EXPLORING THE USE OF THE LEAN PRINCIPLES TO DELIVER AFFORDABLE HOUSING IN LATIN AMERICA

by

Eder Martinez

A dissertation submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy in Engineering - Civil and Environmental Engineering in the Graduate Division of the University of California, Berkeley

Dissertation Committee in charge:
Professor Iris D. Tommelein, Chair
Professor Carolina K. Reid
Professor C. William Ibbs

Summer 2016
Exploring the use of the Lean Principles to deliver affordable housing in Latin America

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ABSTRACT

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Finding the means to scale up the provision of adequate and affordable housing is a global challenge. In Latin America, several countries have favored the implementation of a Direct Housing Subsidies (DHS) policy. The DHS policy has encouraged the involvement of private developers in housing provision, increasing housing construction and helping countries to reduce housing shortages. However, in the last decades, several issues related to design and construction quality of affordable housing developments built with DHS have been revealed. The inadequate location and excessive size of developments, in addition to the disconnect between the housing units’ design vs. resident needs, have affected the quality of life of subsidy beneficiaries. Thus, housing provision under the DHS policy has to address two main challenges. First, to increase housing construction in order to cut the remaining housing shortage. Second, to improve the quality of design and construction of affordable housing developments.

Literature dealing with issues on affordable housing provision in the region focuses on the macroeconomic aspects of the DHS policy. Studies emphasize the flow of resources and interactions among housing supply stakeholders so that low-income households have sufficient funds to purchase their house and private developers sufficient capital to invest in housing production. Despite the pivotal role that private developers and the construction industry play in housing supply, the potential benefits of improving industry efficiency in housing production have received little attention. In this aspect, the use of Lean Principles in the delivery of affordable housing may contribute to addressing housing constraints in terms of housing design and production efficiency.

This research explores the potential use of Lean in the delivery of affordable housing in Latin America by analyzing the DHS policy context and its implications for production systems. For this purpose, the research includes the analysis and comparison of three Case Studies of affordable housing provision in Latin America. The researcher defines a framework to analyze and compare the use of Lean Principles in the three Case Studies based on the fourteen Lean Principles described by Liker (2004). The researcher describes the approach for housing provision in each Case Study and provides insights about the outcomes of Lean implementations.

By analyzing and comparing the Case Studies the researcher reveals opportunities and challenges on the use of Lean Principles for affordable housing delivery under the DHS policy. The researcher found that the housing policy in which the production system takes place can help or hinder the implementation of Lean initiatives. It was also found that the excessive fragmentation of the construction industry and the increased number of stakeholders involved in the project delivery process are the main barriers for Lean implementation. In terms of construction cost and efficiency, the researcher found that Lean initiatives may drive value generation, cost savings, and reduction of delivery time to customers when implementing a house customization strategy. The research
also shows that depending on the scale of the project, the building capacity of residents and the local economy can be incorporated into production systems design. This research contributes to knowledge by 1) Providing a rational connection between issues in affordable housing provision in Latin American countries and the potential benefits of using Lean Principles. 2) Synthesizing literature on the use of Lean Principles and Practices for affordable housing. 3) Documenting Case Studies on the use of Lean Principles to deliver customized affordable housing. 4) Describing and proposing novel Information Technology tools to facilitate project planning and control. 5) Describing innovative approaches for affordable housing delivery from a Lean Perspective. 6) Revealing opportunities and challenges for implementing Lean in the context of Latin America and contributing to understanding how these can improve the efficiency of housing design and construction in the region. 7) Providing an analysis of how Lean Principles may be implemented in affordable housing in Latin America. 8) Proposing a new model of housing provision in Latin America that aims to combine the positive aspects of the Case Studies covered in this research.
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ACKNOWLEDGMENTS

It would not have been possible to reach this point and write this dissertation without the help and guidance of several people that have supported me during all these years.

I would like to thank my family. Despite the fact I have been many years away from home trying to reach my academic and professional goals, my family has supported me unconditionally along the way. I would also like to thank my beloved wife and her family who joined me in the second half of this journey.

Becoming a Ph.D. would not have been possible without the guidance and support of my advisor Iris Tommelein and the committee members of my dissertation Carolina Reid and William Ibbs. Special thanks to Alice Agogino who devoted significant time discussing my research and participating in my qualifying examination.

My time at Berkeley would not have been the same without the help and support of my Chilean amigos Ernesto Guerra, Cesar Díaz, Rodrigo Araya, Nacho Gutiérrez, Pablito Munoz, Virginia Rivas and Carolina Munoz (only to mention a few). I was very lucky to have them all the time by my side.

I would like to thank my colleagues in McLaughlin 407. Paz Arroyo, Audrey Bascoul, Dani Dietz Mike Taptich, Adam Frandson, Nigel Blampied, Doanh Do, Andy Yu, Rolf Bohne and Sigmund Aslesen for all those inspiring discussions about Lean (and other topics) that in one way or another helped me to think critically about our field and brought many ideas that enriched my dissertation.

I spent significant time working in the Villa Hermosa Project. I am very grateful to the project owners and Ariana Alvear who allowed me to participate in the project. My gratitude also goes to Villa Hermosa’s engineers, architects, field engineers, supervisors and construction workers.
DEFINITIONS

Advantage A benefit, gain, improvement, or betterment. Specifically, an advantage is a beneficial difference between the attributes of two alternatives.

Attribute A characteristic, quality, or consequence of one alternative

Beneficiary Person or household receiving governmental support in the form of a subsidy for accessing to housing

Candidate Person or household applying for a housing subsidy

Choosing by Advantages A decision-making system that supports sound decision making using specific comparisons of advantages of alternatives (Suhr 1999)

Community In this research, community is a group of beneficiaries of housing subsidies or individuals obtaining help in accessing to proper housing

Criterion A decision rule, or guidance – usually, either a must or want.

Developer Enterprise dedicated to the production of housing

Direct housing subsidies Explicit, once-only, non-repayable contribution given by the state to families that comply with certain established requirements in order to provide them with a purchasing power greater than that afforded by their own income (Gonzales 1999)

Enabling approach Housing provision approach in which the primary governmental policy goal is to create a well-functioning housing sector that serves the needs of all key stakeholder groups while ensuring that the needs of the poor are met (Mayo 1999)

Factor An element, part, or component of a decision.

IDempiere Is an open source computer-based system for Enterprise Resource Planning

Lean Construction Lean philosophy applied to construction

Unidad de Fomento Is the Chilean inflation-protected bond, and its exchange rate is calculated on a daily basis relative to Chilean currency. This exchange rate is based on inflation in the last two months so that the real purchasing power of one UF remains the same, but its value fluctuates in relation to the Chilean peso (Jimenez 2006)
## ACRONYMS

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<td>CChC</td>
<td>Camara Chilena de la Construccion (Chilean Construction Chamber)</td>
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<td>CEPAL</td>
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<td>CESCR</td>
<td>Committee on Economic, Social, and Cultural Rights</td>
</tr>
<tr>
<td>CHP</td>
<td>Chile pesos</td>
</tr>
<tr>
<td>DHS</td>
<td>Direct Housing Subsidies</td>
</tr>
<tr>
<td>ECLAC</td>
<td>United Nations Economic Commission for Latin America and the Caribbean (CEPAL in Spanish)</td>
</tr>
<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
</tr>
<tr>
<td>FLM</td>
<td>Fuzzy Logic Model</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>IDB</td>
<td>International Development Bank</td>
</tr>
<tr>
<td>IGLC</td>
<td>International Group for Lean Construction</td>
</tr>
<tr>
<td>INEC</td>
<td>Instituto Nacional de Estadisticas del Ecuador (National Statistics Institute, Ecuador)</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technologies</td>
</tr>
<tr>
<td>JIT</td>
<td>Just-In-Time</td>
</tr>
<tr>
<td>LAC</td>
<td>Latin America and the Caribbean</td>
</tr>
<tr>
<td>MDG</td>
<td>Millennium Development Goals</td>
</tr>
<tr>
<td>MIDUVI</td>
<td>Ministry of Urban Planning and Housing Ecuador (Ministerio de Vivienda y Urbanismo del Ecuador)</td>
</tr>
<tr>
<td>MMR</td>
<td>Mixed Methods Research</td>
</tr>
<tr>
<td>NAHB</td>
<td>National Association of Home Builders</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>NNs</td>
<td>Neural-Networks</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Co-operation and Development</td>
</tr>
<tr>
<td>PNNs</td>
<td>Probabilistic Neural Networks</td>
</tr>
<tr>
<td>SIV</td>
<td>Sistema de Incentivos para Vivienda (Housing Incentive System)</td>
</tr>
<tr>
<td>TPS</td>
<td>Toyota Production System</td>
</tr>
<tr>
<td>TVD</td>
<td>Target Value Design</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UN-Habitat</td>
<td>United Nations Human Settlements Programme</td>
</tr>
<tr>
<td>WIP</td>
<td>Work In Progress</td>
</tr>
<tr>
<td>WRC</td>
<td>Weighting Rating and Calculating</td>
</tr>
</tbody>
</table>
CHAPTER 1 INTRODUCTION

The introductory chapter is organized as follows: Section 1.1 describes the problem that the author is addressing. Section 1.2 describes his motivation. Section 1.3 provides insights about the gap in knowledge and Section 1.4 presents the research questions. Section 1.5 and 1.6 corresponds to the research outline and methodology. Section 1.7 introduces the Case Studies used in this research. Section 1.8 defines the scope of the research and Section 1.9 presents the structure of the dissertation.

1.1 Problem

Latin America is experiencing significant housing deficits. The high rate of population growth in urban areas has created an unprecedented housing demand that formal housing supply mechanisms have not been able to meet (UN-Habitat 2011). Low-income households facing insufficient response of economies in housing provision are forced to build housing on their own, leading to the proliferation of unplanned and inadequate urban settlements or slums.

Slums are parts of cities with poor living and housing conditions. Commonly, households living in slums lack access to improved water, sanitation, and sufficient living area. Slum-dwellers do not have property rights over the land, and housing infrastructure does not meet minimal standards of habitability (UN-Habitat 2003). In Latin America, an estimated 110 million people are living in slum conditions (Bárcena et al. 2012).

Low-income households in search for adequate housing are facing escalating land and construction costs. This issue is exacerbated considering that developing economies in the region lack sufficient resources to support affordable housing construction. Bouillon (2012) estimated that in order to cover housing needs, the current investment in affordable housing programs has to be increased seven-fold, reaching expenditures of around $310 billion annually, equivalent to 7.8% of the regional GDP.

Considering the amount of resources needed to address this issue and the escalating costs of housing construction, exploring the implementation of innovative techniques to produce houses faster and more efficiently may offer an opportunity to ease housing constraints in the region (Bouillon 2012). Woetzel et al. (2014), for instance, argue that by implementing Lean Construction approaches including standardization and industrialization, construction costs for affordable housing may be cut by 16%.

The problem is that the literature does not offer a comprehensive research documenting the implementation of innovative methods in the delivery affordable housing in the context of Latin America. The context in which affordable housing construction takes place is highly influenced by the characteristics of the construction industry in developing countries, which significantly differs from its counterpart in developed nations (Ofori 2012). In addition, the financing mechanism used by governments to support affordable housing construction results in a complex process involving several actors whose interactions influences the way housing is produced and consumed in the region.

1.2 Motivation

The motivation of this research is to help address the problem of affordable housing provision in Latin America. Despite the fact that access to shelter is considered a human right (United Nations...
and essential for individuals’ development (Maslow 1954), it is striking that millions of families do not have access to a decent home.

This research aims to expand the scope of application of Lean Construction to the affordable housing field. By revealing the opportunities and challenges for implementing Lean Construction in the Latin American context, this research contributes to understanding how these can improve the efficiency of housing construction in the region and the construction industry overall.

This research is also driven by the author’s personal history. Because of his socio-economic origin, he has witnessed numerous challenges that low-income families have to overcome to achieve a better quality of life. Inadequate access to health care, education and housing are common issues affecting the well-being of the poorest in the region. The author aims to use his expertise in the engineering and project management field to conduct research that contributes to expanding housing provision in Latin America.

1.3 Gap in knowledge

Exploring the implementation of Lean Construction to deliver affordable housing in Latin America is important given the ways in which housing is financed and produced. Several countries in the region have adopted the “enabling approach” to incentivize private participation in housing construction. In the enabling approach, the government abandons its role as direct housing supplier and becomes a facilitator creating the conditions that allow the actors in the housing market to work towards meeting housing needs. The enabling approach heavily relies on private housing supply since governments provide low-income families with Direct Housing Subsidies (DHS) to enable them to access privately-built housing (UN-Habitat 2011).

Several Latin American countries adopting the enabling approach have reported an increase in the number of housing units produced yearly. Nevertheless, a number of drawbacks in this approach have been discovered as discussed in the literature. Researchers have recognized that efficient housing provision under the enabling approach requires adequate coordination of the several stakeholders involved in housing supply. To a large extent, the literature has focused on the macroeconomic parts of the financing mechanisms, aiming to secure the flow of resources so the beneficiaries have enough funds to buy and developers have enough capital to invest in housing construction. Despite the pivotal role that the private construction industry plays in housing supply under the enabling approach, the potential benefits of improving industry efficiency in housing production have received little attention.

Figure 1-1 illustrates a simplified model of the enabling approach. In the final stage, it depicts that resources flowing on both sides (supply and demand) result in housing transactions where affordable housing producers meet beneficiaries of subsidies (hereinafter customers). Given the importance that private developers play in housing provision under this scheme, it is logical to ask to what extent the production system used by developers to build affordable housing impacts its affordability. In addition, questions emerge as to whether this production system produces a housing stock that fulfills the needs of the customers.

This research aims to contribute to the knowledge in two main aspects, first, by exploring the implementation of Lean Principles in production systems for affordable housing, and second, by investigating to what extent the production systems for housing production enables the delivery of housing solutions that fulfills customers’ needs.
1.4 Research questions

This research aims to contribute to the body of knowledge of Lean Construction by answering the following principal research question:

- What are the opportunities for Lean Construction implementation in the delivery of affordable housing in Latin America?

In order to narrow the scope of the research, the author reviewed the literature on affordable housing in Latin America and Lean Construction, trying to address more specific research questions in each subject.

1.4.1 Affordable housing provision in Latin America

- What issues affect the delivery of affordable housing in Latin America?

