's lowest income range, the number of households with internet connection grew from 30% in 2017 to 40% in 2018 (Centro Regional de Estudos para o Desenvolvimento da Sociedade da Informação, 2019). Even if an individual does not own a digital device, it is common, once the community is established, for access to technology to be shared. For example, families may have access to a

computer in a community center, or a member of a household may use the neighbour's computer to access the internet. In another scenario, teenagers of some families may have smartphones through which they access digital services for their parents, including some public services that are only available online. In a study regarding the use of the internet to access the federal government's digital services, the authors indicate that the primary place for accessing the internet for the lowest income range is in their own house, as it is in the other ranges. However, for the lowest income range, the amount of people that access the internet in someone else's house, at school, at work, or in lan-houses is significantly higher than in the other income ranges (de Araujo, Reinhard, & Cunha, 2018). The authors of this study highlight the importance, in the lowest income range, of the access to the internet in someone else's house, that being the second most common (17.1%) and showing the existence of networks of relationships for internet access within this income range.

Phones are the most commonly available devices to allow internet access (Centro Regional de Estudos para o Desenvolvimento da Sociedade da Informação, 2019). However, phones have small screens. It would be useful to have devices with larger screens available for using the co-design system. For example, if it is part of the social work to offer such assistance within the neighbourhood, a larger screen tablet or laptop computer could be part of the social work equipment. Alternatively, if computers are available to the population in places like the local school or community association, those could be used to access the co-design system both individually and with assistance.

An initial challenge faced when planning a co-design system for use in social housing neighbourhoods refers to the availability of internet connections versus personal devices' memory

and capacity to process data. Given the bigger challenges for access to the internet faced by this population, compared to other income ranges, it would be desirable for the co-design system to require an internet connection as little as possible. For example, the system could require an internet connection at the start of the process, to download the current status of the house for the specific family, and at the end of the process to send the chosen, validated solution to the city. The manipulation, visualization and validation could be done within the system without internet connection. However, this means a larger application would need to be downloaded initially, and all the processing would have to be done locally on the device. This approach requires more memory and a more powerful processor than if the system operated through a server online (Buchenberg, 2017). Therefore, it could limit which devices would be able to use the application. Providing both options, processing offline with a larger application or processing online, would be an ideal solution to allow as many people as possible to access the system with their own resources. For example, a version with local processing could be available for computers and tablets while a version with processing on a server could be available for phones. However, this could add cost and effort in creating the co-design system itself.

Another aspect that may add complexity to the system refers to being able to apply it to different developments with varying design solutions. While one neighbourhood is being used as an example for this thesis, it is considered important that such a co-design system should be developed to be used across many different developments. Although this implies more complexity and higher costs to develop the system initially, it also has the potential for savings through time by facilitating and even automating parts of the process. Furthermore, this automation of parts of the process can make it easier to adopt the system itself. An example is the possibility of having

the pre-defined expansion solutions, such as those shown in the example in Chapter 4, automatically generated for each development. In this case, the system would use the compilation of parameters, and desired combinations of type of change and location of expansion from the solution space to automatically generate one solution for each combination within that neighbourhood's parameters. Although previous studies demonstrate that there is sufficient technology available to allow the use of such generative solutions (De Almeida, Taborda, Santos, Kwiecinski, & Eloy, 2017; Duarte, 2001; Mororó, Romcy, Cardoso, & Neto, 2016; Veloso, Celani, & Scheeren, 2018), its implementation requires more effort when creating the system. Thus, it is only feasible if many developments are going to use the same system.

Considering the similarities in different cities, both in the process of provision of social housing, as well as in local urban and building codes, implementing a system that can be used across many different developments is feasible. Thus, using a generative solution for the implementation of the needs-based aspect of the co-design system would be feasible. It could also be an effective way of saving resources later in the process, as many cities adopt this approach. Such a generative solution would not be necessary if the design for the neighbourhood were developed with a focus on post-occupancy differentiation from the start. In this case, the design should already include many options for expansions to be used as part of the solution space. However, for this scenario to be feasible or attractive for developers would require more significant changes to the current process of provision of social housing. Therefore, implementing a generative process for the system that does not require someone to develop all the alternatives of the solution space manually for each development, is currently more feasible.

Therefore, I propose that the system should consist of two main processes: (1) the generation of pre-defined solutions for each development; (2) the parametric manipulation by the families. These two parts operate with different mechanisms, as classified by Hermans (2012). The first phase in which the local authority inputs the local parameters and the system generates the pre-defined solutions is a mechanism of generative customization. The user of the system in this phase is the local authority who is customizing the pre-defined solutions to the specific development. The result from the customization in the first phase is then used in the second phase that allows further customization by the families through a parametric mechanism.

It is important to highlight that this co-design system would be used mainly as an interface between local authorities and the residents of the neighbourhood. As shown in the previous chapter, it could include information that is input by other stakeholders, but this is not necessary in all cases. Thus, the initial phase with the generative mechanism is considered as a preparation of the system to allow it to be useful for the primary user, the families. Therefore, it is the process that the families go through within the co-design system that is being addressed when referring to the customization process.

The co-design system has two main roles within the process of post-occupancy differentiation of social housing units. One is diminishing the probabilities that renovations will result in problems; i.e., validation of the solutions. The second role is as an educational tool providing a medium through which the families can interact with, visualize, and receive feedback on their solutions before starting construction. This educational role of the system gains importance when considering that if the families are restricted within the system from moving forward with certain solutions, without understanding why they are not allowed, they may turn

away from the strategy. Therefore, the system should provide educational feedback for the solutions in the process of validation. This way, the co-design system will not only allow the users to gain better insight into their preferences as exposed by Franke and Hader (2014), it will also allow users to gain a better understanding of the design solutions.

There are four factors that determine the guidance the system provides to the user in a customization process: start point, guiding method, instructions, and feedback (Hermans, 2012). For this co-design system, templates, the pre-defined solutions, would be provided as a starting point so that the user does not start with a blank canvas. For the guiding method, since the system has many different categories of options, restricting the changes to individual sequential steps would not be appropriate for everyone. The users have different priorities and may lose interest if forced to make choices for many different options, which they do not consider important. Therefore, the options should be presented in a way that allows the users to choose their own path through the customization process as much as possible.

Equally important, instructions would be provided both at the start of the process, to give the user some confidence in using the system, and throughout the customization process. Throughout the process, instructions should be available in parallel with the process and by unlocking information about specific options when necessary. Furthermore, different kinds of feedback are necessary for the user to understand the implications of the changes they are proposing to the unit and to avoid frustration with the process. Therefore, the system should provide visualization of the proposed changes, but also textual feedback for any proposed changes that are not validated by the system.

Given that the families have varying skills in design, construction and use of digital technology it is necessary to customize the customization process (Randall et al., 2005). Consequently, the combination of a needs-based approach and a parameter-based approach is recommended. Initially, the system should guide the user through options regarding the combination of what kind of space they need and where they want it relative to the existing unit. Once the family has made that choice, a pre-defined solution of this combination should appear to the user. They can then manipulate the parameters of this solution, such as the exact position, the dimensions and positioning of windows and other elements. Users that do not wish to manipulate the parameters can keep the pre-defined solution for the combination of space and location they chose.

The co-design system needs to allow customers to specify several parameters within the product rules, not being limited to pre-defined modules. The co-design system should allow the user to alter geometric and dimensional parameters, which categorizes it as a make-to-order configurator being of medium-high complexity, as classified by Blazek (2017). This approach of allowing users to alter parameters, meets the recommendations of providing a parameter-based interface for users who feel comfortable changing the parameters directly (Blazek, 2017; Randall et al., 2005). If only pre-defined options are available, the family may decide that since it is possible to build beyond what is pre-defined, it is better to do so without engaging in the system. Thus, the definition of viable parameter ranges should be as broad as possible within legal standards and those of the building system, to allow as much freedom as possible for those that want it.

As well as allowing users to manipulate and validate the design of their unit, another aspect that should be made available in the co-design system is a cost estimate. As mentioned before, self-building significantly reduces the costs of the renovations for the families. Therefore, the cost estimate allows users to see the cost of the materials and components needed for the renovations. This cost should be visible while the interaction with the system is ongoing. Setting a personal budget for validation should be an option. This way, the family could indicate their budget at the start of the process and the cost estimate could change colour when the proposed changes exceed that budget. However, the validation of this aspect, different from the other aspects, is only informative and should not prevent the solution from receiving validated status. Furthermore, leaving the budget blank or changing it while the process is ongoing should also be an option.

To conclude the choice navigation process, the validated solution should be sent to the city and receive automatic approval of the design. Once this is done, the final solution should still be available for viewing during construction. Furthermore, considering the issues around access to digital technologies discussed before, the families should be able to print the validated solution.

6.2. Preparation

Although the system is intended for use in many different social housing developments, the city still needs to prepare some aspects for each development before making the co-design system available to the families. This section refers to those aspects.

It is relevant to highlight that certain aspects of the co-design system depend on what aspects are going to be validated, which in turn depends on the solution space. For the example used here, the proposed validation is for urban and building code aspects, as well as structural integrity. These aspects are considered essential to validate in all cases because of the nature of the

problems with self-built expansions in these neighbourhoods, as shown in chapter 3. Separate validation of the building system's parameters may also be necessary in some cases. For the traditional building system proposed in this example, there is no need for separate validation since the parameters for this system are already accounted for through the building code and structural integrity.

Initially, the original unit design and how it is placed on the different lots must be inserted in the system. The city should do this using a three-dimensional model. This model must allow the necessary properties to be assigned to the different elements of the building. The assignment of relevant properties to each element is essential to allow for appropriate validation later. For example, structural elements should be recognized as such by the system. Ideally, BIM models should be used for the initial model since they already differentiate the building elements and allow attribution of the necessary properties to each element. The automatic recognition of the properties of building elements to be viewed and manipulated with a more friendly interface is possible to be implemented, for example, using gaming engines. Previous studies have shown the use of gaming engines and gamification of design processes as a means to facilitate for the families and engage them in the manipulation of housing design, while ensuring this manipulation is done within the rules previously established by architects (Lo, Mohamed, & Schnabel, 2019; Lo et al., 2015; Lo, Schnabel, & Moleta, 2017). Similarly, Veloso et al. (2018) discuss possibilities for transferring and converting relevant data to and from BIM models for manipulation by users of different skill levels through different interfaces appropriate to each user. It is important to note that most BIM software allows a much higher level of detail of the model elements than what is necessary for the co-design system. Therefore, to facilitate the conversion of the model into the system, it may be

necessary to adjust the original model provided by the developer. From another perspective, the standards needed for the co-design system could be communicated to the developer. A model with such standards could then be required as part of the development documentation. At the end of the preparation process, an individual model for each of the units and their lots should be available in the co-design system.

The local authority should then be able to assign individual units to specific families. This could be done by matching the identity number (CPF) of the family member who signed the contract to the unit. The CPF is an eleven-digit number unique to each person that appears in all the documentation the family provides to the city and CEF. Therefore, it is a number that both the family and the city have easy access to, but others do not. This number can later be used as a password to guarantee that only the assigned family has access to make changes to their unit within the system. Restricting access is necessary because the validated changes the family decides to make are registered as approved in the system. Later, if the family wishes to make further changes, they can start from the new current state, which already shows the previous changes made.

Another aspect that needs previous preparation refers to the input of local parameters. Parameters considered in urban regulations and building codes are similar across cities. However, the exact permitted ranges can vary between cities, and even between neighbourhoods in the same city. For example, the minimum proportion of window area to floor area for each room may be different for each city even though most cities indicate some minimum proportion in their building code. Therefore, the system should have an interface in which the local authority can input the permitted ranges of the parameters for the specific location. Furthermore, the local authority should be able to activate or deactivate specific parameters depending on if there is regulation around

them for the location and use. For example, in some cities, even though there may be a minimum required offset of the building from the back of the lot, this requirement may be waived in social housing neighbourhoods. The compilation of which parameters to use and their permitted ranges should be part of the solution space.

Also part of the preparation, is implementing the models of the pre-defined solutions that will be available from the needs-based section of the system. I propose that these solutions should be generated automatically based on what is possible for each site through a generative mechanism, as explained in the previous section. This generation of the pre-defined options should consider the initial unit design and the specific parameters for the location already input in the system. Furthermore, it should consider all the possibilities for the combination of types of changes and place of expansion, as shown through tables 6 and 7 in section 4.2.2. Only solutions that are possible will then be available. More than one variation could be possible for each combination of type of change and place of expansion. Thus, parameters for the optimization and selection of only one option for each combination should also be implemented. For example, only the option with the lowest cost would be shown for each combination. Further possibilities for the solutions will later be available to the user through the parameter-based interface.

6.3. Customization process

This section refers to the portion of the co-design system that is used by the families. It is organized step by step as if someone were using it but also showing the relevant aspects of the system for each stage.

6.3.1. Initial selections and needs-based options

It is crucial for the changes made by the families to be associated with their specific unit. Thus, the families must be able to select their specific housing units within the system at the start of the process. In this step, the user should choose from a menu their city and neighbourhood by name. Once the neighbourhood is selected, the choice of unit number should become available for choosing. Then the system should request the number password (the CPF) for the user to access their specific unit. Once the family has access to their unit, the system should show a brief tutorial of the system explaining what will happen in the next steps. An option for skipping the tutorial should be available since users more familiar with digital applications may not need it.