Housing conditions vary across countries in the region. Nevertheless, two issues can be generalized:

First, the enabling approach has led several countries to reduce housing deficits but there is still an enormous gap between housing supply and demand. Thus, given the significant housing deficits and resource constraints, there is a critical need to speed up housing construction at a reasonable cost.

Second, implementation of the enabling approach has defined the technical and economic conditions that govern the way affordable housing is designed, built and consumed in the region. In response to such conditions, most private developers have favored building large and monotonous housing developments with design and construction standards that do not necessarily meet the needs of customers. Thus, there is a need to look for ways to produce affordable housing that best fits the contextual needs of beneficiaries.
1.4.2 Lean Construction

- What are the possible uses of Lean Construction Principles in affordable housing construction?

Lean Construction emerged as the application of Lean Production theory in the construction industry (Koskela 1992). According to Womack (1991, p. 13), Lean Production combines the advantages of craft and mass production, by “avoiding the high cost of the former and the rigidity of the latter” allowing the production of high volumes and variety at a reasonable cost. Thus, Lean Construction may be useful to address the two issues in affordable housing provision described in Section 1.4.1. The author defines a preliminary framework to investigate affordable housing production based on value generation and value delivery, two critical steps in Lean thinking defined by Womack and Jones (2003). Table 1-1 correlates the work of Womack and Jones (2003) with the issues in affordable housing provision in Latin America.

Table 1-1: Preliminary framework for the research.

<table>
<thead>
<tr>
<th>Lean steps</th>
<th>Issues in affordable housing provision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Value generation: identify value from</td>
<td>There is a need to look for ways to produce affordable housing that best fits</td>
</tr>
<tr>
<td>the perspective of the customer.</td>
<td>the contextual needs of customers.</td>
</tr>
<tr>
<td>2) Value delivery: deliver value to the</td>
<td>There is a critical need to speed up</td>
</tr>
<tr>
<td>customer with efficiency.</td>
<td>housing construction at a reasonable cost.</td>
</tr>
</tbody>
</table>

1.4.3 Specific research questions

After revealing a preliminary connection between of value generation for affordable housing issues in Latin America and Lean, the author organizes the research in two parts and poses the following questions:

**Part A:** Focus on housing production systems (value delivery):

Q A.1: Is the implementation of a production system for affordable housing construction based on Lean Principles feasible?

Q A.2: How does the implementation of Lean Principles contribute (or not) to deliver variety with efficiency in housing production?

**Part B:** Focus on housing design (value generation):

Q B.1: How can Lean Principles be used in the design of affordable housing in order to fit the needs of the customers?

Q B.2: What are the potential benefits of delivering customized housing for the customers?

1.5 Research outline

This research is conducted according to the outline depicted in Figure 1-2.
1.5.1 Literature review

The first part of the research is a literature review of affordable housing provision in Latin America and Lean Construction. The author intends to discover overlapping areas between the two subjects. On the affordable housing side, the review focuses on the investigation of the issues affecting affordable housing supply. On the Lean Construction side, the review focuses on researching the use of Lean Principles for housing construction. The author then identifies gaps in knowledge and defines the research questions (section 1.4.3).

1.5.2 Research design

The second part of the research is the design of a plan of work to address the research questions. The author assesses the challenges and opportunities for performing the investigation and defines a plan of work accordingly. As a result, the research is performed in two parts.

Part A is intended to address Q A.1 and Q A.2 with focus on production systems for housing construction or value delivery. This corresponds to the Case Study of Villa Hermosa, an Ecuadorian affordable housing developer aiming to deliver customized housing.

Part B is intended to address Q B.1 and Q B.2 with focus on the characteristics of housing design or value generation. This includes the Case Studies of “Quinta Monroy”, an example of slum rehabilitation and Build Change, a non-profit organization engaged in the provision of tailored and earthquake resistant housing solutions.

1.5.3 Research execution

The third part of the research is the execution of the Part A and Part B.

For Part A, the author became part of the organization of Villa Hermosa housing Developer implementing Lean Construction initiatives at different stages of the project delivery process. He worked in this project from May 2014 to December 2015.

For Part B, the author reviewed the literature in the selected Case Studies in order to understand the working model implemented in both cases.

1.5.4 Final results

After reviewing and analyzing the three Case Studies, the author performs a Cross-case Analysis in order compare and contrast them using as a framework the Fourteen Lean Principles described by Liker (2004):
• Principle 1: Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
• Principle 2: Create continuous process flow to bring problems to the surface.
• Principle 3: Use "Pull" system to avoid overproduction.
• Principle 4: Level out the workload (heijunka).
• Principle 5: Build a culture of stopping to fix problems, to get the quality right at the first time.
• Principle 6: Standardized tasks are the foundation for continuous improvements and employee empowerment.
• Principle 7: Use visual controls so no problems are hidden.
• Principle 8: Use only reliable, thoroughly tested technology that serves your people and process.
• Principle 9: Grow leaders who thoroughly understand the work, live philosophy and teach it to others.
• Principle 10: Develop exceptional people and teams who follow your company's philosophy.
• Principle 11: Respect your extended network of partners and suppliers by challenging them and helping them improve.
• Principle 12: Go and see for yourself to thoroughly understand the situation (Genchi Genbutsu).
• Principle 14: Become a learning organization through relentless reflection (hansei) and continuous improvements (Kaizen).

The final part of the research corresponds to the conclusions.

1.6 Research methodology

Figure 1-3 expands on Figure 1-2’s research outline linking the main subjects of research, the parts, research questions, research methodology, and Case Studies. According to the characteristics of each part, this research uses different research methods. Although this research uses both, qualitative and quantitative data, the emphasis is given to qualitative information.

This research uses mixed methods research (MMR) integrating qualitative and quantitative data. Caruth (2013) argues that the use of MMR has the potential to offer more robust research since “words, photos, and narratives can be used to add meaning to numbers while numbers can add precision to words, photos, and narratives”. In practice, if the results of qualitative research converge with the quantitative ones, the validity of the conclusion is reinforced. In contrast, if qualitative and quantitative results are divergent, it may lead the researcher to further reflection, a revision of the hypothesis, and extra research (Lund 2012).
**What are the opportunities for Lean Construction implementation in the delivery of affordable housing in Latin America?**

<table>
<thead>
<tr>
<th>Affordable housing in Latin America</th>
<th>Search for overlapping areas</th>
<th>Lean Construction</th>
</tr>
</thead>
</table>

**Outcomes**
- Need to improve the output of the house building industry
- Need for alternatives to mass housing production that consider customers' preferences

**Lean Principles**

<table>
<thead>
<tr>
<th>Value Delivery</th>
<th>Value Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PART A</td>
<td>PART B</td>
</tr>
<tr>
<td>Q A.1: Is the implementation of a production system for affordable housing construction based on Lean Principles feasible?</td>
<td>Q B.1: How can Lean Principles be used in the design of affordable housing in order to fit the needs of the customers?</td>
</tr>
<tr>
<td>Q A.2: How does the implementation of the Lean Principles contribute (or not) to deliver variety with efficiency in housing production?</td>
<td>Q B.2: What are the potential benefits of delivering customized housing for the customers?</td>
</tr>
</tbody>
</table>

**Case Study**

<table>
<thead>
<tr>
<th>Standpoint</th>
<th>Developer</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Villa Hermosa - Ecuador</td>
<td>Decision making</td>
<td>Housing design</td>
</tr>
<tr>
<td>2. Quinta Monroy - Chile</td>
<td>Project planning and control</td>
<td>Slum rehabilitation</td>
</tr>
<tr>
<td>3. Build Change - Various locations in Latin America</td>
<td>Formwork selection using Choosing By Advantages</td>
<td>Housing stock rehabilitation</td>
</tr>
<tr>
<td></td>
<td>Design and construction</td>
<td>Literature Review</td>
</tr>
<tr>
<td></td>
<td>Formwork standardization and production flow</td>
<td>Literature Review</td>
</tr>
<tr>
<td></td>
<td>Information Technology implementation: Interactive Plan and Production Tracking Application</td>
<td></td>
</tr>
</tbody>
</table>

**Type of analysis**
- Cross-case Analysis based on the fourteen Lean Principles described by Liker (2004)

**Conclusions**
- Conclusions, contributions to knowledge and future work

Figure 1-3: Refined research outline.
1.6.1  Case Study research

This research uses Case Study research design and follows the strategies recommended by Yin (2014). Case study research is “an empirical inquiry that investigates a contemporary phenomenon within a real-life context, especially when the boundaries between the phenomena and context are not clearly evident” (Yin 2014). The use of this research method is suitable when it is believed that contextual conditions may be relevant to the phenomenon that is under study. Case Study research uses multiple sources of evidence and benefits from prior knowledge to guide data collection and analysis. It can include single and multiple case studies and qualitative and quantitative evidence. In addition, Case Studies can employ an embedded design, including multiple levels of analysis within a single Case Study (Yin 2014).

In Part A of the research (Case Study of Villa Hermosa), the author observes and participates in the Case Study. In contrast, in Part B (Case Studies of Quinta Monroy and Build Change), the author analyzes the Case Studies in a retrospective way since all the events have already occurred and many of the outcomes are known. The characteristics of Case Study research make it a suitable research method for this research.

1.6.2  Action Research

For Part A, this research also uses Action Research. Action Research is social research that combines theory generation with changing the social system through the researcher’s intervention (Susman and Evered 1978). In this research methodology, “the researcher is not an independent observer, but becomes a participant, and the process of change becomes the subject of research” (Benbasat et al. 1987). For instance, in the Case Study of Villa Hermosa, the author contributed to the development of Information Technology (IT) tools intended to address operational issues in the Developer’s organization.

1.6.3  Cross-case Analysis

In order to compare and contrast the Case Studies, this research uses Cross-case Analysis. Cross-case Analysis is a research method that enables the comparison of commonalities and differences in the events, activities, and processes that are the units of analyses in Case Studies (Morgan 1983). The use of Cross-case analysis research may offer advantages to building or test new theories (Rueschemeyer 2003). As described by Eisenhardt (1989), a deep analysis of similarities and differences may enhance the understanding of the subject under study, resulting in new categories and concepts which the researcher did not anticipate.

1.7 Description of Case Studies approach

Using MMR, a researcher may approach the data collection differently. For instance, a study may begin with a qualitative research phase in order to analyze a phenomenon. This phase can be used to build an artifact that best fits the subject under study in order to capture data in a second quantitative phase (Creswell and Plano Clark 2007). This approach is compatible, for instance, with the interventions in the Villa Hermosa Case Study. Here, the author first analyzed the project in a qualitative phase (exploratory phase). In a second phase, he contributed to create an artifact (IT tool) aiming to address organizational issues and to collect data. The author described the development of the artifact through qualitative research and then analyzed the data resulting from the artifact’s implementation.
Based on the diagrams of Creswell and Plano Clark (2007), in the following sections, the author depicts the research approach for implemented in the Case Studies.

1.7.1 Part A: Villa Hermosa Case Study

The focus of Part A is on value delivery from the perspective of production systems design. The Villa Hermosa Case Study includes three Lean initiatives. Each initiative is intended to study and document the efforts of a Developer aiming to set a production system able to deliver custom housing models in a continuous production flow. Because of the importance of concrete related operations in project outcomes, the interventions focus on concrete related activities, specifically in the selection, design and use of the formwork system.

1.7.1.1 Initiative 1: Choosing By Advantages (CBA)

Initiative 1 consists in the implementation of the CBA decision-making method for the selection of a formwork system that suits the characteristics of the project.

Figure 1-4 shows a first qualitative phase corresponding to the description of the CBA implementation process. Subsequently, in order to expand data collection, the author creates a survey to interview the participants of this experience in a second qualitative phase. In the final phase, the author interprets the data for the findings.

1.7.1.2 Initiative 2: Formwork standardization

Initiative 2 consists in the implementation of a collaborative process intended to standardize housing unit designs according to the formwork system selected in initiative 1. The Developer and the Formwork Supplier engages in a standardization process aiming to optimize formwork design so as to enable an efficient production flow on site. In this process, concrete elements of housing units are adapted to the dimensions of standard panels marketed by the supplier in order to have flexible modular formwork sets that can be arranged into different configurations to build the structure of custom housing models.

Figure 1-5 depicts a qualitative approach to describe the standardization process. Afterward, in order to demonstrate the results of standardization, the author uses quantitative data (e.g., cost savings and reduction of formwork inventory pieces). Finally, he combines qualitative and quantitative data for the findings.
1.7.1.3 Initiative 3: IT tools for project planning and control

Initiative 3 consists in the creation and implementation of two IT tools, Interactive Plan and Production Tracking Application for project planning and control.

Interactive Plan is an IT tool that facilitates the implementation of a house customization strategy. Allowing customers to select some features of housing design inputs variability to the production system. Thus, efficient communication among the different Developer’s departments is needed to build variant housing configurations efficiently. Thus, the Developer created Interactive Plan to enable quick response to varying customer requirements.

Production Tracking Application is an IT tool that facilitates tracking the construction progress of the different housing models. Since the project has several housing models, and every house includes several activities, the amount of information resulting from project control is hard to capture and manage by manual means. The Developer decided to automate this process by implementing the Production Tracking Application.

Figure 1-6 depicts a first qualitative approach in which the author explored the situation of the Developer. Based on this, he got involved in the creation of the IT tools intended to address organizational issues while at the same time documenting the development process. Subsequently, the author collects data using the IT tools. The author finally integrates qualitative and quantitative information for the findings.
1.7.2 Part B: Quinta Monroy and Build Change Case Study

1.7.2.1 Quinta Monroy

Quinta Monroy is an innovative example of slum rehabilitation in Chile. The project consists of the replacement of a slum by a new affordable housing development in downtown Iquique. This project faced two challenges. First, the available budget for construction was only $7,500 per housing unit, including land, second, the development had to be built on the same slum’s site, without pushing their inhabitants to the periphery of the city, where land is cheaper. For this purpose, the design team worked collaboratively with slum-dwellers to design a project that best fit the needs of their community. The result was an innovative concept of core housing (also called progressive housing) that allows for expansion of the housing unit based on the building capacity of homeowners (Aravena and Iacobelli 2012).

1.7.2.2 Build Change

Build Change is a non-profit organization that builds disaster-resistant housing solutions in developing countries. In contrast to the typical approach of mass housing Production that does not always fit the local context of the inhabitants, Build Change aims to optimize the use of local capacity to create housing solutions that best meet the needs of homeowners and match the local context. For this purpose, Build Change investigates the local context of the housing sector searching for the most cost-effective way to build permanent housing with high participation of local stakeholders (Build Change 2016a).