Following this, the user starts making their own choices. There are different ways of presenting options within a configurator, each with advantages and disadvantages (Buchenberg, 2017). A single page configurator is a good option for this case for allowing the user to visualize and manipulate all the parameters on the same page. However, it is also necessary for the needs-based options to be presented first, such as in multi-step configurators. This is necessary to determine which pre-defined solution will appear to the user. Therefore, a hybrid strategy, which starts with a series of sequential steps leading to “a page with the characteristics of a single page configurator” (Buchenberg, 2017, p. 233), is advised. The needs-based options would still be available in the single page portion of the configurator, to allow the user to change this initial option if they change their mind. The portion with characteristics of a single page configurator is also the portion that allows direct manipulation of the parameters, the parameter-based interface.

For the needs-based options, it is important for the user not only to be able to change their answer from previous steps but also that all the options of the previous steps remain visible. In this

sense, it is relevant that all the options for the current element are also visible even if it is not a possibility because of their selection in previous elements. The impossible options should only have a different appearance and not be possible to select. The relevance of this approach lies in allowing the user to gain a better understanding of what all the options are and how one choice affects other options available. Thus, the user goes through the needs-based portion of the co-design system to determine the pre-defined solution that will be shown in the parameter-based portion. An example of the needs-based options is shown in Figure 6.1; the resulting pre-defined solution can be seen in Figure 6.2.

The family can indicate their budget for the project at this point. However, the indication of a budget does not affect the solution that will be shown. In the parameter-based portion, a cost estimate will also be shown, and the system can highlight this estimate if the budget is exceeded. The family's initial budget must not affect the options available to them because of the over-time character in which these changes happen. This way, the family can still validate the solution of what they want to build even if their budget now is not enough since the costs can be distributed over time.

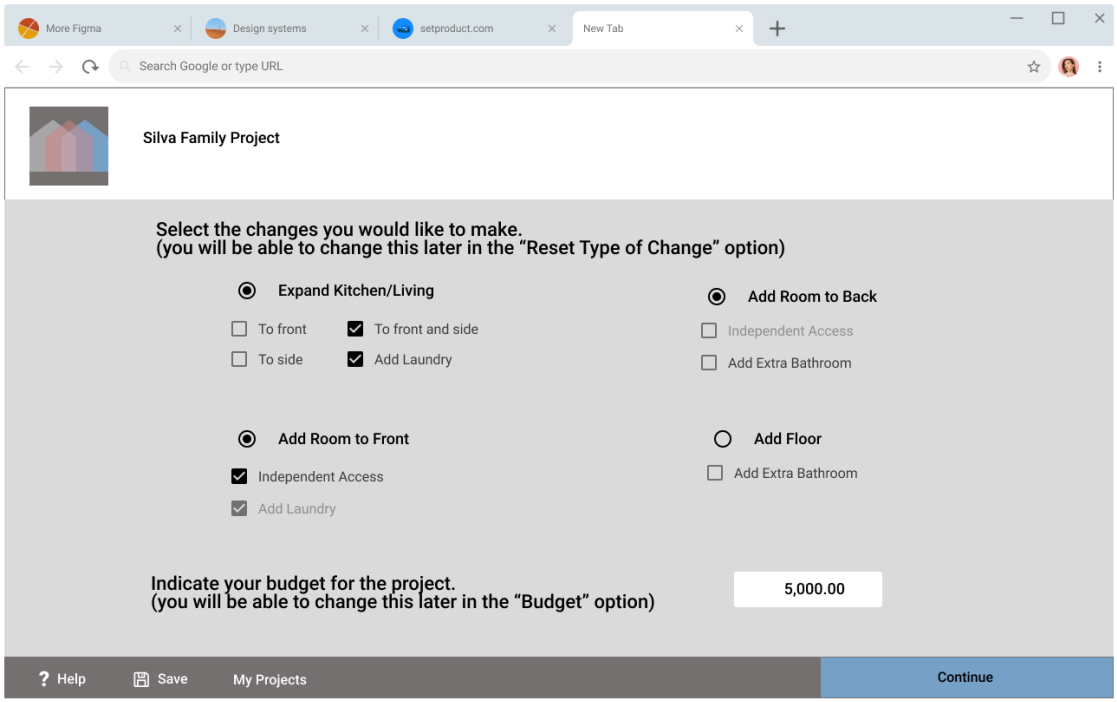

Figure 6.1 Example of needs-based selection and budget indication

6.3.2. Parameter-based interface

Once the user chooses to continue from the initial selection of needs-based options, the parameter-based portion of the configurator is shown; an example can be seen in Figure 6.2. This portion consists of a single page in which the user has the possibility of modifying the pre-defined solution that appears. The design options should include all the elements that the user can add to the design, as well as the possibility of moving or removing them. Furthermore, resetting the type of changes (the needs-based options) should also be available. Other options that should be visible on this interface include: viewing, saving, budget, the cost estimate to make the changes currently shown on the screen, and an option to view instructions about how to use the co-design system. The following sections discuss these options.

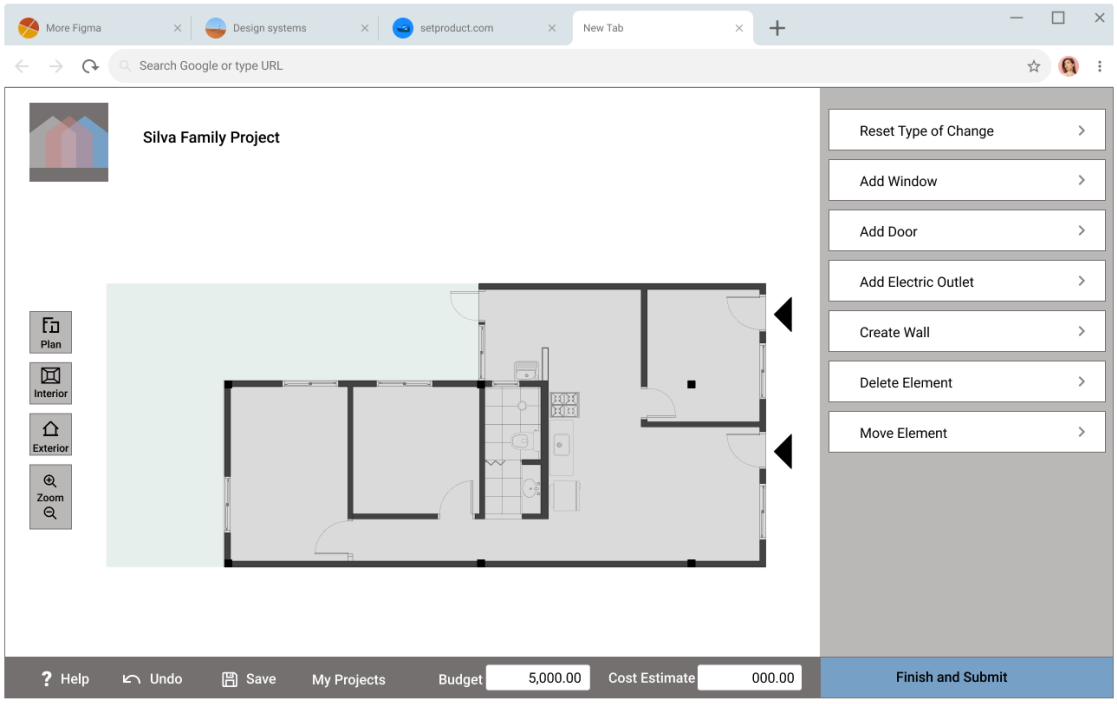

Figure 6.2 Parameters based interface

6.3.2.1. Design options

Each element shown as a possibility for changing the design should expand a sub-menu with the options available for that element, such as shown in Figure 6.3. In this figure, the options for adding a window are visible. The user can select from a menu of windows or input the dimensions of a window they already own. The options of windows that appear for selection are standard size, low budget windows. It is vital to have an option for the user to input dimensions for elements they own since it is not uncommon for families to have some of these elements donated to them by friends, relatives, or, in some cases, by organized non-profit initiatives. Furthermore, if a wall containing a window is demolished in the design, the user should see a

message, as soon as they select the add window option, asking if they would like to re-use that window. The elements added through these two options (input of dimensions, or re-use from demolished walls) should not have their cost added to the estimate. Once the user chooses which option they wish to add, the representation of the element appears on the screen and can then be dragged to a wall and positioned. Adding a door should work in the same way.

For adding electrical outlets, the options visible to the user are only the three standard heights the outlet can have on the wall. The user can then position the outlet horizontally on the desired wall. The representation of the outlet on the screen should be the standard symbol used for the representation of each of the three heights of outlets in electric circuit floorplans. The calculation of costs considers standard low-budget outlets and the minimum necessary wiring and conduits, which the system calculates as part of the validation process.

For creating walls, there is no need to include further options of types. Instead, the space of the sub-menu should show brief instructions on how to add a wall to the design. This task should be as easy as possible for the user. Clicking at the start point and dragging for the length of the wall is suggested. Similarly, the option to delete elements should also have brief instructions on how to proceed to remove the desired element. I suggest that once the user chooses this option, they should then select on the floorplan the elements they wish to remove, and those elements disappear immediately.

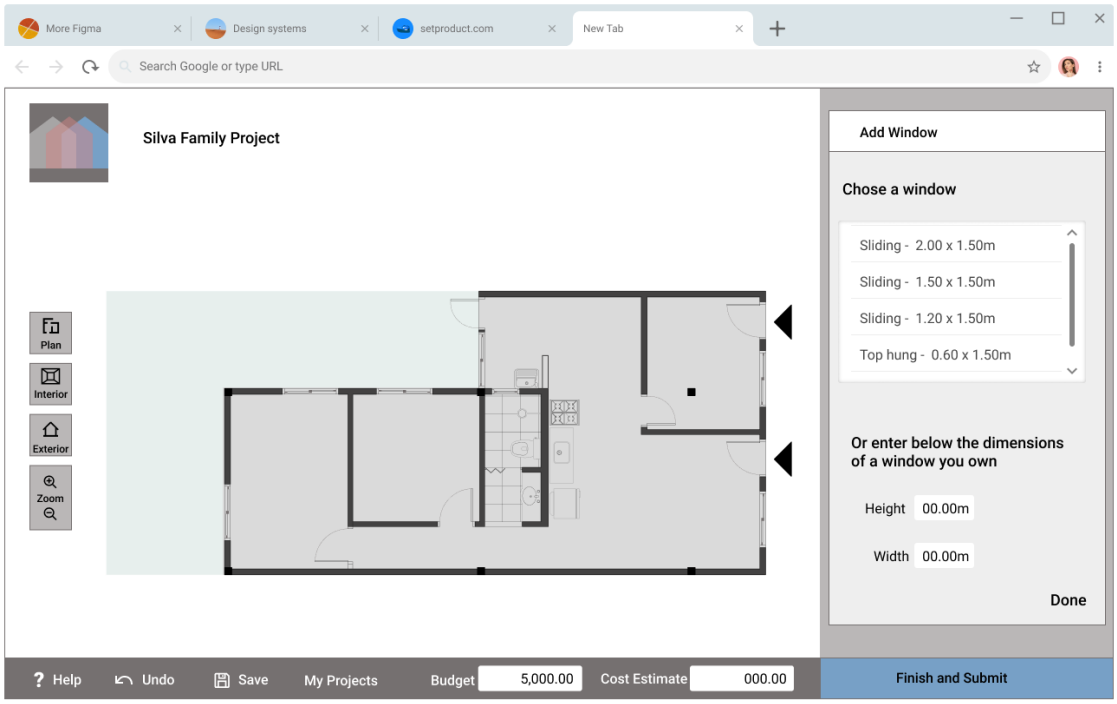

Figure 6.3 Expanded sub-menu

An option to move elements that are already part of the design also should be available. Once activated, this option allows the user to select and then move the various elements on the screen. However, each element has a different behaviour; thus, moving them should integrate the specific aspects of each element. Once selected, doors, windows and electric outlets can only be moved from side to side on the same wall or to another wall. Walls can only be moved perpendicularly to the wall plane, increasing or decreasing the size of the room. Other walls of the same room as the wall being moved would have their length automatically changed so that the room continues whole, with no gaps between walls. Depending on the initial unit design, the user should not be able to move particular walls, such as the original wet walls.

The sub-menu options for resetting the type of change (example shown in Figure 6.4) should show the same options as in the previous step. Using this option will reset the entire design. Thus, if new options are made through this sub-menu, once the user chooses ‘Done,’ a new pre-defined solution appears. If the user has not saved the changes they were working on, they should be prompted to save it to their projects folder before the new pre-defined solution is shown.