1.8 Scope of the research

1.8.1 Scope in terms of affordable housing in Latin America

Developing countries have adopted various housing production systems over time (Okpala 1992). Given the diversity of housing provision modes, separating them in a particular structure depends on the level of abstraction or simplification assumed for this purpose (Keivani and Werna 2001a). To define the modes of housing provision covered in this research, we use the conceptual model developed by Kevani and Werna (2001a) in Figure 1-7.

![Figure 1-7: Modes of housing provision in developing countries (Keivani and Werna 2001a).](image)

In Figure 1-7, unconventional (informal or irregular) modes are self-building approaches adopted by urban households unable to access housing in the conventional sector. In contrast, conventional
(formal or regular) modes are those developed under the official channels for access to land, finance, and building materials. This research focuses on conventional modes of housing provision. For example, Part A is a Case Study of indirect government housing provision through DHS and Part B includes Case Studies of slum rehabilitation and housing stock upgrading.

1.8.2 Scope in terms of Lean Construction

This research focuses on the application of Lean Principles for housing construction. Womack and Jones (2003) stated that specifying value from the standpoint of the customer and to deliver such value with efficiency (value generation and value delivery) are essential steps in pursuit of the Lean ideal. In this aspect, this research is designed to explore the implementation of Lean in value generation and value delivery in the housing construction context.

On the one hand, Part A of the research adopts the developer’s production system design perspective, focusing on delivering value to the customer with efficiency while adhering to the Lean Principles. On the other hand, Part B is executed from the customer perspective, aiming to explore the potential benefits of Lean implementation on identifying and capturing value for the housing product.

1.9 Structure of dissertation

This research has nine chapters.

Chapter 1 corresponds to the introduction, the purpose of the research and research methodology.

Chapter 2 presents the literature review of affordable housing provision in Latin America.

Chapter 3 presents the literature review on Lean for housing construction.

Chapter 4 presents the research framework.

Chapter 5 presents the Case Study of Villa Hermosa.

Chapter 6 presents the Case Study of Quinta Monroy.

Chapter 7 presents the Case Study of Build Change.

Chapter 8 presents the Cross-case Analysis based on the fourteen Lean Principles described by Liker (2004).

Chapter 9 corresponds to the final analysis and conclusions of the research.
CHAPTER 2 LITERATURE REVIEW ON AFFORDABLE HOUSING IN LATIN AMERICA

“To live in a place, and to have established one’s own personal habitat with peace, security, and dignity, should be considered neither a luxury, a privilege nor purely the good fortune of those who can afford a decent home” (UN-Habitat 2002)

Chapter 2 presents a literature review of affordable housing provision in Latin America, and it is organized as follows: Sections 2.1 and 2.2 describe the process of urbanization and the nature of slum formation. Sections 2.3 and 2.4 provide insights into current housing needs and the manner they are measured. Section 2.5 corresponds to a historical overview of housing policies. Section 2.6 describes the functioning of the housing market in order to introduce the Direct Housing Subsidies (DHS) policy in Section 2.7. Based on the case of Chile, Section 2.8 describes the results of DHS policy. Section 2.9 presents outcomes of DHS implementation in other Latin American countries. Section 2.10 describes the connection between DHS and the characteristics of housing production. Section 2.11 describes the role of the private construction industry under the DHS policy. Section 2.12 and 2.13 explore the opportunities and challenges for the construction industry. Finally, Section 2.14 offers to the conclusions of the chapter.

2.1 Urban growth and housing

Urbanization is a process of population concentration (Tisdale 1942) occurring when people move from small rural settlements in which agriculture is the dominant economic activity, towards more densifying areas characterized by industrial and service activities (Montgomery 2003). This transformation is framed in a process of economic development since people move to the city searching for better education and employment opportunities available in industrialized areas (Henderson 2003). Urbanization has been significant over the last years. Figure 2-1 shows that in 2007 for the first time the world’s urban population surpassed its rural population. In 2014, 54% of the population was urban (vertical line) and by 2050, this figure is expected to reach 66%.

Figure 2-1: Urban and rural population of the world, 1950 – 2015 (United Nations 2015a).
The increase of urban population had resulted in an unprecedented demand for infrastructure. People moving to urban areas need to be provided with basic services like water, sanitation, and housing. According to UN-Habitat (2003), every year the global urban population increases by about 70 million which is equivalent to building two new mega-cities similar to Tokyo. Regarding housing construction, estimates suggest that 3 billion people must be provided with housing by 2030. This means building 96,150 housing units per day from now until 2030 (UN-Habitat 2012). Countries with a well-functioning economy and adequate urban and housing policies are prepared to provide such infrastructure. However, these conditions are not present in developing economies, leading to the proliferation irregular urban settlements or slums (UN-Habitat 2003).

2.2 Slum formation

In Figure 2-2, slums are a result of a combination of several factors that lead to poverty and lack of affordable housing provision (UN-Habitat 2003). The relatively low income of the poorest families compared to housing costs of the poorest families deprive them accessing even to the least expensive dwelling available in the formal housing market (Ferguson and Navarrete 2003). Households in this situation require assistance in accessing to proper housing. Nevertheless, the insufficient response of housing supply mechanisms forces them to cover housing needs by themselves in the informal housing sector or through self-construction, shaping the formation of irregular urban settlements or slums (UN-Habitat 2003).

Slums are parts of cities with poor living and housing conditions. Households living in slums lack access to improved water, sanitation, and sufficient living area. Moreover, slum-dwellers do not have property rights over the land and in most cases, housing infrastructure does not meet minimal standards of habitability and safety (UN-Habitat 2003).

In Figure 2-3, despite the proportion of urban slum-dwellers in developing economies has been reduced in the last years, the absolute number of people living in slums has still a growing tendency. 689 million people were reported to live in slums in 1990 and 881 million in 2014 (United Nations 2015b, p. 61). To put this in perspective, current housing needs are equivalent to shelter 22 times the population of the state of California, USA.

Figure 2-2: Inequality, poverty, and slum formation (UN-Habitat 2003)
The magnitude of the issue has drawn the attention of world leaders and intergovernmental institutions. In September 2000, United Nations included within its Millennium Development Goals (MDG) the target to improve the lives of at least 100 million slum-dwellers by 2020 (Millennium Project 2006).

2.3 Context in Latin America and the Caribbean

The accelerating rate of urbanization has exacerbated housing issues in Latin America and the Caribbean (LAC). In 2010, 80% of the population was living in urban areas and by 2050, this figure is expected to reach 89%. In Figure 2-4, within LAC region, South America has the highest degree of urbanization, followed by Central America and the Caribbean (Bonet et al. 2011).

The accelerated urbanization growth combined with inefficient housing provision mechanisms had led several countries in LAC to face major housing shortages. An estimate of 23% of urban residents (110 million people) lives in slums conditions (Bárcena et al. 2012). Significant resources are needed to address this problem. Bouillon (2012) estimates that the current investment in housing programs have to be multiplied by seven, reaching expenditures of around $310 billion annually, equivalent to 7.8% of regional GDP.

2.4 Measuring housing needs: housing shortage

Based on national population and housing censuses, several Latin American countries use a measure of housing deficit to calculate housing needs. The housing deficit is divided into
quantitative and qualitative deficits. The quantitative deficit is the difference between the number of households and the housing stock. The qualitative deficit corresponds to the portion of the housing stock that do not meet minimal standards of habitability (e.g., poor quality of construction materials or lack of basic services) (CEPAL 1996).

Housing deficit drives housing policies in the region. In addition to providing a notion of housing conditions, the nature of the deficit also provides insights into the strategies that must be pursued. The quantitative deficit may be addressed by new housing construction while the qualitative deficit by housing stock upgrading strategies (UN-Habitat 2015).

The methodology to calculate qualitative deficits has been the subject of debate because of the subjectivity of this concept. The qualitative deficit is calculated based on minimal standards of habitability that define “adequate housing.” Nevertheless, there is little consensus about these standards (Rojas 2011). Since housing conditions vary from country to country according to social and economic trends, the criteria to define minimal standards of habitability and thus, the baseline to measure qualitative deficits differs among countries (Gilbert 2001). Furthermore, the perception of minimal standards of habitability may change over time which may also result in dissimilar baselines to perform the calculations at different points of time (Ducci 1997; Özler 2012). These situations lead to figures which are difficult to compare each other among countries and at different points of time.

In order to address the shortcomings in methodology to calculate housing deficits, UN-Habitat (2015) recommends considering the criteria established by the Committee on Economic, Social,
and Cultural Rights (CESCR) which defines seven integral aspects of adequate housing. These criteria are: 1) legal security of tenure, 2) availability of services, materials, facilities and infrastructure, 3) affordability, 4) habitability, 5) accessibility, 6) location and 7) cultural adequacy (CESCR 1991).

Despite criticisms about the calculation methodology, authors agree that the calculation of housing deficits is useful since it provides an overall estimation of housing needs and the seriousness of housing issues in the region (Gilbert 2001).

2.5 Historical overview of affordable housing policies in Latin America

In order to address housing shortages, Latin American countries have implemented various housing policies. Such policies have experienced a striking evolution over time.

From the 1950s to the 1970s, housing financing and policy were characterized by predominant government intervention (Fay 2005). Governments acted as direct housing suppliers, usually offering subsidized interest rates on loans or directly subsidized prices of housing units (Gonzales 1999). Furthermore, the government over-regulated the functioning of housing financing institutions by setting limits to the interest rates charged on housing transactions. In terms of the housing product, housing design, and construction were influenced by Western practices, particularly by the principles of Le Corbusier (Fay 2005; UN-Habitat 2011). Housing solutions took the form of high-rise blocks with reasonable standards of construction and infrastructure, usually accompanied by the removal of slum areas (Mayo and Gross 1985).

From the 1970s, governments began incorporating the nature of slum formation in housing provision approaches. This trend was influenced by the work of JFC Turner who argued that governments should consider the characteristics of slum formation and building capacity of slum-dwellers into housing policy (Turner 1967; Turner 1968). This resulted in the adoption of policies focused on slum rehabilitation rather than eradication. Governments supported slum rehabilitation by enabling access to serviced land or by providing housing units that can be expanded by families according to their priorities and building capacity (i.e., progressive or core housing). In the case of large existing slums, governments helped communities to regularize their condition by facilitating access to property rights (UN-Habitat 2011). In comparison to new housing provision, slum upgrading initiatives were easier to implement since they needed less planning, less engineering and minimal construction standards (Fay 2005). Nevertheless, some argued that in many cases governments’ oversimplified the type of housing solutions delivered having a minimal impact on the welfare of slum-dwellers (Van De Laar 1980). From an urban development point of view, some argued that this approach led to the excessive expansion of cities to the detriment of green areas or agricultural land (Hidalgo 2004). In addition, upgrading programs suffered several problems in terms of affordability, and poor design and location of the solutions offered to the low-income households (Fay 2005; UN-Habitat 2011).

Several authors argued that government-centered housing provision initiatives were counter-productive. First, housing units were not always affordable for low-income families resulting in expanding government subsidization that taxed national budgets, endangered the continuity resources for public housing and limited the scale of the programs (Fay 2005). Moreover, excessive government intervention significantly drove the characteristics and prices of affordable housing affecting the well-functioning of the housing market. This discouraged private involvement in housing supply since financing mechanisms were unattractive for builders and
financial intermediaries in terms of profitability (Gonzales 1999). Second, housing styles were misaligned with the gradual, progressive and low-rise housing approaches usually accepted by low-income dwellers (UN-Habitat 2011). Additionally, housing units were usually located on inconvenient sites in the city border demanding extra transportation for access to urban services (Fay 2005). As stated by Mayo (1999, p. 41), government-centered housing programs were “small in scale, largely unaffordable by the poor, poorly targeted, and largely inefficient.”

Failure of previous housing policies led governments to recognize that the state alone is not capable of covering housing needs; collaboration with the private sector is required to scale up housing provision (Gonzales 1999). In the 1980s, international agencies began advocating for a market-oriented approach to address housing issues based on DHS (Gilbert 2004). In this approach, instead of acting as a direct housing supplier, the government plays the role of a facilitator who enables the proper functioning of the housing market (Mayo 1991).

The best example of this new housing policy model is offered in the Chilean case. In 1977, the Chilean government pioneered implementing a DHS policy (Mayo 1991; Gonzales 1999; Mayo 1999; Gilbert 2004; UN-Habitat 2011). This approach consists of an up-front capital subsidy equivalent to 60% to 95% of the cost of a new housing unit which, complemented with beneficiaries’ savings and mortgage credit, can be used in the private housing market (Mayo 1999; Moye and Horne 2013). This model became the bedrock of Chilean affordable housing policies, helping the country to become the first Latin American nation to cut its housing shortage (Gilbert, 2004). The success of this housing policy was an experience to be replicated in the region (Mayo and Angel 1993; Mayo 1999; Gilbert 2002; Jha 2007; UN-Habitat 2011; Posner 2012), leading to its adaptation in other Latin American countries like Colombia, Costa Rica, Ecuador, Panama, El Salvador, Paraguay and Uruguay (Mayo 1999; Gilbert 2004; UN-Habitat 2011).

2.6 Housing market

In order to understand housing policies based on DHS, it is important to understand the functioning of housing markets. The well-functioning of a housing market is influenced by the availability of resources, such as residential land, infrastructure, and construction materials (Mayo and Angel 1993) as well as the interactions among the main stakeholders involved in housing supply (Mayo 1991). Figure 2-5 describes how inputs such as land, materials, and labor are acquired by supply stakeholders, such as developers, that through production processes deliver housing services.

![Figure 2-5: Housing market (Mayo et al. 1986).](image)
Housing services are then offered and consumed in the output market by demand stakeholders, like homeowners and renters. Mayo et al. (1986) argued that problems in the housing market are often caused by issues in the input markets. However, in most developing countries, government-centered housing policies have mistakenly focused on production aspects (the middle rectangle).

As discussed in section 2.5, some authors argue that excessive state intervention is detrimental for the well-functioning of the housing market, depriving stakeholders of being able to attain their interests and creating an imbalance between supply and demand. On the supply side, housing producers and financing institutions are not willing to participate in the housing market because excessive government regulation threatens the profitability conditions they expect to operate (Mayo 1991; Gonzales 1995). Particularly in the affordable housing market, this unbalance is exacerbated because of insufficient demand. Low-income households do not generate enough income for home purchasing. Moreover, financing institutions are reluctant to provide them mortgage loans. Historically, banks in the region have strict standards to approve loans, requiring significant records to ensure the financial capability and stability of borrowers. Low-income households struggle to meet those requirements because the informality and volatility of employment conditions significantly affect their financial stability. In addition, financing institutions usually request borrowers to pay upfront at least 75% of the housing unit value (Diplomatic Courier 2013). Under these conditions, low-income households do not have enough resources to create proper demand for affordable housing that encourages the private sector to invest in this market (Mayo 1991; Gonzales 1995).