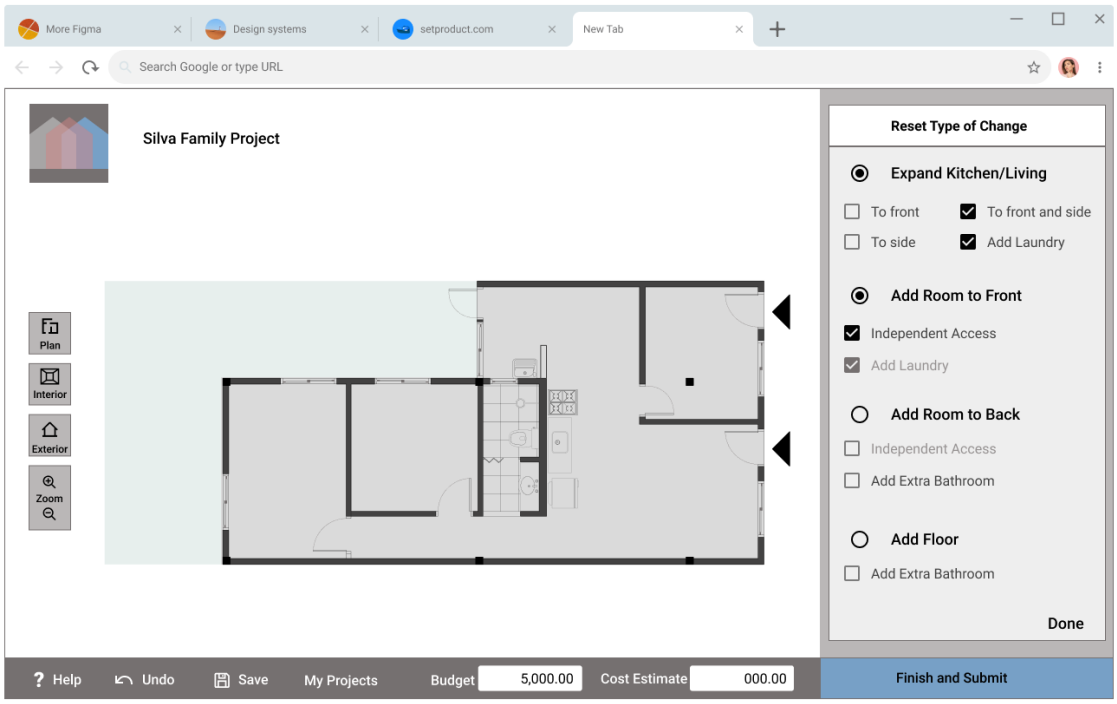

Figure 6.4 Reset type of change sub-menu

6.3.2.2. Viewing options

Many kinds of views are possible to be implemented for the visualization of products within mass customization configurators, from orthogonal views to rendered perspectives. Likewise, varying levels of manipulation of the views are also possible. The representation of the

product should allow the user to understand it while keeping the configurator as easy as possible to use. Usually, the more complex a configurator is, the more complex a visualization system is needed. As the proposed co-design system is of medium-high complexity, it requires more possibilities in terms of visualization so that the customer can explore the design and understand the implications of different choices. It should include the possibility to view the housing unit from different angles, including in three dimensions (Avella & Albano, 2017). Therefore, this section outlines the visualization elements for the co-design system.

Three main viewing possibilities are considered necessary, each with their manipulation possibilities: a floorplan view, outside views, and inside views. When the user selects the plan option, the system shows the floorplan of the entire unit, including any free space on the lot and both floors if that is the case. The users can then use the zoom option to zoom in and out. Zooming in should show more details on the floorplan, such as dimensions and position of electrical outlets. Usual shortcuts should also work within the view, such as scrolling to zoom in and out (pinching in mobile devices), and clicking and dragging to view different portions of the floorplan. Since the manipulation of the design requires changing dimensions of rooms and the positioning of elements, making such changes to the design should only be possible in the plan view. Therefore, the plan view should appear whenever the user selects any of the design options.

An exterior view should be available to show a rendered view initially of the façade of the house. The manipulation of this view can then show three-dimensional views of the outside from different angles. This manipulation should happen by clicking and dragging the view itself. The user can see rendered views of the interior through the interior button on the example. When chosen, the user sees a message to click inside the room they wish to view. Once the interior view

appears, the user can manipulate it by clicking and dragging, allowing them to look all around the room. It is important to note that the manipulation of the perspective is different for inside and outside views. For outside views, the camera can be moved around a fixed target in the middle of the house. For inside views, it is the camera itself that has a fixed position within the room. In this case, the camera can only be rotated (around both axes, vertical and horizontal) to allow the user to view different portions of the room.

The three-dimensional views, both inside and outside of the house, should not be photo-realistic renders. The system's focus is on the changes to the geometry and function of the building, allowing the user to explore possibilities in this regard. Using photo-realistic renderings could distract the user from the dimensional aspect considered more important in this case. Furthermore, if the materials are realistic and do not represent what the user intends for their house, it could be even more distracting. Several studies indicate that viewing photo-realistic images in early stages of the design process can lead to misconceptions about the precision of the design, and also hinder the viewer's willingness to make changes to the overall design due to focusing on details of materials (Chastain, Kalay, & Peri, 2002; Hannibal, 2005). Finally, to use photo-realistic renderings requires more processing capacity from the device, or more significant amounts of data transmitted over an internet connection, and could result in slowing down the co-design system. Therefore, non-photo-realistic rendered views that use colour-shaded faces have a higher potential to allow the user to understand the space as a whole without being distracted by other aspects, and to run smoothly on older devices or through slower internet connections.

6.3.2.3. Saving and other options

As suggested by Randall et al. (2005), "customizing a product is a cognitively challenging task typically requiring many iterations," and therefore, the system should allow customers to save their work and compare options. Thus, in the co-design system, I propose including the following two options to allow this: an option for saving the current project, and an option to view and open previous projects saved. In the figures, these options are represented by the 'save' button and the 'my projects' button. The save option allows the user to save their current configuration without submitting it. This option allows the user to continue working on this design later. The 'my projects' option brings up a list of the iterations the user has already saved; they can then select which one they want to open. This approach allows the user to work on several different designs and compare them.

Additionally, an 'undo' option could facilitate the co-design process for the user. While deleting newly added elements or moving elements back to the previous position would have the same effect on the design, using an 'undo' option to return to the previous state of the design is easier for the user.

Also aiming to make the process easier for the user, instructions for using the system should be available through a 'help' button. Selecting this option should open a separate window that allows the user to view the instructions without closing the design they are working on. This approach allows the user to go back and forward between working on their design and viewing instructions. Given the relevance of this option, it should be easy to find and identify through all the steps. The help page should open with explanations about the section of the system that the user was in when the option was activated. For instance, if the user activated the help option from

the needs-based interface, instructions about that section would be shown, but the screen still would allow the user to navigate to instructions about other parts of the system.

6.3.3. Validation

Validation should happen at the same time as the design choice, providing immediate feedback for each aspect as the users propose their solutions (Zhao, Mcloughlin, Adzhiev, & Pasko, 2019). For example, the system should allow a window to be placed on any wall of a proposed new room. However, if the window is placed on a wall on the limit of the lot facing into a neighbour's lot, the system should mark that solution and show an explanation of why it is not valid. Furthermore, the user should have the option of opening further explanation. This further explanation should expose the potential problems for the neighbourhood and highlight the problems for the family that is proposing the solution. Therefore, emphasizing the advantages for themselves of having a validated solution. It is the ranges for the parameters established within the solution space that determine if the design is validated. Therefore, all aspects that the system will validate should have the valid ranges of parameters previously determined in the solution space.

The co-design system can provide validation for many different aspects such as lighting, ventilation, compliance to urban policy, compliance to building code, the parameters of the building system, and structural integrity. In most cases, the building code already accounts for lighting and ventilation parameters. Similarly, several aspects of the building system are also part of the building code. However, depending on the building system used for the mass customization strategy, some aspects may still need to be validated separately. This is especially the case regarding innovative building systems for which, for example, specific dimensions and combination of prefabricated panels need to be validated.

When an element is added or moved, validation of the parameters associated with that element should run within the system to provide the user with feedback as necessary. The user only receives a message if there are any problems with the situation they are proposing. For example, when a wall is added or moved, the system should indicate if there are any problems before allowing the user to move forward with further changes. If the user placed a wall in an invalid position – beyond the limits of the lot, for example – then a message indicating the problem would appear. Once the user dismisses the message, the previous state of their design is shown, from before adding or moving an element into the problematic situation.

The other kind of message the user can receive in the case of windows refers to when it is in a possible position, but it does not suffice in terms of ventilation and lighting. In these cases, the user would receive a message indicating that the window is too small for that space, and requesting that the user change the window or add another. In this case, when the user dismisses the message, the changes remain but are highlighted, giving the user a chance to make the necessary modifications.

Structural integrity can involve a range of different aspects with varying complexity, not all of which need to be validated. How structural integrity is validated depends on the building system and the initial unit design, especially regarding how expansions can be made. For the example considered here, validation for structural integrity can be done by checking that no structural elements are being destroyed since all the structural elements are included in the pre-established solutions. Verifying that no load-bearing elements will be demolished is necessary in most cases.

Another aspect of validation that should occur as each change is made refers to calculating the amounts of added materials and components. For some aspects of the construction, this is the only validation needed since the user only receives the information, not being able to change it. This is the case, for example, for electrical installations. While the user can choose where to place electric outlets, the system should calculate the amounts of the electric wires and other elements needed to complete the circuits, and the user cannot change them. Similarly, roof elements the system adds cannot be changed. The calculation of materials is necessary to provide the user with an updated cost estimate. If the system is going to process information offline, it should download the updated costs for materials at the start of the process.

At the end of the process, the system should run a complete validation. This should include checking that all the elements in the final design are within the permitted parameters. At this point, the system should also process the final calculation of how much of each material is needed to build the proposed changes. It is important to highlight that this calculation of materials for the cost estimate should include only the added materials necessary to make the changes. Reused components should not add costs to the estimate.

6.3.4. Final steps and documentation

When the user is satisfied with their design, they select the option to move to the next step, ‘finish and submit.’ However, before moving to the next step, the user should see a message asking to confirm that they are sure this is the design they wish to submit to the local authorities, the design they are going to build. With this confirmation, the system then moves to the final complete validation. At this point, the system should request an internet connection if the processing is being done offline. The validated solution is then sent to the local authorities. Once this process is

finished, the user should see a message confirming that their design was sent and can now be built, prompting them to view the final documentation.

The final documentation should include architectural drawings such as a floorplan and section with dimensions of each element. These drawings should graphically differentiate between the original unit and new portions that need to be built. On the same page as each drawing, a stamp should be present to confirm the city's approval of the design. Part of the final documentation includes a list of the components and materials the user needs to obtain in order to build the solution. This list should include the amount of each material and component. Furthermore, instructions and tips for construction within the building system could also be made available at this point as further reference for the families. These instructions can be presented in a standardized manner for all the units that use the same building system. Moreover, the validated model should continue to be available for the family to visualize within the system. Being able to visualize the design from different angles and zoom levels could be helpful to the families during construction. All these materials should be possible to download and view offline within the system and provide the option for printing.

It is important to note that the final documentation for the user has varying aspects according to the chosen building system. For example, if the system is composed of prefabricated panels, the user would only see a list of which panels they need to build, not a list of the components that go into fabricating the panels. Similarly, the instruction documents would show how to assemble the panels. For traditional systems, these instructions could include things like best practices for electric installations and bricklaying.

6.4. Further possibilities

The functionality of the co-design system, as described in this chapter, represents what is considered the minimum to achieve the goals of implementing such a mass customization strategy. However, other possibilities could be implemented within the system to enhance the design outcomes further. More aspects could be considered in the validation of designs, like other comfort parameters.

The inclusion of further aspects must carefully consider several factors to ensure that it adds value to the mass customization strategy: (1) The benefits it could bring in relation to the added effort and cost of implementing it in the system, a cost-benefit evaluation. (2) Whether implementing those aspects could result in reducing the likelihood that the population will want to use the system. This reduction could be due to increased complexity and need for assistance to use the system, or increased limitation in the changes the user can make to design, for example. (3) Whether those aspects are within the capabilities of the devices that will be used to run the system. It cannot require so much from the device that it would be impossible to run on older or less capable devices.

For example, the generation of pre-defined solutions in the co-design system could incorporate environmental parameters to optimize internal comfort within the social housing units, such as shown by Mororó et al. (2016). Their system ran as a plug-in within BIM software, thus taking advantage of all the capabilities of that software. The implementation, in the co-design system, of a similar tool, capable of suggesting designs with optimal internal comfort, would require the inclusion of several other aspects within the co-design system, such as solar orientation. Furthermore, the results of implementing such a tool may not have the desired effect (of improving

internal comfort). The user could perceive the resulting suggestion as a prescribed solution for telling them where each room should be, or where and how big openings should be. Then, they would likely either change the design, reversing the value that such a tool would add to the system, or opt not to use the co-design system at all, compromising the benefits of implementing the strategy. All aspects added to the system will add complexity, and could make it more difficult for the families to use the system both because they could get lost with too many tools, or because the system might not run on the devices available to them.