Consequently, one of the main priorities of the government is to focus on providing low-incomes households with the adequate financial capacity for housing purchasing. In order to ensure this financial capacity, the government grants DHS and provides guarantees and incentives to private stakeholders to serve low-income households.

2.7 DHS to enable the housing market to work

Gonzales (1999) defines DHS as an “explicit, once-only, non-repayable contribution given by the state to families that comply with certain established requirements in order to provide them with a purchasing power greater than that afforded by their own income.” Thus, the government and each household share the responsibility in financing the housing solution. The total amount of money is built up from three sources: 1) beneficiaries’ savings, 2) mortgage credit, and 3) the DHS provided by the government (Ferguson et al. 1996).

Although DHS vary from country to country, in practice they are managed as follows (CEPAL 1996):

- Through a saving account, candidates voluntarily accumulate savings targeting to reach the minimum amount required by the government to apply for a DHS.
- Once the candidates have reached a targeted amount, they are allowed to apply for a DHS. The government selects candidates based on their socio-economic conditions.
- Once the government awards DHS, savings and subsidy are used to pay the upfront cost of the house. The remaining cost of the house cost (if any) is financed with a mortgage credit.
- Beneficiaries are allowed to select a housing unit in the private housing market.
Figure 2-6 describes the role of the main stakeholders in the housing market based on a DHS policy. The government subsidizes demand for housing by granting households and individuals DHS. DHS increase demand for housing which stimulates housing builders to supply housing. In this aspect, the government should abandon its role as housing builder enabling competition among private builders. Financing institutions should contribute mobilizing resources across the sectors in order to ensure the availability of credits with reasonable conditions for supply and demand agents. The government as a facilitator should promote the synergy among demand and supply stakeholders based on access to finance opportunities that allows them to satisfy their interests. In the affordable housing market, this synergy provides low-income households with adequate purchasing power for housing, while at the same time ensuring profitability to private stakeholders, which favors the balance between housing demand and supply (Gonzales 1995).

![Figure 2-6: The role of different stakeholders in a housing policy based on DHS (Gonzales 1995).](image)

2.8 Results of DHS in the case of Chile

To represent results of the DHS policy, the author uses the case of Chile. Chile is adequate for this purpose because it is the pioneer, and thus most experienced country implementing DHS. This fact results in a broader literature analyzing the results of this housing policy.

The author acknowledges that the outcomes of a housing policy can be analyzed in several dimensions. Among others, Ruprah (2010) assessed the transparency, incidence and targeting efficiency of subsidies. The OECD (2012) reviewed the housing model and its linkage with the mortgage credit sector and Mayo (1999) revised the experience of the International Development Bank providing loans for DHS. Nevertheless, since the focus of this study is on the housing product, the emphasis is given to aspects related to housing design and construction.

2.8.1 Halting the spread of slums and reduction of housing shortage

In several Latin American cities, the number of people living in slums is still increasing (Bouillon 2012). However, in Chile, this trend was reversed in the mid-1990s and currently nearly all population has access basic services (Ducci 1997). In the 1990s, Chile also became the first Latin American country to reduce its housing shortage (MINVU 2004, p. 231). Figure 2-7 plots the evolution of the housing shortage based on official calculations of the “Ministerio de Vivienda y
Urbanismo de Chile” (MINVU, Chilean Ministry of Housing and Urban Development). The data point corresponding to 2009 was taken from Allard et al. (2012, p. 49).

Figure 2-7: Housing shortage as a percentage of total housing stock (MINVU 2004; Allard et al. 2012).

The reduction of the housing shortage between 1982 and 2002 resulted from a significant increase in housing production. This production increment is related to a vigorous economic growth experienced by the Chilean economy during the nineties, which boosted investment in the construction industry, and the expansion and perfection of the DHS policy. This part of the Chilean housing timeline is referred as the “quantitative” success. However, from the second half of the 1990s, several studies began assessing the impacts of DHS policy beyond the “quantity.” These studies started revealing significant socio-economic issues experienced by beneficiaries of DHS that have a direct link with the quality affordable housing developments. The authors argued that policy makers were blinded by the quantitative success of DHS leading them to ignore the quality of the housing product and its impacts on residents (Rodríguez and Sugranyes 2005).

2.8.2 DHS and housing prices

In order to improve the quality of affordable housing developments, the Chilean government raised investment in housing programs. In 2003, the government spent on average of 8 UF\(^1\) per square meter (US$ 31\(^2\) per square feet). By 2009, expenditures increased up to 12 UF per square meter (US$ 47 per square feet) (Allard et al. 2012). Nevertheless, some argue that increases in the amount of DHS do not necessarily contribute to improving the quality of affordable housing.

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1 “The UF or Unidad de Fomento is the Chilean inflation-protected bond, and its exchange rate is calculated on a daily basis relative to Chilean currency. This exchange rate is based on inflation in the last two months, so that the real purchasing power of one UF remains the same, but its value fluctuates in relation to the Chilean peso (CHP)” (Jimenez 2006)

2 As for March 27, 2014: US$ 1 = CHP 555.75; 1 UF = CHP 23,591.78; 1 UF = US$ 42.45 (Banco Central de Chile 2014)
Based on data from 2007 to 2009, Razmilic (2010) conducted a study to evaluate the relative performance of housing programs targeted to lowest quintiles in a context of major increases in the levels of assistance provided by the government. Based on a housing prices prediction model, he concluded that although increases in subsidies result in housing quality improvements, a considerable portion of this additional investment results in housing price inflation. Figure 2-8 depicts the study’s chart for the “Fondo Solidario de Vivienda” housing program (Solidarity funds for housing). The author argues that beneficiaries DHS have little or no incentive to bargain with regards to housing prices or the quality and characteristic of the housing product. Apparently, affordable housing developers adjust housing prices according to the maximum housing subsidy levels at each point of time. Allard et al. (2012, p.46) conducted a similar assessment arriving at similar conclusions.

![Prices evolution for Fondo Solidario de Vivienda (targeted to the 1st quintile)](image)

**Figure 2-8:** Prices evolution for Fondo Solidario de Vivienda (targeted to the 1st quintile) – Price: corresponds to the real housing market price average. P (p): correspond to the predicted housing price (Razmilic 2010).

### 2.8.3 DHS and land prices

Urban growth in Chile has resulted in increasing demand for land. Between 1990 and 2004, Land prices in the Capital Santiago increased on average 250% (Bergoing and Piguillem 2005). Excessive increase land prices may represent a threat to the quality of housing units because it reduces the budget to pay for construction cost. In affordable housing construction, resource constraints for construction may lead developers to manage the quality of the housing product (Morandé and García 2004) or to locate housing developments in the city border where land is cheaper (Brain and Sabatini 2006).

In order to explore the correlation between land prices on affordable housing built with DHS, Brain and Sabatini (2006) conducted a study including 30% of the affordable housing stock built in Santiago between 1990 and 2004. The author collected statistical information from affordable
developments cost and grouped the data set into four categories: land, urban services, recreational areas and others. From 1994 to 2004, the share of the construction cost was reduced from 84 to 65%. In contrast, land share increases almost three times from 7 to 19%. The authors concluded that 66% of the increase of granted DHS is absorbed by increasing land cost.

![Figure 2-9: Evolution of affordable housing costs grouped into four categories (Brain and Sabatini 2006).](image)

### 2.8.4 Poor location and social segregation

In 1979, along with the implementation of DHS, the Chilean government instituted a land trade liberalization which according to some authors triggered land speculation. Developers and construction companies started to acquire cheap parcels in Santiago’s city border with the intention to accommodate the incoming demand for affordable housing. In parallel, under strong control of the military dictatorship, the state also pursued the eradication of slums. Slum-dwellers occupying central plots of the city were gradually relocated in new affordable housing projects situated in the periphery of the city far away from urban services (Rodríguez and Sugranyes 2005). Several authors argued that land deregulation contributed to defining the location of affordable housing developments, exacerbating segregation of low-income households and creating new ghettos in the perimeter of Santiago city (Ducci 1997; Jirón 2004; Rodríguez and Sugranyes 2005; Ruprah and Marcano 2007; Allard et al. 2012; OECD 2012).

### 2.8.5 Design and quality of housing

The limited availability of resources for affordable housing construction and increasing land costs have affected the quality of design and construction of the housing product.
The size of housing units has been reduced over time. Between 1979 and 1985, 172,218 people were located in mass affordable housing developments in which units’ size average 42 square meters (452 square feet) (Hidalgo 2004). During the following decade, the size of housing units was reduced, typically ranging from 30 to 40 square meters (320 to 430 square feet) (Ducci 1997).

The design of housing units has received critics because of its oversimplified and monotonous architecture which result in limited variation and thus, minimal choice for families. In addition, housing design does not match the needs of low-income households. Commonly, housing units are located in small plots with a rigid design that does not offer space expansions. For example, 450 square feet of interior space may accommodate a low-income household. Nevertheless, the family grows and requiring more interior space. In most cases, low-income households do not have enough resources to buy a new property which restricts their mobility, forcing them to stay in the same place. Somehow, low-income households have to find the means to deal with these type of issues. When the design of affordable housing does not consider these type of real-life situations, low-income households start implementing solutions on their own which may degrade the overall urban environment of the development. Figure 2-10 depicts a low-income household attempt to fit an increasing number of family members in. It is an awkward extension outside of the footprint of the building and without meeting any urban or building code (Rodríguez and Sugranyes 2005).

![Figure 2-10: Irregular addition attached to an affordable unit in the cover of the book “Los con Techo” (Those with a roof) (Rodríguez and Sugranyes 2005).](image)

The quality of construction has also been criticized. Some argued that in order to reduce costs and to be profitable, developers design and build affordable housing meeting minimum standards. The quality of affordable housing design and construction is overseen by the government based on national design and construction codes along with special regulations for affordable housing built with DHS. Nevertheless, under limited governmental oversight, some developers without ethics in business have managed construction cost, for example, by minimizing the amount of cement in the concrete mix or by reducing the quality of bricklaying. This results in an accelerated housing stock deterioration that also affects residents’ welfare (Ducci 1997). In 1997, the poor quality of affordable housing development became a controversial topic, when after a couple of days of rain...
in Santiago, the water started leaking inside several multifamily housing units. This event, known as “Las Casas Copeva” (The Copeva houses, as a reference to Copeva, the company who built the development), was broadly covered by Chilean media. Figure 2-11 shows multifamily blocks covered with plastic as a temporary solution implemented by authorities to stop water leaking.

Figure 2-11: Affordable housing units covered with plastic. Chile 1997 (From http://www.13.cl/static/img/teletrece/630_casas_copeva.jpg visited on 22 November 2013)

### 2.8.6 Summary of the Chilean case

In order to complement the information provided in this section, in Figure 2-12 the author created a timeline of the most important events in the Chilean housing policy from 1950 to 2010. The chart also includes information about population growth (to have a notion of housing requirements), the evolution of the housing shortage, as well as investment in housing construction (public and private). According to this information, several conclusions may be drawn from the Chilean experience.

First, the implementation of DHS boosted housing production and thus helped the country to reduce the housing shortage. The chart at the top shows that increases in new housing construction resulting from DHS implementation (public and private) were only perceived after a decade. This delay is a result of an experimentation and adaptation period of the different stakeholder in housing supply to a pioneer housing policy. Subsequent governments, even after the return to the democracy, kept the foundations of the DHS policy and perfected it over time (MINVU 2004; Rodríguez and Sugranyes 2005).

Second, increasing housing supply had a direct link with private developers’ involvement in housing production. The chart in the middle separates public and private housing construction. After the implementation of the DHS policy in 1977, private construction has significantly increased over time while public construction has gradually declined. Between 1980 and 1996 almost 80% of the total housing construction, including new housing and housing stock upgrading initiatives, were built with some sort of governmental subsidy (Gonzales 1999). The DHS policy became in the practice a major incentive for of private developers’ investment housing construction. The chart at the bottom shows that after DHS policy implementation, public investment has not substantially increased while private investment has boosted overtime.
Figure 2-12: Timeline of Chilean housing policy and some of its outcomes (MINVU 2004; Observatorio Urbano 2010; Allard et al. 2012; Bravo et al. 2013; Chamorro 2013)
Third, although increased housing production has facilitated the access to housing, several issues have been revealed related to design and construction quality of affordable housing developments. Ducci (1997) described these undesirable outcomes as “the dark side of a successful housing policy.” The poor design and construction of mass housing developments located in the periphery of cities have created several socioeconomic problems affecting the quality of life of one-fifth of Chilean households (Ducci 2007).

Finally, trying to improve the quality of affordable housing developments, the government has increased the amount granted in DHS. Nevertheless, in many cases the imperfections of housing markets in developing countries hampers governmental interventions (Keivani and Werna 2001b, p. 201). These type of imperfection may explain why additional governmental investment is translated into land and house inflation, instead of into improved quality of affordable housing developments. After many years of DHS implementation, the government has been unable to address the issues related to the quality of the housing stock produced under the DHS policy. Consequently, the DHS policy requires adjustments aimed to simultaneously address the reduction of the remaining housing shortage and to solve the quality issues of the built housing stock (Rodríguez and Sugranyes 2005).

2.9 Evidence from other Latin American countries

Several Latin American countries implementing the DHS policy have reported increasing housing supply (Held 2000). Nevertheless, many of the issues previously described are also repeated. Rodríguez (2006) argued that the implementation of demand subsidies in Latin America led to the construction of mass housing developments having several negative impacts on the welfare of residents. In Mexico, Coulomb et al. (2009) identified several negative aspects of affordable housing developments. The authors complained about the excessive size of developments, the monotony and rigidity of design (inability to allow extensions), and its disconnection with urban services.

Similarly, in Colombia, several authors argued that the DHS policy boosted the quantity of housing construction but neglected its design and construction quality (Escallón and Rodríguez 2010; Baena and Olaya 2013). Salas et al. (2012) argued that affordable housing developments in México, Brazil, Chile and El Salvador are small, extremely monotonous and built with outdated construction techniques. The United Nations (2005) identified similar issues in South Africa suggesting that little consideration has been given to the social costs resulting from such approach of housing provision.

2.10 DHS and mass housing production

Evidence from Chile and other Latin American countries indicates that the implementation of the DHS policy influences several characteristics of the housing product as production volume, location, the size of the housing units and quality of construction. The implementation of DHS delineates the roles and responsibilities of the different stakeholders in housing supply defining the economic and technical and conditions that govern the way affordable housing is design, built and consumed in the Latin America. The change in the conditions governing housing supply is clear when comparing the past and present housing policies.
In the past, affordable housing design and construction was highly influenced by the government. Commonly, governmental housing agencies specified the site, design and construction standards of affordable housing. After project definition, the government started a competitive bidding process awarding the construction work to the lowest bid under turnkey contracts. In parallel, the government selected families and located them in affordable housing developments based on their socio-economic background (Ferguson et al. 1996).

In contrast, under the DHS policy, the government no longer specifies what type of housing should be built and shifts this responsibility to private housing developers. The main role of the government is to define the basic standards for affordable housing design and construction and to enforce private developers to comply with them. In theory, this serves as the baseline for private developers to compete in the affordable housing market. The government benefits from this approach because competition among private developers may result in efficient housing production, thus reducing the cost for the government and making housing more accessible for low-income households (Gilbert 2004). Low-income households benefit of a greater freedom of choice because they are no longer selected and located based on government criteria. In contrast, the grated DHS provides them the opportunity to select in the affordable housing market (Hammam 2013).

The DHS policy and the capability of housing markets to address housing issues in developing countries with reduced government control was a matter of significant discussion among specialists in the nineties (i.e., Baken and Van der Linden (1993), and Malpezzi (1994)). The problems described in the case of Chile in terms of housing and land price inflation indicate that excessive deregulation may reduce the amount of the granted DHS available to build a better housing product. Thus, it is not unpredictable a reduction of the quality of the housing product (Gilbert 2004). Limited resources also force developers to accept slim profits per housing unit. Thus, construction activity is only profitable if it is carried out at a large scale (Lizarralde and Root 2008). Consequently, under this scenario several Latin American developers working under the DHS policy have favored the adoption of a mass housing production approach (Rodriguez 2006).

Although private developers’ involvement resulting from DHS policy has boosted housing construction, a major gap still exists between demand and supply. In addition, evidence about the quality of the housing product suggests that the predominant mass housing production approach implemented by developers have been unable to provide a housing product that fulfills the needs of low-income households. Consequently, the challenge for private developers is double. First, they need to improve housing construction productivity in order to speed up housing construction. Second, they have to search for ways to improve the quality of the housing product in order to meet the contextual needs of low-incomes families.

2.11 Opportunities for private housing industry under the DHS policy

In order to search for opportunities in the construction industry to improve productivity and to produce housing units that fit the needs of low-income households, the author created based in the case of Chile, a conceptualization of the DHS policy and its impacts on housing design and construction.

The right side of Figure 2-13 (demand) represents the government investing resources in affordable housing programs. Resources flow through different governmental agencies until they are awarded to beneficiaries in the form of DHS. Using the subsidy, beneficiaries are allowed to select a housing
unit that falls in the affordable market segment. The left side (supply) represents the flow of resources that private developers invest in production systems for the design, procurement, and construction of affordable housing. In the middle, the round rectangles represent the regulations that governmental agencies use to rule the housing production process. Developers have to comply with zoning and urban planning requirements, design standards and building codes defined by government agencies. As part of the competition in the affordable housing market, developers may decide to consider the needs and desires of households in housing design. This may help developers to increase sales and to broaden their market share. At the bottom, the flow of resources from both sides (supply and demand) results in housing transactions where affordable housing producers and beneficiaries of subsidies meet.

Figure 2-13: Conceptualization of the DHS policy and its impact on affordable housing production systems
Since the DHS policy incentivizes private participation in housing production, it is reasonable to explore the implementation of innovative managerial techniques or technology aimed at cutting housing costs in order to expand housing supply (the left side). Similarly, it is logical to search for alternatives to improve the quality of the housing product as an alternative to the rigid mass housing production approach that has been widely criticized in the region. In this aspect, questions emerge as to what extent the production system used by developers to build affordable housing impacts housing affordability, or as to whether this system produces a housing stock that fulfills the needs of the customers.

In order to explore potential improvements in production systems for affordable housing provision, it is important to examine the characteristics of the construction industry in Latin America as well as the components of housing pricing in the region. For instance, if construction costs do not take an important portion of the total housing sales price, potential improvements in a production system to deliver housing may have little impact on housing affordability.

2.12 Characterization of housing industry in Latin America

Understanding the housing construction sector in the region is important to evaluate potential areas of improvement. Literature reveals that the construction industry in developing countries is labor intensive, highly segmented, and lacks in advanced technology implementation.

2.12.1 Labor intensiveness

The construction industry is one of the largest contributors to employment (Bhalla and Edmonds 1983; Forbes et al. 2012). When compared with high-income countries, the construction industry in low-income countries is labor intensive and lags behind in terms of productivity. In Figure 2-14, a survey conducted in 1998 by the International Labor Organization revealed that high-income countries account for 77% of the global construction output with 26% of total employment. In contrast, low-income countries account only for 23% of the total construction output and 74% of employment (Wells 2001).

![Figure 2-14: Distribution of production and employment in high and low-income countries (Wells 2001).](image)

In Latin America, these figures may result from large employment of unskilled workers and limited use of technology. In Chile, 32% of the construction workforce has not completed elementary education and 77% has not graduated from high school (Velasco 1996). In Brazil, 14.6% of the
construction workforce is illiterate, and 57% has less than four years of formal education (Wells 2001). Similarly, in Argentina, 16% of the construction workforce has not completed elementary education and 87% has not completed high school (Ruggirello 2011).

Some argue that the lack of investment in training is a result of the instability of the construction sector. Ups and downs in construction activity result in a volatile demand for workforce and high personnel rotation. This situation discourages construction companies from investing in labor training since they expect to lose trained workers in the short term. In addition, training requires a further investment that harms the competitiveness of construction firms in the short term (Bouillon 2012).

2.12.2 Lack of technology implementation

Housing construction technology in developing countries has not changed significantly over time (Abrams 1964). In Latin America, a study conducted in 1996 concluded that housing units are built with craft techniques which affect the speed of construction and exacerbates housing shortages (CEPAL 1996, p. 180).

Construction companies do not invest in research and development. Innovation efforts are restricted to the importation of technology that has been proven in developed nations. Some authors argue that barriers to the implementation of new technology for housing construction are related to the macroeconomic conditions in the housing sector. The unstable demand for housing discourages companies to develop long-term investment plans. Moreover, in many cases, the shift from craft to industrialized production requires upfront investment which is a risky decision uncertain economic conditions or housing demand. In addition, since labor costs are very low and contracting systems very flexible, construction companies do not perceive significant benefits from reducing labor hours resulting from new technology implementation (Torres and Torres 2009). Others argue that government in developing nations are not interested in changing these conditions. From a social perspective, replacing man-hours by machines does not make sense because construction activity is seen as catalysts of employment. In difficult economic times, governments launch programs to incentivize the construction industry to create demand for jobs (Wells 2001).

2.12.3 Size of business

The Latin American construction industry is highly fragmented and composed of small, specialized and volatile companies. Subcontracting is the most used hiring strategy. Big construction companies prefer to manage and oversee the construction process instead of getting involved in productive functions (Ofori 2012). Housing developers highly rely on intermediaries who recruits the workforce for the construction projects (Bouillon 2012). The instability of economies and demand for construction services became subcontracting the most preferred strategy since it offers flexibility in labor hiring, allowing companies to increase the labor force easily when demand is high, and to avoid bearing fixed labor costs when demand is low (Bouillon 2012). This results in the predominance of small construction firms. For instance, in Colombia, more than 70% percent of the companies sell less than $500,000 yearly and 50% of them last less than 2 years on business (Torres and Torres 2009).
2.13 Components of housing cost

Understanding the components of housing cost is important to evaluate the potential impact that production systems improvement can have on overall housing cost.

To the best knowledge of the author, Bouillon (2012, chapter 5) is the most comprehensive study analyzing the components of housing cost in Latin America. The study breaks down the selling cost of housing developments into three main categories: administrative cost, land development cost (land acquisition and infrastructure), and construction cost (labor, materials, and equipment). The study considers information of housing developments built in the periphery fifteen cities of nine Latin American countries. In Table 2-1, the author compares the results of Bouillon (2012) with a similar study conducted by Brain and Sabatini (2006) in Santiago, Chile. The table also shows the calculations of the author based on the budget of the Villa Hermosa Case Study located in Duran, Ecuador (Chapter 4). The author adapts the breakdown structure of Brain and Sabatini (2006) and Villa Hermosa to Bouillon (2012) for proper comparison.

Table 2-1: Housing costs breakdown in Latin America

<table>
<thead>
<tr>
<th>Source</th>
<th>Administrative</th>
<th>Land development</th>
<th>Construction</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouillon (2012)</td>
<td>15%</td>
<td>25%</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>Brain and Sabatini (2006)</td>
<td>1%</td>
<td>33%</td>
<td>66%</td>
<td>100%</td>
</tr>
<tr>
<td>Case Study Villa Hermosa</td>
<td>1%</td>
<td>45%</td>
<td>54%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2-1 shows that administrative cost counts for up to 15% of the total housing cost. It is important to notice that Brain and Sabatini (2006) and Villa Hermosa do not include administrative cost related to managing affordable housing programs which may be the main reason of divergent results in this item. Land development cost ranges from 25 to 45% of the total housing cost. Villa Hermosa is a project that includes designing and building an electric substation and water treatment plants for drinkable and sewage water along with underground urban infrastructure which may be the reason for the 45% in the Land Development item.

The following sections provide more details about the cost included on each item.

2.13.1 Administrative cost

Administrative cost is divided into two categories. First, the cost related to managing affordable housing programs, which includes gathering and distributing resources at the central and regional level, as well as cost related to assisting beneficiaries in obtaining subsidies. The proportion of this cost varies from country to country depending on the administrative complexity of the local organizations (Bouillon 2012). Second, the cost of construction permitting. In emerging economies, the supply of affordable housing is highly constrained by the difficulty that developers face in obtaining construction permits at a reasonable cost and within acceptable time frames (Chiquier and Lea 2009). In Latin America, the average cost of construction permits accounts for 5.6% of the property value. The timeframe for the permitting process averages 2.2 months. Nevertheless, in some cities it can take up to 6 months (Bouillon 2012).
Excessive permit processing extends project duration which may increase housing cost. Commonly, developers work with capital borrowed from financial institutions, thus the longer it takes to obtain construction permits, the highest the interest a developer should pay for a loan due project time extension (Bouillon 2012). Estimates in the US housing market indicates that reducing permit processing times and regulatory costs can contribute to reducing housing cost up to 20% (Ural and Shen 1989).

### 2.13.2 Land development cost

Land development includes the acquisition of land and its connection to urban services for residential use. Land cost is driven by many factors including population growth, changes in household composition, and zoning codes (Bouillon 2012). Population growth, for instance, increases demand for residential land affecting and resulting in increased prices. Similarly, the excessive share of land for industrial purposes in zoning codes may limit the availability of land for housing, and reduced availability of land usually means an increase in price.

The cost of preparing land for residential use is influenced by local building codes and site development regulations. Flexible regulation codes that promote efficiency in infrastructure design and construction have a great potential to make housing more affordable. Likewise, the design of development clusters that increase density without affecting habitability may contribute to reducing infrastructure cost (Ural and Shen 1989).

The increase in urban population in big Latin American cities has resulted in escalating land prices. Bouillon (2012) estimates that on average, 12% percent of the population cannot afford to pay for the cheapest plot available in Latin America cities. The cost of urbanized land also has significantly increased. In Santiago, for instance, urbanized land cost has risen at an annual rate of 15% in the last 15 years (Trivelli 2010). Some argue that the implementation of DHS along with deregulation of land markets are the main causes of escalating land prices (Sabatini 2000; Brain and Sabatini 2006).

### 2.13.3 Construction cost

Construction cost shares a significant portion of total a home sales price. A 2011 survey in the US indicates that construction costs account for 59.3% of a single family house sales price (NAHB 2011). The share of construction cost varies across countries and depends, for instance, on the type and quality materials and the technology used for construction. In Latin America, construction cost represents an average 60% of the total house sale price. When considering only affordable homes in Latin America, the share of construction costs rises up to 70% (Bouillon 2012).

### 2.14 Conclusions

The implementation of the DHS policy in Latin America has resulted in a strong involvement of private developers in housing supply. Private involvement has boosted housing construction helping several countries to reduce housing shortages, which is a remarkable success. Despite increased housing construction there is still a big gap between housing supply and demand.

The implementation of the DHS policy has also influenced the way housing is produced and consumed in the region. It has redefined the roles and responsibilities of the different stakeholders in the housing market, as well as the technical and economic conditions for housing production. Under such conditions, affordable housing developers have favored the implementation of mass
housing production. Evidence from different Latin American countries reveals several issues in the design and construction quality of the mass housing product. Researchers have pointed out that issues regarding the inadequate location of developments, their excessive size, the small size of the housing units and the monotony of design has had significant impacts on the quality of life of beneficiaries.

Considering the need to speed up housing construction and the indirect problems resulting from the mass housing production approach, the challenge for the construction industry in the region is twofold. First, there is a need to scale up housing construction in order to achieve a level of housing supply that contributes to reducing housing shortages. Second, there is a need to improve the quality of the housing product in order to meet the expectations of beneficiaries.

Since the DHS policy relies on private housing supply, it is rational to explore ways to improve the efficiency of the construction industry and evaluate its impact on housing affordability.

In terms of the potential impacts of such improvements, the literature reveals that the housing construction industry in the region is labor intensive, very fragmented, and lacks advanced technology implementation. Moreover, construction activity accounts for an important fraction of the final sales price of affordable housing. Thus, there is substantial room for improvement.

To the best author’s knowledge, Bouillon (2012) is one of the most comprehensive studies analyzing the role of the construction industry in affordable housing provision. Bouillon (2012) recognized that the construction industry and governments should take action to enable innovation in the housing construction sector. Affordable housing developers should develop a better understanding of what consumers want, and they also need to focus on their production processes to cut construction costs. To this end, he proposed the following actions:

- To establish a deeper understanding of the needs of the affordable housing market and align demand and supply, as in the automobile industry.
- To increase the value of the final housing product by expanding choices for the client without losing the concept of standardization and mass production.
- To set production systems based on efficient use of labor.
- To implement production systems that allow different production lines to be integrated resulting in a high-quality final product.
- To establish new business alliances that facilitate the integration of different stakeholders involved in housing provision.