Another factor that should be weighed when deciding what to include is what the city prioritizes. If it is a priority for the city to reduce energy consumption, for example, then this should be considered. In this case, implementing a tool to optimize internal comfort, as mentioned above, could be prioritized. This approach could be part of a more extensive city program and could mean that the city would approve only the solutions that had this optimization.

6.5. Feedback

This section discusses the feedback received from selected key stakeholders. During individual follow-up sessions I presented the mass customization system I designed to the stakeholders previously interviewed about the process of social housing provision. They were asked to give feedback on the aspects of the mass customization system about which they felt knowledgeable and comfortable to discuss. It is important to note that each stakeholder interviewed has only a partial understanding of social housing provision. Therefore, their feedback is limited to the portions of the process that relate to each of their roles within the process. For the structure of these follow-up interviews, see the presentation slides and questions in Appendix B.

Most of the stakeholders interviewed agree that there would be advantages in considering post-occupancy as an integral part of social housing provision. They believe that having funds to support the post-occupancy processes guaranteed from the start of the proposal for new developments would be a significant advantage. It would allow the better management of resources throughout the whole process (Interviews 1, 2, 3, 5, and 11). However, some interviewees considered that the funds reserved for post-occupancy renovation should account only for the added cost of managing the mass customization system and hiring someone to assist the families in using the co-design system, as proposed in my option requiring less funding. They considered that funds should not be reserved for each family to purchase the materials for the renovations. They commented that each of these families in formal social housing developments has already received a significant amount of funds to provide them with adequate housing. Therefore, any further funds explicitly designated for construction materials should go to families that are still living in informal settlements (Interviews 2, and 3). However, other interviewees disagreed and considered that having funding for materials post-occupancy within the proposed mass customization system would be a significant advantage. In their view, such funds would help to guarantee that the families' living conditions would continue to be adequate and healthy through time. These stakeholders stated that they are aware of many cases in which the original unit was transformed into inadequate living conditions shortly after the families moved in (Interviews 1, 5, and 11).

Regarding the proposed inclusion of flexibility guidelines in the regulation of social housing programs as part of the required parameters for the initial unit (shown in Table 8), most stakeholders agreed that it would benefit the programs by having a positive impact on the design

of the housing units (Interviews 1, 2, 3, 5, and 11). They agreed that such guidelines should be as quantifiable as possible and as detailed as possible to prevent misinterpretation and facilitate their inclusion in a "checklist" of compliance to regulation for project approval. While enthusiastic about the proposed inclusion of new flexibility guidelines, one of the architects considered that the other rules about the units, those that are already in place, should also be reviewed. He believes that while necessary to guarantee a minimum of quality for the housing units, these current required standards could also be improved aiming to achieve higher quality design for future developments (Interview 1).

Two interviewees highlighted that the original units' electrical system needs to be dimensioned to allow the growth of the units. They mentioned that the expansions made to housing units, including adding electrical circuits, has resulted, in many cases, in an overload of the original electrical equipment of the units and the neighbourhood. This has caused several problems, including fires (Interviews 5, and 9). Similar situations have also been reported in terms of plumbing and sewage being overtaxed by house expansions. Therefore, it would be useful to include specific guidelines about the electrical, plumbing, and sewage systems in the regulation of the housing units and of the neighbourhoods' infrastructure.

The developer interviewed noted that such flexibility guidelines should consider the different kinds of technologies used for the construction of the housing units. He believes that not all guidelines are applicable depending on the building system. However, he saw the inclusion of several guidelines, from which the company can choose a few to show compliance, as a positive aspect. In agreement with interviewee 1, he mentioned that the regulation of the units should allow more freedom for the companies to develop creative solutions. He is aware that there must be a

minimum standard because, usually, designs will include only the minimum required. However, he stated that having a set of options from which the company can pick a few to show compliance, as proposed for the flexibility guidelines, is an excellent way to require quality while allowing the company creative freedom within the project (Interview 9).

According to the interviewees, municipalities would be perfectly capable of preparing the co-design system. The interviewees' cities already do most of the interactions for project approval online. The companies upload the documents and plans in pdf format to be reviewed by the city. According to one of the architects, it also would be easy to require a BIM model with the rest of the documentation (Interview 1). However, the developer interviewed noted that his company does not currently use BIM in their processes. Thus, they would need to adjust their processes with an initial cost for software purchase and training (Interview 9). In this regard, one of the architects commented that his city is working towards requiring BIM models to approve all projects. However, he believes CEF will manage to implement this requirement before the municipalities, thus, forcing developers to produce such models for social housing projects (Interview 1). Therefore, it is likely that all developers and municipalities will need to transition to having BIM models as part of their processes soon. It is important to note that some municipalities already require such BIM models for publicly funded projects.

According to the city architects and engineers that I interviewed, having a tool to verify the project's standard parameters for approval would be beneficial for many kinds of projects. They commented that local legislation often leaves room for interpretation, which is not always beneficial. It can lead to some projects being denied approval for using the same parameters of other approved projects. In their view, having a digital tool to verify such parameters could help

maintain a standard for approval. The fact that the parameters would need to be implemented in the digital tool would force the city to decide the acceptable ranges for specific parameters, thus, eliminating subjective judgement for those parameters. Several interviewees see the potential for such a tool to make their approval processes much more agile (Interviews 1, 2, and 3). It is important to note that these interviewees envision a use for the co-design system that goes beyond what I proposed in this study.

Similarly, some interviewees see much potential for the co-design system to be used in other social housing contexts. For example, they considered that it would be a valuable tool in processes that happen under the technical assistance law. They see the potential for saving time and resources in generating relatively simple design solutions, which would solve the problem in most of those cases, with the input of needs from families, and automatic validation. In their view, such a system could even be used in informal settlements with the assistance of architects or other professionals, facilitating their work and allowing them to reach more families with less personnel (Interviews 1, 5, and 11).

For the context considered in this research, the interviewees highlight that having someone to assist the families in using the co-design system is essential because many families have difficulty using digital technologies or understanding floorplans (Interviews 1, 2, 5, and 11). However, several of the interviewees indicated that this is a problem only for the current generation of homeowners because they can see, through their work, how easily the children and teenagers handle all aspects of technology including those that require reading floorplans and maps. Thus, they believe that in the future, it will be easier for families to manipulate such a system without assistance. Related to this aspect, the interviewees also indicated including different ways of

visualizing the design, such as perspectives and façade drawings, is important (Interviews 1, 2, and 5).

The interviewees considered that having automatic design approval by the city would be feasible. Having a system to keep track of changes to housing units would also be useful in other contexts beyond social housing (Interviews 1, 2, 3, and 11). Interviewees 1 and 2 also considered that it would be essential to have an inspection mechanism in these neighbourhoods to guarantee that the families build the design that the city has approved. They mention that it is frequent, in many contexts, for people to seek approval for a project and then build something different. In their view, the financial benefits proposed, and the modified unit's legal status should only be granted once it is verified that the family built what was approved. One suggestion was that this inspection could happen in parts while the family is building and not only at the end. Another suggestion was that the projects' automatic approval would free time for the employee that reviews projects to carry out the site inspections.

When questioned about the availability of digital devices in those neighbourhoods, the interviewees noted that such devices' presence is extensive (Interviews 2, 3, and 5). However, they mention that there are significant differences from one family to another. Therefore, it would be useful to have a designated device to aid the families in using the co-design system. This device could be a laptop computer, for example, that the social work team members could either bring to the houses during their visits or use in a local school or community center. The interviewees consider that all the families have a mobile phone, but that their devices are sometimes too "simple" or old to use such a system. However, interviewees 2 and 3 expressed concern about taking such devices to some of these neighbourhoods since they can be violent places, and such

devices are highly targeted for theft. In a different perspective, a social worker expressed that she is always surprised by the apparent high value these families place on owning “top of the line” digital devices. She mentions that often when she visits such families, they will have deplorable living conditions but at the same time will have the “biggest” or latest smartphone (Interview 5).

In all the follow-up interviews, I asked the interviewee to indicate what they believe would be significant challenges in implementing such a mass customization system. The main challenges they indicated relate to political and cultural aspects. All interviewees indicated that the political power struggle is a challenge for implementing anything new in municipalities. They highlighted that politicians often want to perpetuate problematic situations, especially in low-income neighbourhoods, to increase the perceived need for such politicians in those neighbourhoods. Furthermore, they also indicated that having processes in place, such as those proposed in this study, could diminish politicians’ chances of requesting payoffs to facilitate processes within the city, such as guaranteeing the approval of projects. In sum, the systemic corruption present in the Brazilian public sector at all levels of government was what all interviewees perceived as the main barrier to implementing the processes I propose in this research.

An aspect noted by some interviewees as a potential barrier refers to such a system, especially the co-design system, relying on processes and technologies often perceived as eliminating jobs for professionals such as architects. However, shortly after making this comment, interviewee 1 mentioned that in his view no one does this kind of work anyway, referring to professional design for low-income families. Another significant aspect noted by several interviewees refers to cultural aspects of the families that live in these neighbourhoods. They noted that these families face many challenges and are often used to doing things in a certain way.

Building whatever they want, wherever they want, is one of those habits, which often remains from their previous living conditions. Since they had no other option in informal settlements, they would build a “hut” wherever they chose. Thus, reaching the families and gaining their interest in participating in a formal process could be challenging (Interviews 2, 3, and 5). However, interviewees 2 and 3 also commented that providing a formal way for the families to build legally could make it more acceptable within the community for the authorities to take action against illegal construction.

In sum, all the interviewees consider it beneficial to implement a mass customization system as proposed. Some suggested further purposes beyond what I proposed for the system. All the interviewees that are city workers requested if it would be possible to formally present this proposal to the city authorities. They were enthusiastic about the possibilities they saw in slowly implementing some aspects of what I am proposing. There were few aspects of the proposed mass customization system that were seen as negative or impossible to implement. The central aspect in this regard refers to the families’ inability to use the system by themselves. Therefore, there should be someone to assist the families in using the co-design system as proposed as one of the options for the system. The interviewees also made several suggestions that could further improve what is being proposed. Several of the suggestions referred to aspects of the system that would be necessary to implement to allow further uses that they envisioned. Therefore, the mass customization system proposed is a feasible solution to problems identified in this research. For future projects, there would be value in adapting some of the processes and tools proposed to other programs and contexts.

Chapter 7. Conclusions

This research acknowledges that the current way in which many social housing programs are organized in Brazil is problematic, especially the most extensive program Minha Casa Minha Vida (MCMV). It adopts a financialization approach that has been shown to result in many negative consequences for the neighbourhoods (Rodríguez & Sugranyes, 2012; Rolnik, 2012, 2013; Rolnik, Pereira, Moreira, et al., 2015; Valenzuela Aguilera & Tsenkova, 2019). Furthermore, many authors, as well as the expert informants interviewed for this research, have indicated the many problems that are a result of the current setup of MCMV housing program. These problems include many different aspects ranging from poor placement of new neighbourhoods within the city to poor quality design and construction practices. However, the literature review, and the interviews, also indicated that many practices and ideas within the current social housing programs have been present in social housing programs for decades. This includes aspects such as the standardization of design solutions and the perception that the provision of adequate housing is tied to individual ownership. Therefore, despite using the regulations of MCMV program as a starting point, this study sought to propose processes to address a problem that has been present in social housing neighbourhoods long before this program and is likely to continue. Furthermore, the processes were proposed for the benefits they could bring regardless of the social housing program in place when and where they are applied; thus, only needing minor adjustments for its application in many different programs in Brazil and beyond.

This research sought to answer two main questions: (1) How can a mass customization system be implemented in the context of social housing units for the lowest income range of

Brazilian programs and facilitate future additions and renovations to be made? (2) How can the interaction of families with the design of their unit be promoted to engage the homeowners in more informed choices aiming to improve the quality of the changes made to their units, thus promoting better environments in the unit and the neighbourhood? These questions, associated to considerations of how to answer them, led to two main objectives for the research: (1) examine the context of provision of social housing in the lowest income range in concert with the concept of mass customization to determine how mass customization could be applied; (2) propose a mass customization system for this context, aiming to promote better environments within the unit and the neighbourhood as these neighbourhoods evolve over time. Therefore, the path to answering the questions included an analysis of the context seeking to answer specific objectives, and the proposition of a feasible solution for the context considered.

The reflections from chapters 2 and 3 allowed me to propose, in chapters 4, 5, and 6, a mass customization system for the lowest income range of Brazilian social housing programs. As part of this mass customization system, I propose, in chapter 6, the use of a co-design system to allow the interaction of the families with the design of their house units. Thus, the research objectives were achieved through the proposal of the mass customization system and the discussions shown.

This research contributes to two main areas: mass customization of housing and social housing in Brazil. A significant contribution of this research to both areas refers to the analysis of the ecology of the system of social housing provision in concert with the concept of mass customization. The approach of examining the context in a broad way and including post-occupancy processes led to unique conclusions. The main conclusion from this analysis is that it

would be more feasible and generate longer-lasting benefits if the strategy focused on differentiating the units post-occupancy.

This conclusion led to the second significant contribution of this research to mass customization in housing. This research has shown a feasible way to implement mass customization with post-occupancy differentiation of the units. Furthermore, the proposed mass customization system also contributes to the area of social housing in Brazil. It demonstrates how a few changes in the existing processes could significantly improve the chances of maintaining adequate living conditions as social housing neighbourhoods evolve. It also shows how those few changes in process could reduce the problems for the families and the city that result from the changes families make to their housing units.