The application of cutting edge managerial techniques and technologies to design production systems for housing construction may help to achieve this purpose. In this aspect, the implementation of the Lean Principles to improve production processes, which have been realized in the automobile industry (Womack et al. 1991), offers a great opportunity to achieve cost saving and to make housing more affordable for low-incomes. For instance, Woetzel et al. (2014) estimated that by implementing Lean approaches, industrialization, standardization, among others, developers can cut construction costs for affordable housing by 16%.

The large scale of resources needed to address housing shortages and the significant impact of construction activity on final housing cost are a major incentive for the government and housing construction industry to explore the implementation Lean Principles in housing construction.
Documenting the success, failures, and challenges of these efforts may serve as a starting point to realize the potential benefits of Lean implementation.
CHAPTER 3 LITERATURE REVIEW ON LEAN FOR HOUSING CONSTRUCTION

Chapter 3 presents a literature review of Lean Production with emphasis on its applications for housing construction. Section 3.1 correlates Lean Production with the challenges in affordable housing provision in Latin America. Section 3.2 explains Lean Production by describing the evolution of different production paradigms. Section 3.3 describes the theory behind Lean Construction. Section 3.4 presents a review of production paradigms in the housebuilding industry. Section 3.5 corresponds to a literature review about the implementation of Lean Construction in Latin America. Finally, Section 0 presents the conclusions.

3.1 Lean Production and challenges of affordable housing delivery in Latin America

Since this study explores the use of Lean Principles to address housing constraints in Latin America, the author links Lean Production theory with the challenges of affordable housing delivery in the region.

Womack et al. (1991) described Lean Production by contrasting two of its precedent production paradigms: craft production and mass production. Craft production combines highly skilled workers and flexible tools to produce personalized goods, one item at a time. High customization in craft work results in an exclusive but costly product. In contrast, mass production uses less skilled workers and specialized, single-purpose machinery to produce standardized goods in high volumes. Taking advantage of economies of scale, the mass product is cheaper but sacrifices variety. Lean Production aims to combine the advantages of both, by “avoiding the high cost of the former and the rigidity of the latter” by using multi-skilled workers and flexible production systems to deliver high volumes with increased variety. Womack and Jones (2003) defined two critical steps in the Lean Production theory. First, value generation, which involves designing products or services according to customer requirements. For this purpose, understanding customer needs and translating them into products/services specifications are essential procedures in Lean Production. Second, value delivery, which involves delivering the products/services to customers through flexible and efficient production systems.

As described in Chapter 2, affordable housing developers in Latin America have favored the implementation of mass housing production. This approach has contributed to scale up housing production but it has, at the same time, neglected the incorporation of customer needs into housing design. Thereby, the use of Lean Production in housing construction may contribute to expand housing production without sacrificing the delivery of variety that fits the profile and needs of diverse families. Bouillon (2012, p. 175) stated that affordable housing developers should develop a deeper understanding of consumers and design their production systems accordingly.

Table 3-1 links the critical steps in Lean Production with the challenges in affordable housing provision in Latin America using the work of Womack and Jones (2003) and Bouillon (2012).
Table 3-1: Links among Lean Production and the Challenges in affordable housing in Latin America

<table>
<thead>
<tr>
<th>Essential steps to pursue the Lean Production ideal.</th>
<th>Recommended actions for affordable housing developers in Latin America.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value generation: to understand customer requirements and translate them into products/services specifications.</td>
<td>1) To establish a deeper understanding of the needs of the affordable housing market in order to align demand and supply, as in the automobile industry.</td>
</tr>
<tr>
<td></td>
<td>2) To increase the value of the final housing product by expanding choices for the client without losing the concept of standardization and mass production.</td>
</tr>
<tr>
<td>Value delivery: to deliver the products/services efficiently.</td>
<td>3) To set production systems based on efficient use of labor.</td>
</tr>
<tr>
<td></td>
<td>4) To implement production systems that allow different production lines to be integrated resulting in a high-quality final product.</td>
</tr>
<tr>
<td></td>
<td>5) To establish new business alliances that facilitate the integration of different stakeholders involved in housing provision.</td>
</tr>
</tbody>
</table>

3.2 Overview of production paradigms

The automobile industry is a good example to represent innovations in manufacturing and production paradigms. Altshuler (1984) provides an overview of the evolution of the automobile industry. This evolution can be classified into three main phases: craft production, mass production, and mass production plus product differentiation.

3.2.1 Craft production

The automobile industry was born in Germany and France in the mid-1880s. In its early times, automobiles were produced using craft techniques in which craftsman designed and produced mostly luxury models. Although automobiles were well-designed and excellently crafted, high production cost per unit became them only affordable by upper-class people. This resulted in a very specialized and reduced market segment that discouraged further innovation in manufacturing techniques. Even 15 years after its invention, automobiles were produced with no further manufacturing sophistication than a house. By 1906, Germany and France were the leading automobile producers accounting together for 58 percent of the global production. However, the market was still small averaging 50,000 automobiles per year in all Europe (Altshuler 1984).

In the early 1900s, several factors contributed to the growth of the automobile market. Advances in automobile design widespread the enthusiasm and confidence of the general public on them as a reliable way of transportation (Flink 1990). Moreover, governments began investing in the construction and maintenance of roads which facilitated the use of automobiles (Wells 2007). The
main impediment to the expansion of the industry was the inability of manufacturers to scale up the production of affordable automobiles. The narrative of Flink (1990, p. 34 - 35) suggests that several automobile producers attempted to manufacture low-costing cars at a large scale. In 1902, Ransom Olds started the production of the tiny and low-cost "curved dash" Oldsmobile which was explicitly intended for a mass market. In 1906, Henry Leland designed a Cadillac with interchangeable parts which are fundamental for mass production. Nevertheless, Henry Ford was the one who made it possible on a larger scale.

3.2.2 Mass production

In 1906, Henry Ford and his mechanical engineers started to work in the Model T. The targeted feature of the new model was simplicity. Ford wanted to design an automobile that can be produced with simple and inexpensive components, easy to manufacture and thus, cheap to sell. The Model T incorporated many features already tested on previous Ford’s models. Nevertheless, this time, they incorporated advances in fabrication techniques and materials to ease manufacturing. In 1908, Ford launched the Model T experimenting excellent sales. In addition to the design features in the Model T, Ford experimented new ways of production. In 1913, he implemented a production plant equipped with a moving assembling line arranged with specialized machinery and workers performing standardized and repetitive tasks. By focusing on the Model T, Ford benefited from economies of scale and increased productivity in the production line (Ford and Crowther 1922). In summary, Ford designed an automobile easy to manufacture, and complemented it with a system of social organization and production machinery that led the automobile industry to the phase of mass production. In 1903, the company sold 1,700 automobiles. In 1908, before the Model T, the company rose 10,000 sales. In 1914, after the Model T and the assembly line implementation, the sales rose 300,000 units. In 1923, once the Model T became more popular and the assembly line system was perfected, the company sold 1.9 million units sharing 44 percent of the global automobile production. The Ford’s mass production approach spread in North America helping the country to become a leader in automobile production. Alfred Sloan at General motor perfected Ford’s approach helping the company to increase sales. By 1920, North America automobile manufacturers shared 85 percent of the global market (Altshuler 1984).

3.2.3 Mass production plus product differentiation

The success of American manufacturers did not take Europeans manufacturers away from the competition. Several factors as the inadequacy of transportation systems and the implementation of tariffs protecting European domestic manufacturing after World War I harmed the competitiveness of North American automobile exports. This resulted in a large number of small European automobile manufacturers producing a wide range of automobile models with different specifications to satisfy the local conditions of European nations. For most American manufacturers, this approach generated confusion and did not contribute to exploit of their major strength, economies of scale.

In the late 1950s, once the tariffs were reduced, most manufacturers began increasing production to reach global customers. The characteristics of the European market provided local manufacturers the ability grow volumes of production with increased variation, which became an important competitive weapon for European manufacturers. In contrast, their North American counterparts tended to focus on the mass production approach. The ability to produce more variety
led Europeans to increase the market share. By 1970, the total European manufacturer equaled North America (Altshuler 1984).

After World War II, as a part to recover the economy, the Japanese government made significant efforts to create a local automobile industry. The takeoff of Japanese manufacturers took a while. In 1950, Nissan experimented with new organizational techniques and product development but the new approach had significant resistance from the labor force. Moreover, the acceptance of their automobile designs was minimal in North America and Europe. By 1960, the Japanese realized a new manufacturing philosophy in production organization based on the concepts of Just in Time (JIT) and Total Quality Management (TQM). This manufacturing philosophy had its origins in the Toyota Production System (TPS) (Ohno 1988). Toyota Manager Taiichi Ohno embraced the concepts of Ford but considering a broader set of objectives: produce customized cars, deliver them instantly and reduce inventory levels. Ohno found the way to sustain the economies of scale with smaller lot production than Ford’s mass production in the so-called one-piece flow. The TPS reported substantial gains in productivity and revolutionized the automobile manufacturing industry allowing Toyota to manufacture automobiles with different specifications with fewer resources and reduced quality defects (Altshuler 1984). The principles of the TPS contributed to the development of Lean Production, a new theory of production which is considered the evolution of manufacturing beyond Ford’s mass production approach (Krafick 1988).

Lean Production theory captured the attention of researchers and practitioners expanding its application beyond the automobile manufacturing industry, including construction. Inspired in part by the success of the TPS, Koskela (1992) proposed the implementation of a new production philosophy to construction, which led to a new mode of practice coined as Lean Construction.

### 3.3 Lean Construction: a new production theory for construction

Koskela (1992; 2000) studied the conceptual basis of production philosophies applied in manufacturing. According, he proposed a new production theory to construction based on three predominant views of production (Table 3-2): Transformation – Flow – Value (TFV).

In the Transformation view, production systems are broken down into small processes, each one converting inputs into outputs. The belief is that by reducing the amount of resources used in each task independently of the others, the entire production system will be improved. This view of production is predominantly used in mass production systems and construction engineering and management.

In the Flow view, production systems are perceived as series of interconnected processes in which raw materials gradually flow from one process to another to become finished products for the customer. The belief is that elimination of waste (non-value adding activities) from the process flow will result in overall production system improvement. The Flow view provided the basis for the development of Just-in-Time (JIT) and Toyota Production System (TPS), thus it is embodied in Lean Production.

In the Value view or production as value generation, the objective is to achieve the maximum possible value for the customer. This view offers a conceptualization of production system that incorporates the customer. The belief is that transformation and flow are not the only views valuable in a production system, but the fact that the final output meets the requirements of customers.
Koskela (2000, p. 88-89) stated that the Transformation, Flow, Value views of production should not be considered as competing but rather partial and complementary theories. Each of them focuses on certain aspects of production and has its own tools and methods. Accordingly, he proposed their integration in the TFV model of production.

### Table 3-2: TFV production model

<table>
<thead>
<tr>
<th></th>
<th>Transformation view</th>
<th>Flow view</th>
<th>Value generation view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptualization</td>
<td>As a transformation of inputs into outputs</td>
<td>As a flow of material, composed of transformation, inspect, moving and waiting</td>
<td>As a process where value for the customer is created through fulfilment of his requirements</td>
</tr>
<tr>
<td>Main principles</td>
<td>Getting production realized efficiently</td>
<td>Elimination of waste (non-value-adding activities)</td>
<td>Elimination of value loss (achieved value in relation to best possible value)</td>
</tr>
<tr>
<td>Methods and practices</td>
<td>Work breakdown structure, MRP, organizational responsibility chart</td>
<td>Continuous flow, pull production control, continuous improvement</td>
<td>Methods for requirements capture, quality function deployment</td>
</tr>
<tr>
<td>(examples)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practical contribution</td>
<td>Taking care of what has to be done</td>
<td>Taking care that what is unnecessary is done as little as possible</td>
<td>Taking care that customer requirements are met in the best possible manner</td>
</tr>
<tr>
<td>Suggested name</td>
<td>Task management</td>
<td>Flow management</td>
<td>Value management</td>
</tr>
<tr>
<td>for practical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>application of the view</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The work of Koskela (1992; 2000), Ballard and Howell (1994), and (Ballard 2000) set the foundations of Lean Construction, a new way of thinking and managing production systems. It contributed to begin a constructive dialog about how to improve organizational and operational aspects of the construction industry (Winch 2006) based on theoretical foundations (Ballard and Howell 2003).

### 3.4 Production paradigms in the housing industry

In order to address increasing demand for housing, housebuilders began exploring new ways of housing production based on the use of new technologies and off-site production (Abrams 1964). Although with some delay in the implementation dates, the literature suggests that the evolution of production approaches used for housing construction resemble the production paradigms described in Section 3.2.
In 1906, Aladdin and Co. started selling wood-prefabricated houses in the US (Marquit and Limandri 2013). The company aimed to cut construction costs based on the principle that “modern power-driven machines can do better work at a lower cost than hand labor. Then every bit of work that can be done by machines should be so done” (Aladdin Company 1917, p. 3). By 1911, the company offered 41 models selling around 3,000 units per year. The depression after World War II significantly affected company’s sales. Aladdin and Co ceased operations in 1981. The company sold around 100,000 homes all over the United States, Canada, England and Africa (Johnson 2006).

In 1908 Sears Roebuck and Co. began selling timber prefabricated homes through their mail-order modern homes program. The company focused on producing construction materials at a mass scale, eventually transferring these savings to customers. The company allowed customers to select some features of the houses. Based on customer orders, Sears precut and shipped the materials to assemble the house on the site. The company sold around 70,000 housing units with 447 model variations. Sears ended its housing program in 1940 (Sears 2012).

Factory-built of houses gained momentum thanks to the success the mass production approach used by Ford. In early 1930, Aiming to “Fordize” housing production, Foster Gunnison became the first housebuilder to set a moving line to assemble houses in a factory environment. Gunnison engineered and produced standardized interchangeable wall panels that can be rearranged to build twelve different housing models (Hounshell 1985). Gunnison focused on affordability highlighting he could build houses 25 per cent cheaper than similar models built with conventional methods. By 1941, the company claimed to sell 4,500 housing units in 38 states. In 1942, Gunnison sold 70 percent of the company to U.S. Steel. In 1953, Gunnison retired selling the remaining portion of the company. U.S. Steel produced houses till 1974 (Modular House Builder 2012).