This research also contributes to the advancement of knowledge by showing that the main focus of mass customization strategies can be their broader benefits to society, achieved by providing customized products. The following section further discusses these contributions. Findings, contributions, and benefits of the proposed systems pertaining to the specific social housing context I studied were discussed in the previous chapters. The following section broadens the discussion to include other contexts and the theoretical contributions of this research to related areas, especially regarding mass customization of housing.

7.1. Discussion

A significant contribution of this study refers to the analysis of the broader context and interests of the stakeholders in the provision of social housing for the lowest income range of housing programs, in concert with the concept of mass customization, its processes and tools. Some previous studies have considered the benefits that mass customization could bring to the

social housing context and indicated some paths for its implementation. However, most of these studies focus on only a few aspects of the provision process or do not refer to post-occupancy as part of the process. Thus, they start from the premise that differentiation of the product must occur at the stage of the initial unit (Azuma, 2016; Taube, 2015; Taube & Hirota, 2017). In contrast, this study indicates that it would be more feasible and bring more and longer-lasting benefits to the stakeholders involved if mass customization were applied with differentiation of the units happening post-occupancy. I reached this result by looking at the broader context, the interests of different stakeholders, and considering post-occupancy as an integral part of the process of provision of social housing.

This research has shown that applying the concept of mass customization in the context of social housing for the lowest income range of housing programs could bring significant benefits to those neighbourhoods as they evolve. I discussed the significant differences between the way this concept is usually addressed, including in other housing contexts, and the way this research proposes its use in this context. One of the main contributions of this research is its demonstration of a feasible application of a social approach to mass customization, having the main focus on broader benefits to society. As in other mass customization applications, the concerns with implementing processes that can maintain low production costs while providing customized solutions and the customer-centric aspect, seeking to maximize the benefits to the user, are still present in the processes proposed by this study. However, the approach taken in this study focuses the aim of the strategy on broader benefits to society, the neighbourhood, and the city, by providing customized solutions that benefit the individual end-user, the families. This shift in focus of the concept's application also drives other differences in how the processes are proposed. The main

difference refers to the principal agent of mass customization being the local authority, the public sector, and not a private company, as seen in most other mass customization applications. Therefore, the proposed processes are not seen as a business strategy that brings profit to the agent that provides mass customization. Instead, it is seen as a strategy to optimize the use of resources to improve environments in the city, bringing benefits, through the customized product, not only to the families but also to other stakeholders and broader society.

In this regard, the proposed processes would make it feasible for families that are not usually concerned with following the city's urban and building codes when it comes to construction, to want to follow them. These processes provide a way in which these rules, and design within these rules, can become accessible to this population. Furthermore, the study considers that the strategy, and benefits stemming from it, are dependent on the families' willingness to engage with it. Therefore, the study proposes processes that not only make it easy for the families to engage but also that they would want to engage with it by gaining advantages that are perceived as such by them, such as reduced costs in materials and legal standing of the renovation within the city.

Aspects of the proposed way of applying mass customization in housing shown in this study could be valuable in many other housing contexts. The aspect of the initial unit not being seen as the final product, and the possibility of having differentiation occur post occupancy could be easily extended to other housing contexts. Several of the contextual aspects that lead to the conclusion that post-occupancy differentiation would be a better solution for this social housing context are also present in other contexts. For example, in North America family transformation over time is a factor that is often present in housing (Friedman, 2002). When combined with

concerns of housing affordability, which is also present in many housing contexts, post-occupancy differentiation could become an attractive option for families and developers alike, in suburban housing contexts. The developer would build initial affordable houses which could be customized or not (i.e., the mass customization strategy could start with pre-occupancy customization). As the families changed over time, they would continue to engage with the same company to build further according to their need and budget in a structured process of post-occupancy mass customization.

In North America, it may be even easier to overcome some of the challenges that in the context considered for this study imposed limitations to how the mass customization strategy could be applied. For example, lighter building systems such as wood-framing are widely accepted, and pre-fabrication within those systems is more widely available. In some of the examples shown by Smith (2010), in North America, companies that have pre-fabrication design systems in place may seek local factories, close to each of the sites where they will build, to keep the costs low. This could be an opportunity for companies to provide an initial small affordable unit combined with a system of design and prefabricated parts or panels of the same building system that the user continues to engage over time at their own pace. The user would engage with the design of their specific house using a co-design system as proposed in this study. This system would validate for all the parameters of the company's prefabricated system and building code. Once the order is placed the company fabricates and delivers the parts necessary for the expansion. The company can include building the addition in the services provided or, similar to the context of this research, the families can be responsible for the construction on-site. Further research within each context would be necessary to establish the specific processes of such mass customization strategies.

Similarly, placing the focus of the mass customization strategy on broader benefits to society by providing individually customized products could also be extended to other housing contexts.

It is important to highlight that, although arguing for post-occupancy differentiation, the processes proposed in this research are still considered mass customization. This research acknowledges the relevance of post-occupancy renovation within the context considered. However, it proposes the structuring of processes, both before and after occupancy, to bring about those customized renovations at lower prices than a regular renovation process (pure customization). Thus, the processes proposed in this research meet several of the definitions of mass customization given by different authors. Starting with Davis' (1987) explanation, the processes proposed here could reach a large number of families while treating them individually. Treating them individually is currently the norm for renovations and could be possible for low-income families, especially after the inception of the technical assistance law (Lei N^{o} 11.888, 2008); however, it is not possible to reach a large number of families with the current processes. The processes proposed also include the use of information technology, and organizational structures to be able to deliver the customized products while maintaining costs low, as indicated in a more practical definition of mass customization synthesized by Da Silveira et al. (2001). Without the organization of these processes, the post-occupancy customization that reaches a large number of families is not possible within legal and adequate design parameters. Furthermore, within the mass customization system proposed in this research, customization happens within a finite solution space in order to maintain stable processes aiming to achieve efficiency similar to mass production (Piller & Kumar, 2006). This is characteristic of mass customization and

strikingly different from the current craft renovation processes in which a specific and different process is put in place for each customer.

The processes proposed in this research follow the recommendations of many previous mass customization studies to organize the institutional processes to be able to deliver a mass-customized product. The main difference is that for housing most companies and studies consider that manufacturing must be finished once the family moves in, whereas this study acknowledges that for individually owned houses the manufacturing process continues long after the family moves in. This shift in perception to match the reality of the users broadens the scope in which the mass customization agent can operate. For the social housing context considered in this research, this broader scope allows the inclusion of more actors in the value chain of the mass customized product. Thus, the developer who builds the initial units is seen as one of the suppliers in a process that, as proposed, is managed by the local authorities. In other contexts, the developer could act as the main agent in the mass customization process and profit from the post-occupancy differentiation as explained above.

Aspects of dimensional or geometric co-design in housing are also relevant to discuss. It has been shown that an aspect that can add value to mass customized products refers to the satisfaction of the customer in perceiving themselves as the creator of the product, the “I designed it myself effect” (Franke et al., 2010). However, design complexity and the substantial investment in the product has shed doubt on whether this factor can be considered in housing. One of the reasons for dimensional mass customization of housing not being more widely available refers to the customers not having enough confidence or knowledge to take responsibility for the design of their homes; thus, it refers to social and cultural reasons and not technological limitations

(Kolarevic, 2015, 2019). Many people would prefer to buy the house they perceived as professionally designed even if they had the option of co-designing. Counteracting this is the need imposed by context within the low-income social housing scenarios. Many post-occupancy studies (e.g., Jorge, Medvedovsky, Santos, Junges, & Silva, 2017; Merisio, 2016; Palermo, 2013) in this context have demonstrated the users' willingness to design their own homes, given that the alternative is not building at all. Thus, with the use of the co-design system proposed, the resulting designs may still be perceived as more 'professionally designed' than the alternative. Furthermore, if implemented as proposed in this study, the user would still have an opportunity to express their needs and maintain the resulting pre-defined solution. As previously explained, these pre-defined solutions are a result of the decisions and expertise of professionals and, thus, could be seen as a way to bridge this lack of confidence in the user's own design skill when using the system.

Given the contextual conditions, these social housing neighbourhoods in Brazil could be the ideal place to begin the adoption of such geometric co-design processes, given the reduced emphasis of those social and cultural factors considered by previous authors as significant challenges to the broader adoption of geometric mass customization in housing (Kolarevic, 2015, 2019; Kolarevic & Duarte, 2019). Seeing such processes and their results within this context could be encouraging for developers to adopt geometric co-design in other contexts. Furthermore, positive results from the use of such a co-design system in this social housing context, could also be encouraging for users in other contexts in overcoming some of their insecurities with what they may perceive as self-design.

Explicitly referring to the Brazilian social housing context, this research contributes by showing that the adoption of existing technology could be used to facilitate technical assistance in

design. Design is one of the aspects for which technical assistance should be guaranteed to low-income people under the law Lei Nº 11.888 (2008). The processes proposed in this study show how technology, such as that proposed for the co-design system, could allow such assistance to be applied on a large scale, benefitting many more families without needing to increase the funds or personnel to the same proportion.

However, another aspect to be considered is that the adoption of such approaches also depends on factors that go beyond the availability of appropriate technology and feasible processes. The approach proposed through this study includes the adoption of several concepts and technologies that, despite significant research applications and literature, are still considered new for this social housing context. Such novel factors may face prejudice from the stakeholders involved that could slow the adoption of the proposed processes. Furthermore, some aspects of legislation could also be perceived as barriers to the adoption of concepts and technologies such as mass customization, generative design, and co-design systems.

One aspect that is particularly susceptible to prejudice and perceived barriers in legislation is the designation of responsibility for design. Currently, in Brazil, for architectural design to be legal, it must have a registered professional responsible for the design, usually an architect. This is the case even for individual houses, though for small houses the professional responsible can be a registered architectural technologist. While the legislation requests responsibility for the design, it is often confused with or seen as a synonym of design authorship. For example, the documents used to attribute responsibility for design are often used by architects as proof of authorship. Matters of authorship have been extensively discussed in literature in relation to architectural practice and even in attempts to understand to what extent the creator of a generative system or

the user has authorship of a particular design (Picon, 2016; Ruy, 2016; Theodoropoulou, 2007). With the use of a co-design system, as the word implies, it is difficult to attribute to only one person the authorship for each specific design solution achieved using the system. However, what the Brazilian legislation requires is the attribution of responsibility, which denotes accountability for the solutions of the architectural design. Although in traditional practice, especially in individual housing design, authorship and responsibility are often linked to the same professional, it does not necessarily need to be so.

What I propose in this study is that the layperson would only be able to propose solutions within the current regulations considering the ranges of parameters previously determined by professionals. If the legislation intends to ensure a minimum standard of design quality by having the design done by professionals, then it possible to argue that the designs resulting from the proposed co-design system have design professionals responsible for them just as much as housing designs carried out in a traditional way. The difference, in this case, is that the professionals use their knowledge and expertise to establish ranges of design possibilities within which any solution that the layperson proposes can achieve at least the minimum design standard required as long as the system validates it. For this purpose of ensuring quality in design, the author is irrelevant; with the proposed system legal responsibility still rests with the professionals. Thus, the designs can be legal even if the user is perceived as author of the design.

Even though a minimum standard of design quality can be assured, the responsibility for the design can still be perceived as shared between more than one professional. As proposed, if the system is to be used in more than one development, it still involves the design expertise and judgement of different professionals at different times. For example, those who initially create the

system, and those local authorities who choose the parameters it is necessary to validate for in each development. However, considering that it is not authorship that the legislation requires, it would be feasible for the local architectural authority to assume responsibility for the design. As proposed, this authority would oversee the process and select the validation parameters for each development; thus, part of the responsibility already would be theirs. This authority would also be involved in approving the use of such a system within the city. In order to take responsibility for the designs, the local design authority would have to assume responsibility for portions of the system that were not implemented by them. Thus, they would need to test the system to ensure that it is yielding design solutions that achieve the minimum design standards acceptable to them. Current rules are based on traditional modes of practice. It would be possible to attribute responsibility for the designs achieved through the system within those rules. However, as new approaches to design become more popular, professional associations and cities should also revise such rules to facilitate the adoption of such approaches and the benefits they can bring to the built environment and architectural practice.

In Brazil, another reason for legislation to require a professional to take responsibility for the design is to ensure jobs for such professionals. They usually also have minimum salaries and fees established by their professional associations. In this regard, the use of a co-design system could be perceived as reducing the chances of professionals to be hired to design the expansions. However, as shown by post-occupancy studies, very seldom do families hire professionals in this context. Even considering all contexts in Brazil, research shows that less than 15% of people that built or renovated hired a professional (Datafolha & CAU/BR, 2015). Having an alternate process to the traditional could, in fact, increase the market demand for such professionals. Currently, most

cities do not consider the possibility of providing such design assistance on a large scale, as proposed by this study. Despite legislation indicating that such assistance should be provided without costs to low-income people (Lei Nº 11.888, 2008), the costs associated with individual design done in a traditional way are too high. If these costs could be reduced, it could create an opportunity for cities to start viewing the provision of such assistance as feasible, increasing the need for design professionals to implement such an approach in a variety of different social housing contexts, not only formal social housing neighbourhoods. Currently, to assist a large number of families with their design solutions would require many design professionals to work individually with each family in a traditional design process. Since funding is not available to hire many professionals, such assistance is not provided, and no professionals are hired. If professionals were not required for designing individual homes, there could be an opportunity for cities to hire only a few professionals to oversee and provide some guidance to the families in the self-construction. This way, the city could reach a significantly larger number of families. This possibility would also address the construction aspect that was not addressed in this study.

Providing this assistance to the families to have validated design solutions could also serve as a justification for cities to take more severe action, such as fines and demolitions, towards problematic construction situations. The interviews done for this research indicate that there is currently a perception that any actions taken in this regard would be hurting an already vulnerable population and, thus, that such actions are not socially acceptable. This perception is intensified by the fact that most cities do not offer an alternative to the current practices of self-design and construction, making it morally and politically challenging to take serious action against such illegal construction. However, if processes such as those proposed in this study are in place and

design assistance is available to the families, then it would be a choice of the family to ignore such help and build problematic solutions. This could remove some of the perceived barriers around taking action to correct problematic situations; for example, demolishing construction that encroaches on public space. In other words, if the city is providing the conditions for families to build legally and these families still choose to build illegal solutions, then it could become socially and politically acceptable for the city to fine or demolish such problematic solutions.

7.2. Limitations and Future work

The mass customization system was proposed aiming to avoid problematic situations and achieve better quality environments as the neighbourhoods evolve over time. It is essential to highlight that this study aimed to improve the design aspects of the renovations the families make to their housing units. The goal of proposing how the families' design solutions could be improved was achieved. However, this does not account for problems related to construction. While this research proposes that construction manuals should be part of the documentation provided by the system to the families, this is not enough to prevent all problems related to poor construction practices that could occur. This is especially relevant given that usually, the renovations are self-built. Therefore, further research is necessary, addressing ways to ensure quality in construction within a self-building context.

In this regard, an aspect that also requires further research refers to pre-fabrication for self-building. While traditional building systems are currently the most well-accepted and available in Brazil, prefabricated systems are becoming more popular, especially for large developments. Research to develop prefabricated systems that could be used for self-construction within the

context of lowest-income range social housing developments could help address the quality of construction aspects mentioned above.

Although the processes proposed in this study refer to developments of house units, they could be extended to other types of developments such as duplex units. Although this housing type is less frequently used for the lowest income range of housing programs, authorities often also anticipate that there will be expansions to the units. In this sense, the problems are similar to those seen with the house unit expansions. Therefore, the processes proposed could also contribute to this context. However, some adaptation would be necessary, especially to get around land ownership issues and neighbour conflicts that may emerge. Previous research in another context has shown that there could be value in implementing collaboration and conflict resolution modules with a co-design system to address some of these issues (Lo et al., 2019, 2015). Further research in this regard for the context of social housing in the lowest income range in Brazil would be valuable to expand the proposed processes to other types of developments and units.

This study offers a conceptual design of the mass customization system based on the analysis of the existing social housing processes and the concepts involved in this research. The mass customization system proposed was not implemented and tested during the development of this study, thus, the process as whole was not validated in a real neighbourhood. Such implementation and testing would require a team of several people, the collaboration of the many stakeholders involved, and many years to implement and accompany how the neighbourhood evolves, even if only considering a small pilot project. Although implementing and testing the mass customization system in a real neighbourhood was outside the scope of this study, it is an important direction for future research. Implementing a pilot project through partnerships with

industry collaborators and the public sector will be a valuable way to further build and refine the solution. Partnerships with researchers from other areas, such as health and social work, will also be valuable for future research to allow the evaluation and validation of health and social outcomes along with the urban and architectural implications of such a pilot project.

An essential initial step, for testing of the mass customization system to be feasible, is to implement the co-design system. The co-design system proposed in this research outlines the concepts and tools needed to complete the processes of the overarching mass customization system. Furthermore, ways to overcome contextual difficulties related to access and familiarity with such technologies were also discussed for the proposed system. However, all aspects of the co-design system were proposed conceptually, based on literature, and previous experiences. Therefore, a valuable direction for future work would be to implement and test the co-design system with inhabitants of existing social housing neighbourhoods. This would allow the refinement of the solution based on observation of the system's use, and insights provided by the families regarding the system's usability.

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Appendices

Appendix A: Interview questions

(1) Questions asked to all the stakeholders interviewed.

- What is the role of your agency in the process of provision of social housing?
- In any moment of this process, does your agency interact face-to-face with the families to whom housing is being provided? If so, where and how does this interaction happen?
- Does your agency interact with other agencies through in person meetings? What are other ways in which your agency interacts with other stakeholders? Do you consider these interactions efficient and sufficient for what your agency does within the process?
- Does your agency provide assistance of any kind to the families after they move into the new development?
- Does your agency collaborate with any other agencies to provide such assistance?
- What are some of the challenges your agency faces within the process of provision of social housing?
- Are there any aspects of the process of provision of social housing that you consider should be changed, and why?

(2) Specific questions asked only if relevant to the stakeholder being interviewed.

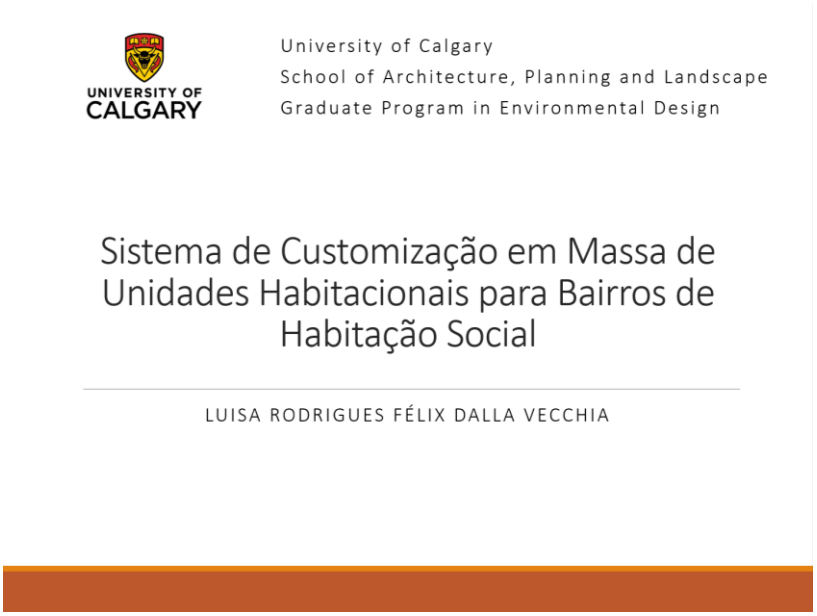
- Does your agency have any mechanisms or strategies in place to guarantee quality of design for new social housing developments? In your opinion are these mechanisms efficient in

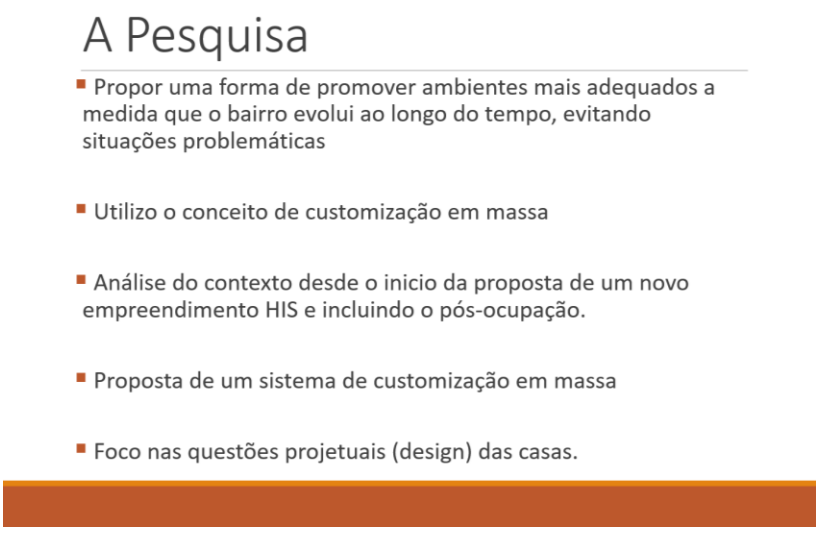
guaranteeing such quality. What are aspects you consider good and aspects you consider could be improved on?

- Does your agency take part in the design of the new developments? In your view, how does this participation benefit the final design?
- Regarding the expansion of the social housing units, does your agency have any programs in place to assist with these? How does it work? Why not?
- How does your agency view the expansions the families make to their houses, particularly those which are not regular (illegal expansions)? Does your agency act on these illegal expansions in any way? How or why not?
- Do these expansions result in any problems which your agency has to deal with later? If so, how does the agency deal with these problems? Does the agency have a budget specifically for this? In your opinion what could be done to avoid these problems?
- What kind of programs does your agency offer to the families after the development is implemented?
- How does your agency evaluate the outcome of these programs?
- What other programs do you consider would be important to offer and why? Why are they currently not offered?
- In your opinion what are good aspects of these programs? What do you consider could be improved? What are some challenges your agency faces for improving these programs?
- What kind of commercial activities does your agency encourage to take place in the housing units?
- What kind of activities does your agency discourage and why? Is this regulated in any way?

- Does your agency have any mechanisms in place to be able to approve, disburse funds, and inspect alternative construction timelines for the social housing developments? (for example timelines that would have foundation work and in factory construction taking place at the same time)
- How often do developers seek this kind of alternative approval?
- Are there any aspects, beyond those required by legislation, that your agency looks for when choosing which social housing projects to approve?
- What are the reasons you perceived as decisive for having your social housing project approved/denied by the city?
- What are the reasons you perceived as decisive for having your social housing project approved/denied by the funding agency?

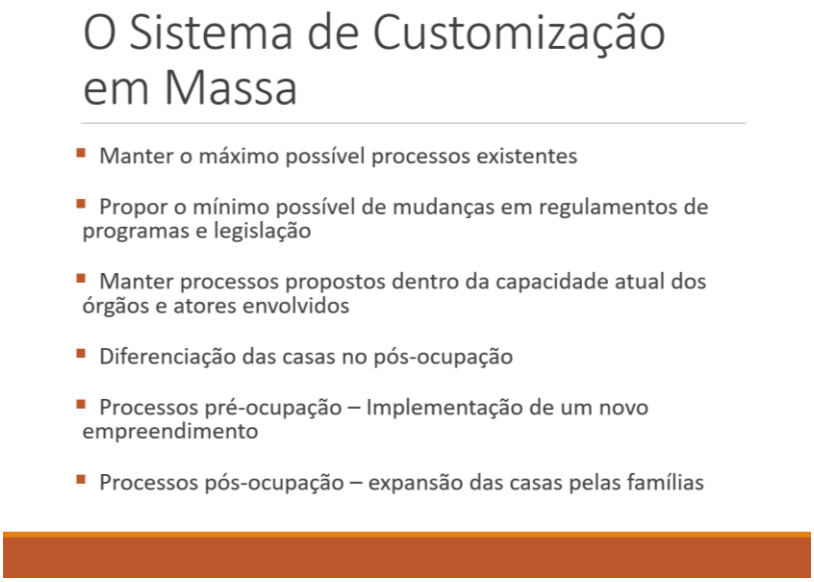
Appendix B: Customizable presentation and notes for requesting feedback





- Brief overview of what the entirety of the research is about.
- Main goal of proposing a mass customization system to promote better environments as the social housing neighbourhood evolves.

- To get there, an analysis of the whole ecology of the system was necessary.
- I propose a mass customization system for this context, and this is what I am going to present and ask feedback about.

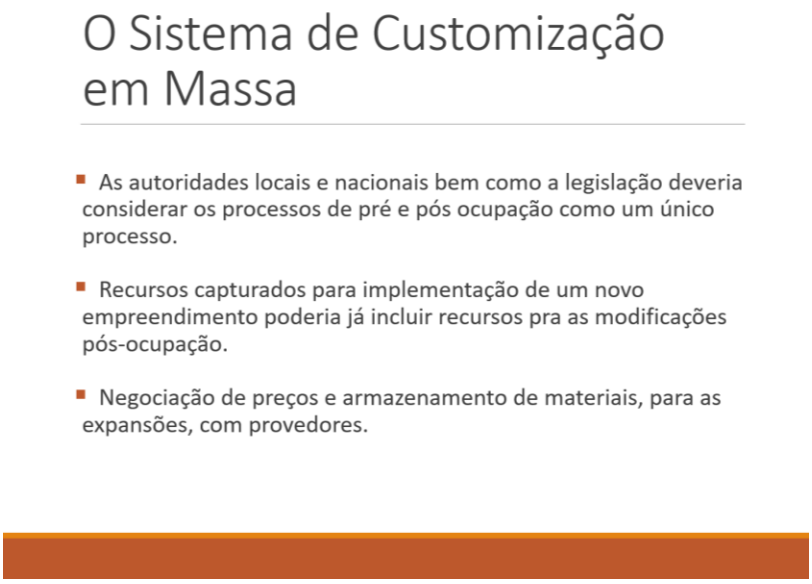


Explain overarching consideration I had for proposing the system

- Propose as little as possible changes to existing processes and regulation
- Maintain all processes within current capabilities of the stakeholders (ask later in the presentation: targeted questions of parts of the process that I am proposing and think that the person being interviewed could indicate if it is within the capability of what they currently do).
- After the analysis of the context, I concluded that it would be more feasible to differentiate the units post-occupancy in the processes. The processes' focus is to facilitate for the families to make changes to their units within acceptable design parameters in terms of comfort, urban, etc.