In 1940, Lustron Corporation was also seduced by the idea that “houses can be turned out like automobiles.” Under the pressure of increasing housing shortages, the US government provided Lustron a loan to build factories to mass-produce metal prefabricated houses. According to Wolfe and Garfield (1989), Lustron had all the elements required for success in the prefabricated housebuilding industry: governmental support, financial, physical and technological resources (Wolfe and Garfield 1989). Nevertheless, the company focused excessively on achieving production savings in the plant and mislead the attention to all the steps in the entire production system. For instance, savings achieved in the plant resulting from an industrialized approach may be easy outrun by extra costs in distribution and erection (Kelly 1959). In terms of distribution, local dealers had to face several hidden costs to transport house components. In terms of construction, Lustron expected to build houses with 150 men hours. This was a very ambitious target considering that by the time, wood houses were built with 1,600 men hours. Rarely local construction partners could build a Lustron house with less than 150 men hours (Wolfe and Garfield 1989). The company expected to produce 30,000 houses per year. However, the company only produced 3,000 houses before declaring bankrupted in 1950 (Johnson 2006).

Overall, the industrialization of the housing industry was promissory. By 1954, the United States had approximately 100 prefabricators sharing around 10 per cent of the housebuilding market. White (1954) reported that a prefabricator could produce 50 houses per day, with 106 in-plant man hours per unit. Mass housing production also received several critics. Mumford (1930) claimed that cost savings resulting from an industrialized approach vanish in the long term. He argued that mass-produced houses wear up faster than the ones built with traditional methods which result in a higher turnover. Henderson (1953) described how monotonous and standardized characteristic
mass-produced houses shaped the formation of new suburbs in the periphery of cities. Ferber and Wales (1951) surveyed 448 families living in a mass-produced housing development in Urbana-Champaign revealing several complaints of the residents regarding the quality and appearance of houses. The Pruitt-Igoe project is commonly cited as an example of failure in mass housing provision. The last part of the project was completed in 1955 and less than 20 year later, it was demolished due to the extreme poverty, crime and the segregation experienced by the residents (Bristol 1991). The literature suggests that mass housing production introduced unanticipated social problems similar to the ones described in Chapter 2 for the case of Latin America.

Housebuilders tended to import production approaches used in the automobile by making construction more like manufacturing. Nevertheless, such approach is insufficient considering the differentiating characteristics of construction activity. Koskela (1992) highlights three peculiarities of construction: 1) one-of-a-kind nature of projects, 2) site production, and 3) temporary multiorganization. The one-of-a-kind nature of construction is relative to the type or projects. For instance, building similar houses in a housing development is closer to manufacturing than building a unique large bridge. Site production relates to the fixed position of projects. For example, most commonly in the automobile industry, automobiles move in the assembly line. In contrast, in construction, the object becomes so large that people move around the whole being built. Temporary multiorganizations are set up for the period of time that takes to build the project. The same organization may work in another project but most likely, construction teams change over time. According to Ballard and Howell (1998), construction is “essentially the design and assembly of objects fixed-in-place, and consequently possesses, more or less, the characteristics of site production, unique product, and temporary teams.” Learning how to deal with the complexity and quickness considering the characteristics of construction projects is fundamental for the implementation of Lean Production in construction.

Most recent examples suggest that housebuilders have learned to deliver a variety of housing model with efficiency as in the case of Toyota (Gann 1996). Toyota established its housing group in 1975 starting the production of prefab steel frame detached housing models (Toyota 2012). The company has been able to transfer learnings from automobile production to its housing business. The use of advanced technologies (Bock 2007) in addition to the implementation of the TPS principles such as JIT, Jidoka, Heijunka, Standardization work and Kaizen (Smith 2008) allows the company to offer housing models that can be defined by customers using more than 300 interchangeable housing modules (Figure 3-1).
In order to deal with variant demand and production times for different modules, the company uses Heijunka (work leveling). For example, the extra plumbing and electrical work required in the kitchen results in an extended production time, if compared with a bedroom. In the event of high demand, Toyota avoids having two kitchen modules in the production line because it delays the production of less complex modules. In this case, the company buffers kitchens production 7 days by having finished modules already assembled in a storage place. In addition, when customers specify housing modules that require special work, they build them off of the production line (Liker 2013).

In the mid-1990s, the construction company Skanska partnered with the furniture company IKEA created BoKloK, a housing concept aimed to produce quality affordable housing for middle-class people (Skanska 2016). By considering customer requirements and improving housing design, the company claims to offer more space for less money (BoKloK 2016). Except for the foundations, BoKloK timber framed modules are almost entirely prefabricated, transported and erected at the construction site (Giles 2008). In addition to design improvement, the company achieves cost saving by implementing industrialized approaches based on Lean Construction (Duc et al. 2014).

### 3.5 Lean Construction implementation in Latin America

In order to assess to what extent Lean concept are implemented in Latin America, the author reviewed the literature regarding applications of Lean Construction in the housebuilding sector in the region. The literature review focuses on the proceedings of the annual conference of the International Group of Lean Construction (IGLC) and Google Scholar database. IGLC was selected because it is the main source of peer-reviewed conference papers related to Lean implementation. Google Scholar was considered because the author acknowledged that many publications may come from Universities in the region (i.e., M.S. thesis and Ph.D. dissertations in Spanish). The author used the keywords “affordable housing”, “social housing” and “low-income housing” and their corresponding translation in Spanish. Table 3-3 presents the results of the search according to the main topic covered in the papers. Figure 3-2 summarizes the results.

**Focus:**

LPS: Last Planner System  
LBS: Location Based Scheduling  
VSM: Value Stream Mapping  
QM: Quality Management  
BIM: Building Information Modelling  
IF: Information Flow  
VC: Value Capturing  
TVD: Target Value Design  
MC: Mass Customization

![Figure 3-2: Summary of literature review](image)
Table 3-3: Literature review on Lean Construction implementation in housing construction in Latin America.

<table>
<thead>
<tr>
<th>Country</th>
<th>Reference</th>
<th>Affordable housing?</th>
<th>Focus</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecuador</td>
<td>Fiallo and Revelo</td>
<td>(2002)</td>
<td>No</td>
<td>X</td>
</tr>
<tr>
<td>Mexico</td>
<td>Loria-Arcila et al.</td>
<td>(2003)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>Botero and Alvares</td>
<td>(2004)</td>
<td>Yes</td>
<td>X</td>
</tr>
<tr>
<td>Brazil</td>
<td>Schramm et al.</td>
<td>(2004)</td>
<td>Yes</td>
<td>X</td>
</tr>
<tr>
<td>Brazil</td>
<td>Santos et al.</td>
<td>2004</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>Loria-Arcila and Vanegas</td>
<td>(2005)</td>
<td>Yes</td>
<td>X</td>
</tr>
<tr>
<td>Brazil</td>
<td>Bortolazza et al.</td>
<td>(2005)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Kemmer et al.</td>
<td>(2007)</td>
<td>No</td>
<td>X</td>
</tr>
<tr>
<td>Brazil</td>
<td>Lima et al.</td>
<td>(2008)</td>
<td>Yes</td>
<td>X</td>
</tr>
<tr>
<td>Brazil</td>
<td>Simoes et al.</td>
<td>(2008)</td>
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LPS: Last Planner System  
LBS: Location Based Scheduling  
VSM: Value Stream Mapping  
BIM: Building Information Modelling  
VC: Value Capturing  
TVD: Target Value Design  
QM: Quality Management  
IF: Information Flow  
MC: Mass Customization
In Figure 3-2, 35% of the literature focuses on Last Planner System (Ballard 2000) implementation. Another 35% focuses on value generation, and 8% is related to Target Value Design. Significant implementation of Lean for affordable housing design is concentrated in Brazil. This work is mainly led by Professor Carlos Formoso. Location Based Scheduling, Value Stream Mapping, Quality Management, Building Information Modeling, Information Flow and Mass Customization accounts for 4% each. During the search, the author identified significant work on Mass Customization in the Zero Energy Mass Custom Homes (ZEMCH) research group (i.e., Traverso and Formoso (2014) and Dos Santos et al. (2014)).

In terms of design, value generation concepts are used to incorporate user needs into project’s specifications. In terms of value delivery, LPS is the most used tool in affordable housing projects. Except for Schramm et al. 2004, which aims to integrate LPS and LBS, most of the studies correspond isolated implementation of Lean Construction tools. Furthermore, most of the studies dealing with affordable housing emphasize Lean tool implementations regardless of the housing policy context in which they are implemented. Although valuable as a starting point for Lean Construction implementation, in many cases, isolated of tool implementation has little impact on overall organization efficiency. Better results can be realized by considering the Lean Principles as part of a Lean enterprise transformation (Picchi and Granja 2004). Therefore, a contribution to the knowledge of this study is the use of the Lean Principles as a framework to evaluate Lean practices along with the consideration of the affordable housing policy environment in which they are implemented.

3.6 Conclusions

The links among Lean Production and the challenges in affordable housing in Latin America reveals that the implementation of Lean theory may contribute to addressing housing constraints in the region.

In terms of production approaches for housing construction, the evolution of the housebuilding sector seems to resemble the production paradigms of its automobile counterpart. As part of this evolution, in the last decades, some companies like Toyota homes and Skanska have incorporated Lean Production to deliver variant housing solutions to satisfy the profile of different families.

Narrowing the scope in Latin America, the literature reveals several cases of Lean Construction implementation in the housebuilding industry. Nevertheless, most of these efforts correspond to isolated Lean tool implementations. Therefore, a broader level of implementation and thus improved results and impact may be reached by implementing practices that adhere to the core Lean Principles. Furthermore, previous research emphasized Lean tool implementation disregarding the affordable housing policy environment in which they are implemented. As described in Chapter 2, the housing policy environment, particularly, the DHS approach has shaped the way affordable housing is designed, built and consumed in the region. Thus, its consideration is important when evaluating new forms of housing provision. Consequently, a novel contribution of this research is the evaluation of practices in affordable housing construction (Chapters 5, 6 and 7) considering the Lean principles along with the affordable housing policy environment.
CHAPTER 4 RESEARCH FRAMEWORK

Chapter 4 presents the research framework used to explore the implementation of Lean practices described in the Cases Study of Villa Hermosa, Quinta Monroy, and Build Change (Chapters 5, 6, and 7, respectively). Section 4.1 provides justification on the use of the fourteen Lean Principles. Section 4.2 describes the principles and Section 4.3 presents the conclusions.

4.1 TPS principles as a framework for study

This study uses the fourteen TPS principles defined by Liker (2004) as a framework for the research. The TPS principles are selected because they are the bedrock of Lean Production (Womack et al. 1991; Womack and Jones 2003, p. 9-10; Liker and Meier 2006, p. 5). Moreover, the foundations of Lean Construction, as well as the development of its managerial techniques, are inspired by TPS (Ballard and Howell 2003; Koskela 2004) and accepts it as a baseline for production systems design (Howell 1999).

Liker (2004) and Liker and Meier (2006) described several tools, methods and managerial techniques that Toyota uses to deploy the fourteen TPS principles. Outside the Toyota world, researchers and practitioners have created Lean tools and techniques that can be applied at different corporate levels, and in different stages of the project delivery process as design, planning, procurement, and production (Diekmann et al. 2004). In practice, although some operations are not explicitly labeled as “Lean”, the degree of “Leanness” can be evaluated based on the degree of adherence of such practices to the Lean Principles. Consequently, in order to link the Cases Studies included in this study with the Lean Principles, the author set a framework based on the fourteen TPS principles described by Liker (2004).

4.2 Fourteen TPS principles

Liker (2004) described the fourteen TPS principles using the 4P model depicted in Figure 4-1: Philosophy, Process, People/partners and Problem solving. The author uses the work of Liker (2004), Liker and Meier (2006) along with other literature to describe the most relevant concepts and practices related to the TPS principles.

4.2.1 Philosophy as the foundation

Principle 1: Base your management decisions on a long-term philosophy even at the expense of short-term financial goals.

The first TPS principle offers the philosophical foundation. It does not define specific actions or practices but represents the North Star that defines the purpose of the organization and serves as a starting point to delineate a company’s operations (Liker 2004). In a market driven economy, many companies exist to make profit. If this is the only objective, an organization may take a few Lean tools, capitalize the resulting cost savings and go out of business. Nevertheless, in this scenario, it will never become a learning organization and will be driven only by short-term objectives (Liker and Meier 2006).

Although the goal of Toyota is the reduction of waste to increase profitability, the TPS pursues a broader set of long-term objectives. The generation of value for customers, the society, and the economy are examples of superior goals that drive company’s operations. Short terms goals are achieved by implementing capable processes and developing people and partners through the
implementation of Lean tools at different organizational levels. Superior goals like growth and consistent value generation for the customer are harder to accomplish. These can only be achieved by establishing a culture of learning and continuous improvement (Liker and Meier 2006).

4.2.2 The right process will produce the right results

Principle 2: Create process flow to surface the problems.

An important component of the TPS is value delivery through a continuous production flow (Womack and Jones 2003). Continuous flow (also called one-piece flow) is achieved by steady elimination of waste in all levels of the production system (Liker and Meier 2006). Waste (or Muda) corresponds to all activities in the value stream that don’t add value to the customer. Waste elimination begins with its proper identification. Ohno (1988) identified 7 types of waste:

1. Overproduction of goods not needed
2. Waiting
3. Unnecessary transportation
4. Unnecessary processing
5. Inventories of goods awaiting further processing or consumption
6. Unnecessary movement

Figure 4-1: Fourteen TPS principles (Liker 2004)
7. Defective products

Whenever there is a product or service for a customer, there is a value stream. The starting point to identify waste is to map all the operations and the flow of materials and information required for production. Once the process has been mapped, the challenge is to identify activities that add value to the product and those that don’t. Those that don’t add value are considered waste and should be reduced or eliminated (Rother and Shook 1998).

In practice, improving an isolated activity is easier than improving the whole production process. Nonetheless, single efforts may not lead to overall efficiency gains (Liker and Meier 2006). Since production systems involve several interconnected operations, improving only one of them may disrupt the balance of the entire process. For instance, enhanced production capacity of a single operation may overload the succeeding tasks resulting in bottlenecks along the value stream. Thus, process improvement requires approaching waste elimination in a progressive way. In Figure 4-2, a level of stability should be achieved in order to improve a single operation in a “disconnected stability.” Then, this process of continuous improvement can be expanded to other related operations in a “multiprocess connected stability.” Finally, the entire process can be improved by considering all operations in order to achieve a “value stream connected stability.” It is recommended to start reaching a “value stream connected stability” at one organization before including the others (i.e., your own manufacturing plant before considering partners and suppliers) (Liker and Meier 2006).