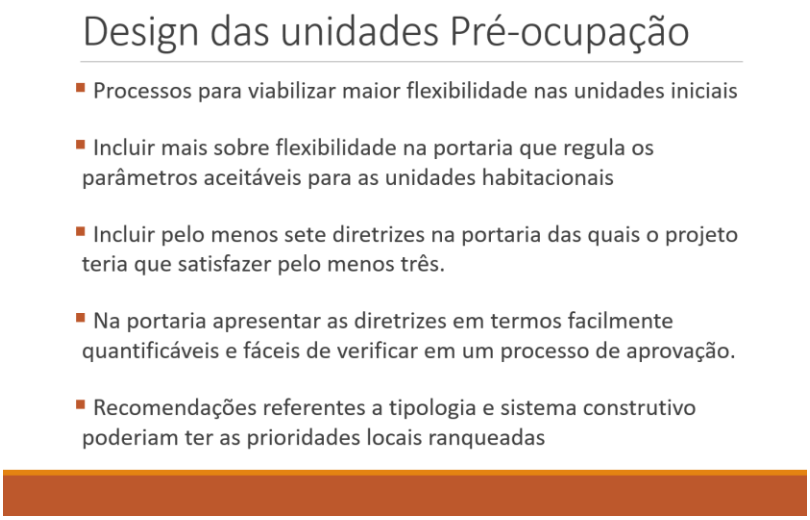
- However, I still propose processes pre-occupancy aiming to facilitate this differentiation and processes post-occupancy

Depending on who is being interviewed, the presentation is further focused, from this slide on, on the processes pertinent to that person. For example, with social workers, I still discuss the pre-occupancy but focus more on post-occupancy processes. The most complete presentation is shown to architects because they have more understanding of the design aspects, which are the focus of this research. Based on each of their roles, I ask targeted questions focusing on their specific role within the process. Some of the slides are different to show and ask about aspects that are being proposed that may affect their role specifically. Throughout the presentation, I also highlight the aspects that are being proposed that would change or add to the stakeholders' role or that they would be able to contribute to even if it is not part of their specific role. This is the complete presentation indicating customizable aspects.



Initial considerations about the process

- It should all be seen as one integrated process, not as two separate things (pre-occupancy and post-occupancy), including for funding purposes. (ask feedback from all stakeholders)
- I propose that funds for post-occupancy differentiation of the units should be included in the funding of each new development, similar to how the funds for post-occupancy social work are guaranteed in the initial funding. Depending on how much funding could be included, it would serve different purposes. It could be only to support the use of the system and maybe hire someone to work on this as part of the social work team, or it could also include funds for each family to buy materials. (ask feedback from all stakeholders)
- I propose that the city should negotiate prices and storage of materials for the families that engage in this mass customization system. (ask feedback from city workers)



Proposed processes to allow the initial unit to be more flexible.

- I propose adding flexibility guidelines to the regulation from which the developer would have to show compliance to at least 3
- These guidelines should be quantifiable and easy to check for in an approval process. (ask feedback from the developer, city workers, and other architects)

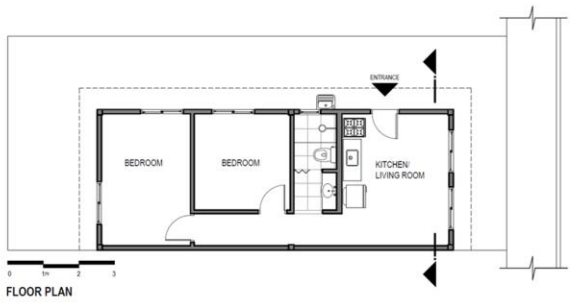
Design das unidades Pré-ocupação

Diretriz a partir de Brandão (2011)	Texto proposto para a portaria	Como poderia ser demonstrado no projeto
Definir a altura da cumeeira, adequada às ampliações	Definir a altura da cumeeira a uma altura que permita adicionar um cômodo de pelo menos 2m de comprimento ao longo da caída da água do telhado sem a necessidade de mudar a inclinação de tal água.	Incluir na documentação arquitetônica plantas e cortes que incluam o cômodo adicionado ao longo da água do telhado demonstrando que esta mantém o mesmo ângulo de inclinação e que o cômodo está dentro das regras de alturas mínimas da localidade.
Permitir a criação de novas águas sem afetar a funcionalidade	Permitir a criação de novas águas sem afetar a funcionalidade.	Incluir na documentação arquitetônica desenhos da unidade com a adição de novas águas.
Separar, se possível, estrutura e vedações	Separar estrutura e vedações de tal forma que as vedações possam ser removidas sem prejuízo a integridade estrutural da unidade.	Salientar na documentação arquitetônica a separação entre elementos estruturais (que não podem ser demolidos) e elementos não estruturais (que poderão ser demolidos).
Preparar a estrutura para receber um ou mais pavimentos	Preparar a estrutura para receber um ou mais pavimentos	Incluir na documentação arquitetônica as cargas usadas para calcular os elementos estruturais bem como destacar quais foram os elementos incluídos para permitir a adição de pavimentos à unidade.
Prever paredes hidráulicas permanentes	Posicionar paredes hidráulicas de tal forma que a cozinha e outros cômodos possam ser expandidos e que cômodos possam ser adicionados ao seu redor sem que estas paredes precisem ser demolidas.	Incluir na documentação arquitetônica desenhos da unidade habitacional com cômodos adicionados ao redor das paredes hidráulicas demonstrando a funcionalidade sem necessidade de demolir tal parede.
Prever afastamento que permita ampliar para frente	Prever afastamento frontal de pelo menos 2m.	Demonstrado na documentação arquitetônica.
Adotar terrenos mais largos	Adotar terrenos com testada de pelo menos	Demonstrado na documentação arquitetônica.

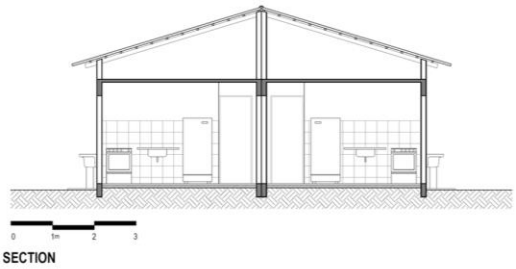
This table shows the guidelines that I am proposing that should be included in the regulation of the programs to increase the flexibility of the units.

Show in the interview to architects and engineers, and to the developer showing how I am proposing the guidelines should be written and quantified. Ask for feedback regarding their capability to do and demonstrate these aspects in the architectural documentation (developer) and to check for compliance for approval (city workers), or how it could potentially impact their processes.

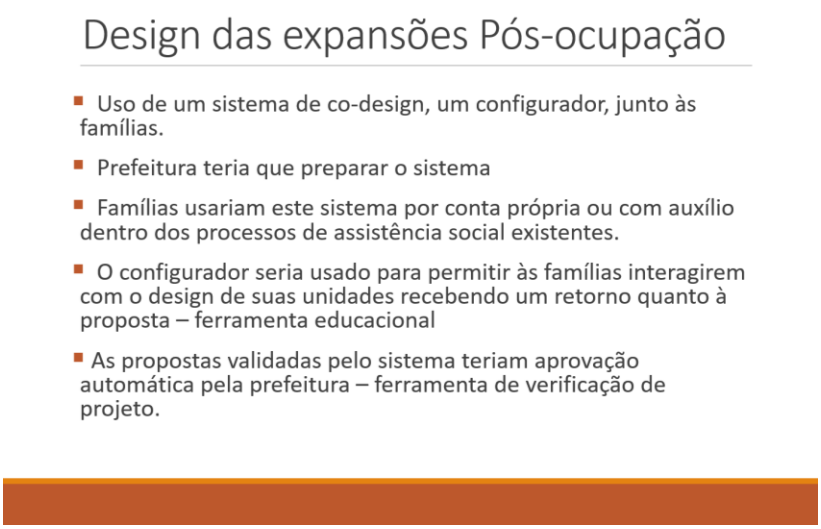
Exemplos



Exemplos



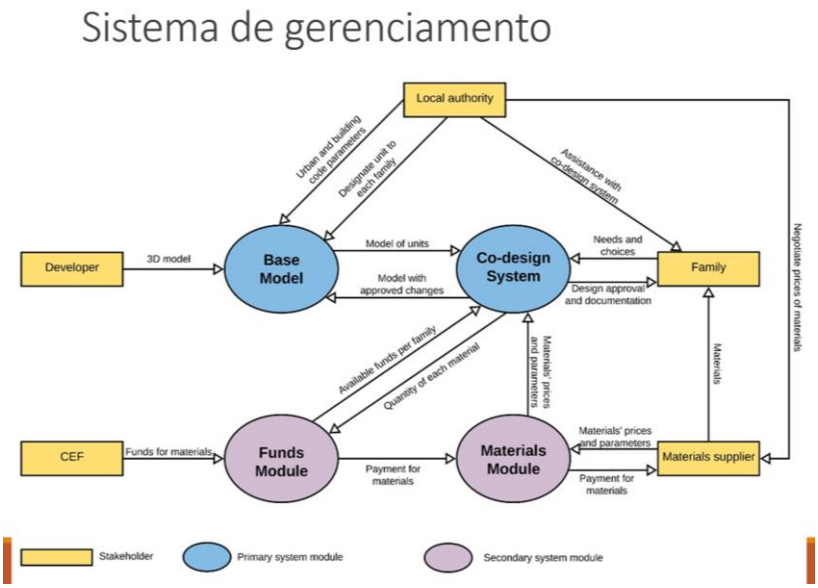
Show the example of initial unit design to architects to demonstrate some of the aspects being proposed.



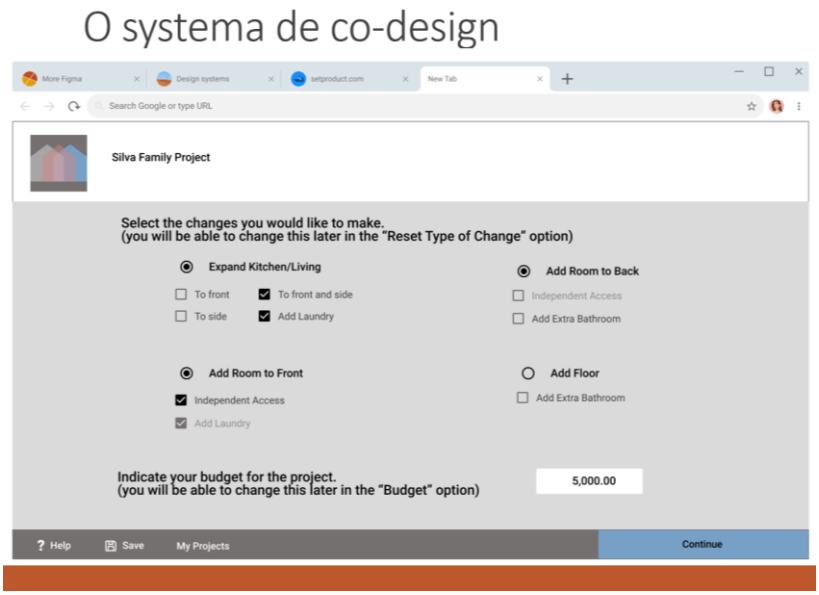
The discussion around post-occupancy processes with the developer is only an overview since they are not currently involved in post-occupancy processes. In the proposed new processes, developers would also not be involved in the post-occupancy processes.

This slide shows proposed aspects linked to the post-occupancy design of the expansions to give an overview of the purpose of the co-design system and how it would be used.

Ask for feedback from architects and social workers, highlighting the implications to each of their roles.

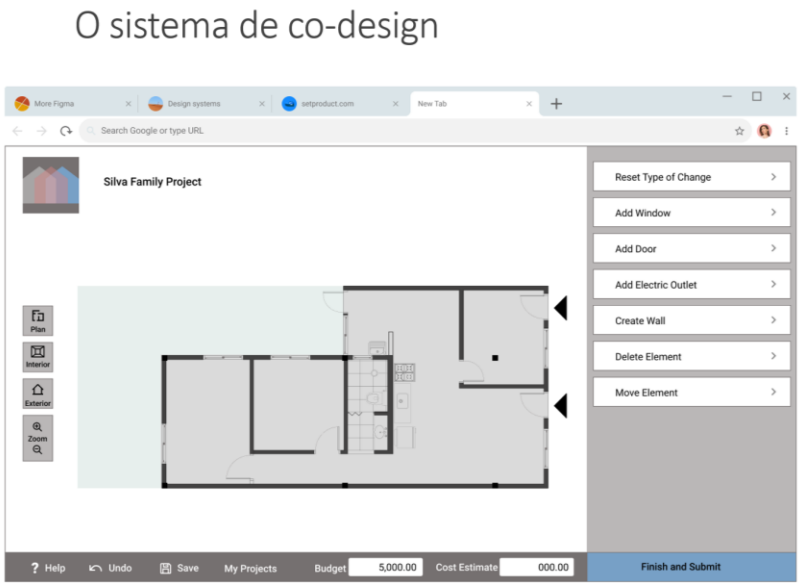


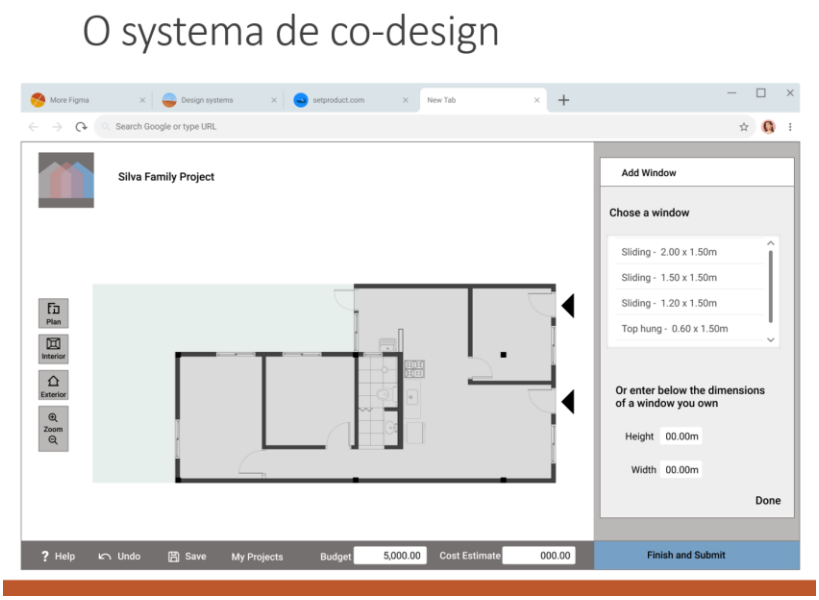
Explain the overarching support system focusing on what it means for the stakeholder being interviewed. Ask about their capability of interacting with such a system and the city's capability to use and maintain such a system (not develop it). There are already some city services that use digital systems to interface with people and help manage some processes, so they may be able to draw a parallel and point out aspects that could be challenging.

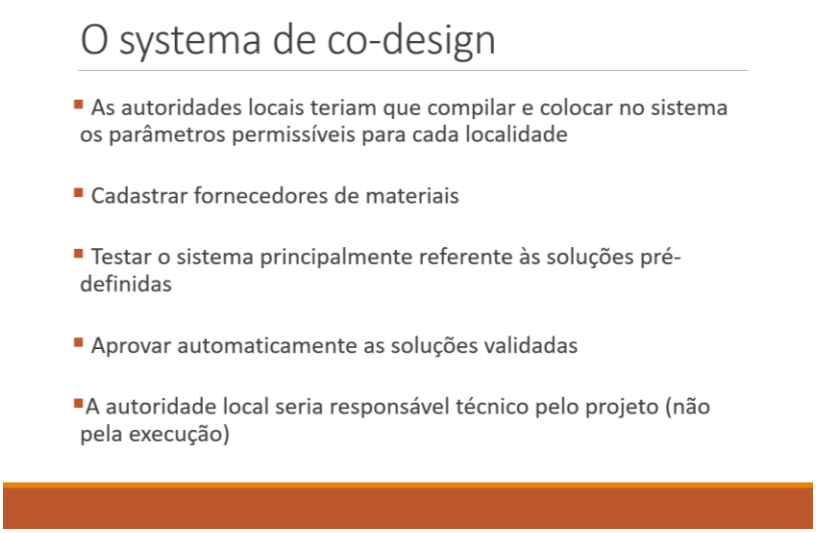


Step by step overview of the co-design system.

Explain how assistance to use the co-design system would be provided to the families (ask for feedback from architects and social workers)







For the co-design system to work, the local authorities would have to do several things that they do not currently do, such as deciding which local parameters and their acceptable ranges to use and input in the system, register material suppliers, and maintain the system.

When interviewing social workers, highlight the aspects that impact them, such as the proposal that their team could assist the families in using this system during the on-call sessions or talk about it in general meetings with the families. Ask to what extent they think it could be done with the current team.

Exemplos

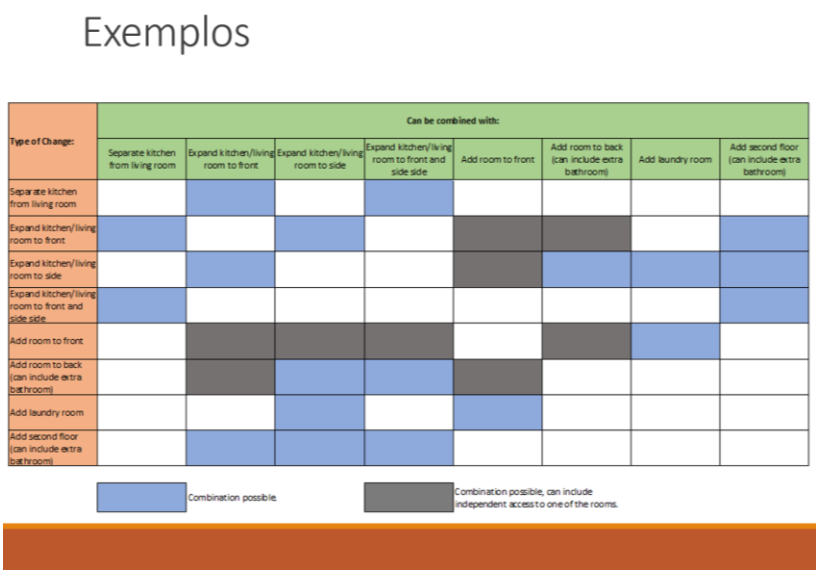
Parameters for Validation per Room Type					
Room type		**Area**	**Height**	**ventilation and lighting (windows)**	
Living spaces (e.g. living room, bedroom, work space)	bedroom	minimum area for first bedroom - 8m² all other bedrooms minimum area - 6m²	minimum 2.4m	Must have windows directly to outside; Minimum area of window = 1/6 area of room.	all windows used for lighting and ventilation must be at least 1m away from any wall it faces, 1.5m away if facing a wall belonging to another unit (must be 1.5m away from division line of lot on sides and back)
	other				
	kitchen	minimum area - 5m² area must allow the insertion of a circle of diametre 1.5m.			
Transient spaces	Corridors	minimum width of 0.9m.	minimum 2.2m		
	bathroom	Minimum area= 2.3m². If lavatory is external, minimum area = 1.8m².Must allow the insertion of a circle of diametre 1.1m. Must have free circulation space with width of at least 0.6m; Minimum shower space must allow the insertion of a circle of diametre 0.8m.		Minimum area of window = 1/8 area of room. Can have window opening to another compartment in which case that room must include this area in the calculation of its window.	
	others				

Exemplos

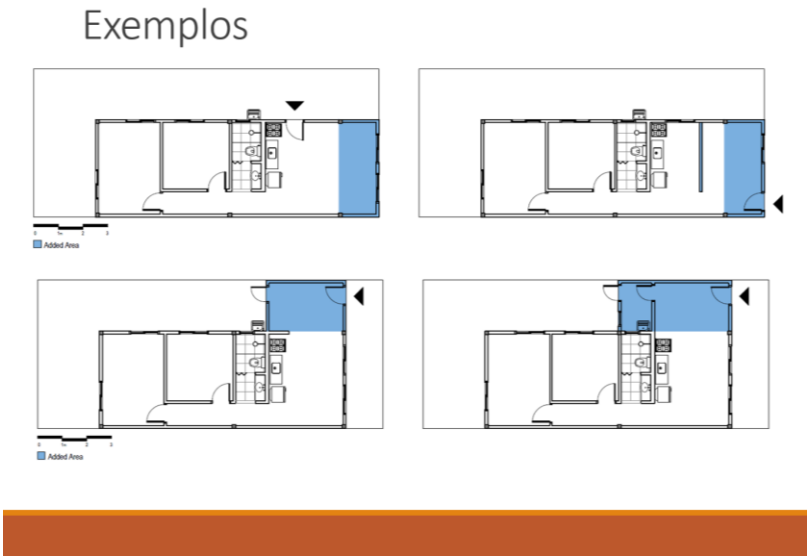
Other Parameters for Valitation			
Stairs	minimum width= 1m	minimum ceiling height at every step = 2m	Formula for dimension of steps: 2h + b = 0,63 to 0,64m; h=height of step; b=depth of step; maximum h=0.18m; minimum b=0.27m.
Walls	Mininmum height = 1.8m	maximum height = 3m	walls to the street (front of lot) must have 70% permeability beyond the height of 1m.
General	nothing can be built past the limits of the lot.	maximum height of building = 10m	

These slides with tables are only shown to architects.

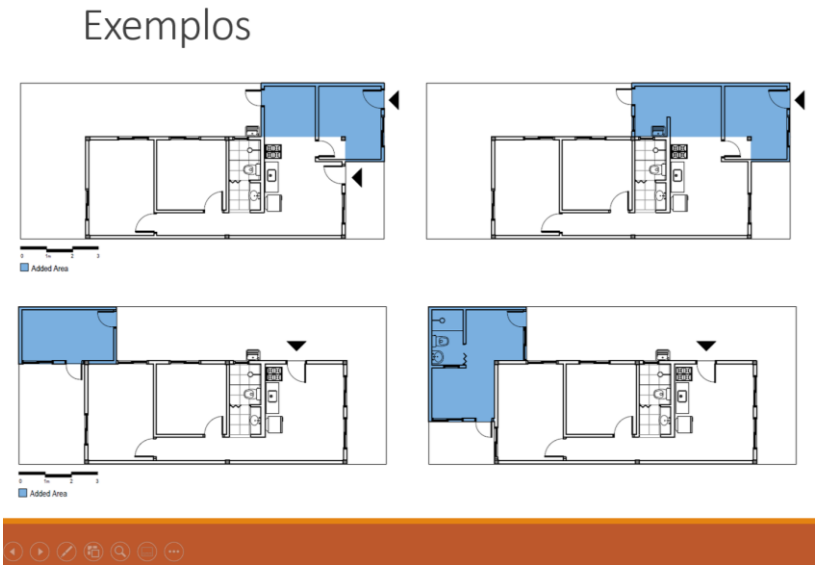
Briefly mention the types of parameters the city would need to compile for use in the co-design system and show how they can be compiled since current urban and building codes are not written in this way. This information is spread out through pages of at least two separate documents. Cities often waive some requirements when considering social housing developments, such as allowing no setback in areas where it would usually be required. Sometimes these reduced parameters already appear in the code in a social housing section but not always. Explain that to use the proposed system would require such parameters to be input in the system, so they would have to be decided if they are not already (which parameters are necessary to validate for and the acceptable ranges).

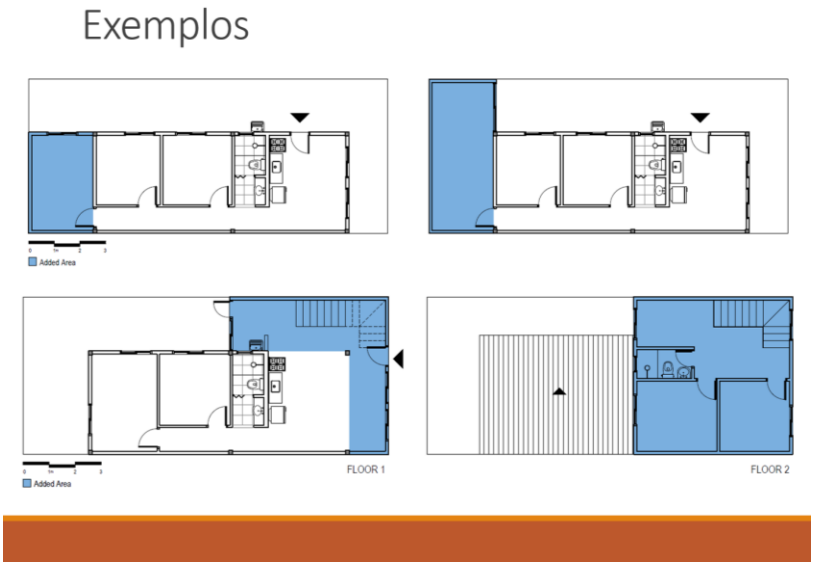


Explain the types and combinations of pre-defined changes and how they could be generated through the system.



Show some examples of pre-defined solutions possible through the system being proposed. Explain that all these options are within legal parameters for the city and could receive automatic design approval.





Ask for general feedback, including positive aspects and aspects they consider may not work if implemented as proposed and why.

Ask for their perception of the main challenges for implementing such a mass customization system.