![Figure 4-2: From disconnected stability to value stream connected stability (Liker and Meier 2006).](image)

Waste elimination results in the reduction of lead time and facilitates the identification of problems. Creating and sustaining the movement of materials and information through workstations, one piece at the time, with reduced waiting times will uncover issues that interrupt such flow. Thus, once problems have surfaced, people are required to act immediately otherwise production line would stop. According to Ohno, the ideal one-piece flow is hard to achieve. At the beginning is recommended to achieve flow with relatively small buffers between workstations. Although considered waste, the use of buffers is necessary as a starting point. The goal is to keep...
identifying and correcting problems, progressively reducing buffering and moving towards continuous flow (Liker and Meier 2006).

**Principle 3: Use “pull” systems to avoid overproduction.**

TPS advocates the use of pull over push production system. Figure 4-3, shows that in a pull production system, a series of defined signals among operations dictates the way they are executed in the value stream. Customer orders trigger the release of these signals and operations delivery work to the next one according to this flow of information. It is the way in which one operation communicated to its predecessor “I am ready to produce more.” Conversely, in a push system, signals among operations don’t exist. Operations release work to the next station whether it is requested or not, based on their own customer demand forecasts (Liker and Meier 2006).

![Figure 4-3: Pull and push systems](image)

Increased customer requests for variety undermine a producers’ ability to forecast demand, which increases production process complexity. In order to deal with such complexity, a production system based on push requires holding large inventories among operations. From the TPS perspective, increasing inventories are waste that generates broader organizational issues without helping to provide what customers wants.

A pull system can be implemented in a variety of ways (Hopp and Spearman 2004). For instance, TPS uses a Kanban system (Sugimori et al. 1977). Kanban is a sign that serves to communicate in the production system that “I am ready for more.” It can be, for example, an empty basket handed from one operator to another upstream requesting more materials required for the operation.

Designing a pull system requires enhanced coordination among operation and proper management of the Work In Progress (WIP). In the TPS, some operators work with racks of inventory that is regularly replenished when parts of a specific type are needed. This is an idea that Ohno realized observing the replenishment system of the shelves in U.S. supermarkets. Here, once products of one kind are consumed, an operator comes to refill the shelves (Liker and Meier 2006).

Hopp and Spearman (2004) defined pull and push systems in terms of WIP. A pull system clearly limits the amount of WIP in the value stream while a push system does not explicitly do that. Nevertheless, “in the real world, there are no pure pull or push systems.” They argue that a pull
system can be implemented as a comprehensive strategy to match the output of the production system with customer demand. Some sort of push can occur at a tactical level resulting in WIP that is used to balance the production system. As discussed by Olhager and Östlund (1990) the integration of pull and push are commonly seen in production systems delivering increased variety with efficiency. Thus, producing goods and services under lean principles involves proper management of WIP (Hopp and Spearman 2004) with the ideal of reaching one-piece flow (Ohno 1988)

**Principle 4: Level out the workload (heijunka).**

Variation in customer order mix and quantity inputs variation in the production processes that hinders process standardization and therefore the achievement of continuous flow (Liker and Meier 2006). Every time customer requires some sort of variation, the production system has to be reorganized and adapted to deliver what the customer wants. In order to reduce the adverse effect of variation in production systems, the TPS includes practicing Heijunka. Heijunka stands for the pursuing of stability in the production through leveling the workload. According to the Lean lexicon, Heijunka stands for “the leveling of the type and amount of production in a fixed period of time. It allows production to meet customer demand, through batches and results in reduced inventories, capital costs, manpower and production lead time” (Marchwinski and Shook 2003).

In Figure 4-4, when different items are produced, the time required to change operation to a new typology of product result in loss of productivity. The common approach to reducing operation changeovers (i.e., traditional mass production system) is to make larger batches of every kind of product. Nevertheless, from the TPS perspective, if those changeovers are not standardized or controlled, production losses are anyways exacerbated and customers may be dissatisfied. Heijunka enables the producer to have broader control over changeovers times for different types of product allowing a faster response (Johnson and Bröms 2000).

![Figure 4-4: Batching versus heijunka in a production system](image-url)
Principle 5: Build a culture of stopping to fix problems to get quality right the first time.

Producing defective products and fixing them is waste (Ohno 1988). Thus, the principle is to get the right quality the first time and avoid defects (Shingo 1986). The strategy implemented in the TPS is to stop production line and fix problems immediately avoiding passing defective work to the next operation. As a result, productivity may be diminished in the short term but this approach drives an organizational culture of problem identification and quick response that results in expanded benefits in the long term (Liker and Meier 2006). On their visit to Toyota plants in Japan, Womack et al. (1991, p. 79-80) found that any worker in the production line can pull a cord at their workstations to stop the line if they find any problem. The authors were impressed to discover almost no rework at the end of the production line and that the line stops less frequently than in other plants.

Principle 6: Standardized tasks and processes are the foundations for continuous improvement and employee empowerment.

Standardization of tasks and processes consist the definition and consistent use of a method that ensures a better performance. The definition of a standard in the execution of a process enables team members to identify procedures that are outside the standards. The creation of standard, stable, and repeatable processes are the foundation for flow and pull. Standardization is fundamental for Kaizen; it is the starting point for continuous improvement (Imai 1986). It serves a baseline to reduce waste. That means future improvements should reduce waste and produce better results than the previous standard (Liker and Meier 2006).

Standardization is needed because tasks and processes performed in a random fashion are hard to improve. For example, the impact of countermeasures implemented in a randomly executed process is hard to measure. Thus, a standard baseline is required to improve (Liker and Meier 2006).

In Figure 4-5, the first step in process improvement is to analyze the process in its initial condition. Since many processes are not stable in the initial stage, one of the first objectives is to achieve stability and to set the standard (Rother 2010). Once the process is stabilized and standardized, the next step is to analyze it in order to reveal waste and to set a new target condition. By removing waste, the process is improved and is moved next level. The new standard is set in order to sustain the improvement. These steps are part of an ongoing effort to identify problems and to implement effective methods that help the organization to address them (Liker and Meier 2006).

Standardization is driven by people, not done by people. People that usually perform the work are able to understand it properly to make the biggest contributions to the standardization process. Thus, the TPS assumes that workers are a valuable source in this process contributing with sound ideas to improve the way the work is performed (Liker and Meier 2006).
Principle 7: Use visual controls so no problems are hidden.

Visual controls in TPS are important in the development of standard work. Using well-designed charts in a workstation help people to identify whether they are performing in the standard condition or deviated from it. A chart in a workstation or in strategic plant locations may help operators to identify deviations from standards facilitating its return to the standard condition. In contrast, in Figure 4-6 the absence of such visual controls may produce a sequence of events that lead to perform activities outside the standards.

The utilization of visual aids is not only related standardization practices; it involves a philosophy of “visual workplace” (Liker and Meier 2006). At a higher level, visual controls aim to align “organizational vision, core values, goals and culture with other management systems, by means of stimuli (information), which directly address one of the five main senses: sight, hearing, feeling, smell and taste” (Tezel 2011). The initial work of Shingo (1981) and Ohno (1988) regarding the
implementation of visual controls in the TPS have served a baseline to Visual Management expanding the application to several other industries (Greif 1991; Galsworth 2005; Tezel 2011).

**Principle 8: Use only reliable, thoroughly tested technology that serves your people and process.**

Research has proven that the integration of technology and Lean Production theory can contribute to optimizing operations. Technology may serve as a valuable source of shared information contributing in handling product configuration information (Nahmens 2007) enabling a faster reply to variant external customer requirements (Riezebos and Klingenberg 2009). Thus, the integration of technology and Lean Practices can be harmonized to increase overall efficiency (Moyano-Fuentes et al. 2012). Nevertheless, In the TPS philosophy, people and process are more important than technology, and its implementation in the production system should never be used as a substitute for thinking. People may benefit from technology implementation but they should never be totally dependent on it.

In Figure 4-7, TPS first focuses on the implementation of a good human process. After a level of stability in the process has been achieved the implementation of technology to support it is evaluated. After screening alternatives, TPS moves to the implementation stage. Technologies that conflict with TPS principles are discarded (Liker and Meier 2006). For instance, Toyota implemented Kanban systems in the form of material storage containers and favored this system over the use of computers (Sugimori et al. 1977). Decades later Toyota experimented with an “e-Kanban” to enhance communication with its suppliers (Kotani 2007). Technology can be an important competitive advantage. Nevertheless, they are only temporary because it may be replicated by competitors (Rother 2010). The most important is that the process prevails in the production system. “There is no a Lean technology. There is an only Lean system with technology playing and appropriate role in supporting them” (Liker and Meier 2006).

This implies that the introduction of technology should not be evaluated in isolation. It should be considered along with the process and people. Literature reveals that Lean Production implementation along with IT tools can improve productivity by 20%. Nevertheless, when IT and improved management practices are implemented independently, they can bring only 2% and 8% of productivity gains accordingly (Koskela and Dave 2008).
4.2.3 Add value to the organization by developing your people and partners

These set of principles are known as “respect for humanity” (Liker and Meier 2006). Even though respect for humanity is mentioned in the early work of Ohno (1988, p. xi), it is considered as the most “unrecognized, ignored, or misunderstood” principles in the TPS philosophy (Emiliani 2006).

Shingo (1981) and Ohno (1988) directly or indirectly mentioned respect for humanity as fundamental in the TPS. Nevertheless, their descriptions focused on operational matters. This fact may have led to misunderstandings when the TPS principles were imported to the U.S. According to Emiliani (2008), cooperation and respect for people were understood by managers solely as a necessity to reduce internal conflict and to increase productivity. He argued that outsiders of Toyota failed to understand fully the “respect for humanity” principle leading to the failure of several Lean implementations in U.S. companies.

In the common industrial management, respect for humanity is understood as the creation of a stress-free and friendly working environment. However, the definition provided by the Toyota Way 2001 reveals this misconception (Toyota 2005, p. 53):

- Respect: We respect others, make every effort to understand each other, take responsibility and do our best to build mutual trust
- Teamwork: We stimulate personal and professional growth, share the opportunities of development and maximize individual and team performance.

Several TPS practices are intended to create a challenging working environment that leads people to think and grow within the borders of respect and trust. Such environment may not be the most
pleasant but people at Toyota, partners, and suppliers are encouraged to grow and to become better (Liker and Meier 2006).

Liker and Meier (2006) describe respect for humanity by breaking it down into three principles:

**Principle 9: Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.**

Toyota in Japan grows their people instead of hiring managers from the outside. When someone has to be hired, they made the selection based on candidate’s technical and managerial skills. Nevertheless, the starting point is working on the field in order to fully learn how to do the work. In average, it takes up to 10 years to grow a trustful manager coming from the outside. The reason is that in the TPS managers are not only required to have managerial skills, in addition, they have to feel and teach the TPS philosophy (Liker and Meier 2006).

**Principle 10: Develop exceptional people and teams who follow your company’s philosophy.**

The TPS relies on exceptional individuals that follow the philosophy. Toyota aims to align individuals’ beliefs and values with the culture of the company. Along time, TPS has created several tools and techniques that are in harmony with company’s philosophy. Such tools can be learned and used by any people. Nevertheless, Toyota success relies on the fact that those tools are used by exceptional people (Liker and Meier 2006). As quoted by Emiliani (2008, p. 5) “Toyota believes its growth as a business enterprise comes through the growth of its people. This means that in order to be successful, Toyota must utilize its employees' abilities as effectively as possible, and help each person develop the ability to think and execute the job more effectively.”

**Principle 11: Respect your extended network of partners and suppliers by challenging them and helping them to improve.**

Partners are an extension of Toyota. Toyota does not abuse of their partner by extracting value from them at the lowest price. The TPS supports partners so they become better working with Toyota and in this way all the system will become better (Liker and Meier 2006). Toyota establishes long-term relationships with their suppliers that ensure stable procurement of products. For this purpose, it is essential to create a mutual trust based on equality that results in relationships that are mutually beneficial (Toyota 2005, p. 58).

4.2.4 Continuously solving problems drives organizational learning

**Principle 12: Go and see for yourself to thoroughly understand the situation.**

Genchi genbutsu means “go and see” and it is a basic principle in the TPS. From TPS point of view, understanding the current state of the process is key to address problems. Thus, people at Toyota are encouraged to have a fully understanding of what is happening on the field from first hand before moving to the countermeasures implementation. It is a belief in the TPS that a deep understanding of issues can be only achieved by personally verified data. This requires avoiding theorizing or making decisions based others reports, or computer screens. Such approach may only provide superficial knowledge about issues, which may lead to the implementation of a non-optimal solution. The root cause of the problem can be found by on-shop floor investigation. Data is always important in manufacturing but emphasis must be given to the facts. This is an important aspect of critical thinking, which Toyota wants to spread on its employees (Liker and Meier 2006).
Genchi genbutsu must be practiced progressively. No matter how much confidence people may feel about their knowledge about the process, they must go and constantly see because processes are always changing as you move forward and improve (Rother 2010)

**Principle 13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.**

For Toyota, the process to arrive at the decision is just as important as the quality of the decision. The process of decision making should include 5 fundamental steps (Liker 2004):

1. Finding out what is really going on, including Genchi genbutsu (principle 12).
2. Understanding underlying causes that explain surface appearances asking why? Five times.
3. Broadly considering alternative solutions and developing a detailed rationale for the preferred solution.
4. Building consensus within the team, including Toyota employees and outside partners.
5. Using very efficient communication vehicles to do one through four, preferably one side of one sheet of paper.

The step 1 Genchi genbutsu was described in principle 12. Step 2 aims to lead people to dig deeper into the possible causes of problems. Toyota encourages people to ask themselves why? 5 times in order to find the root cause of the problems. Just as people may find many causes to problems, they may find many alternative solutions. Thus, step 3 encourages people consider all alternatives in the decision making. Creativity from the TPS point of view is an important part of decision making. In Toyota culture, Nemawashi stands for bringing the problem and potential solutions to all people that will be affected by the decision. Step 4, encourages people to achieve consensus at the moment to define a solution. Consensus does not mean total agreement, which may be hard to achieve among diverse people. Consensus means that people agrees to accept a proposed solution but do not necessarily means they believe is the best one (Liker and Meier 2006). People are visual, thus the communication of steps 1 to 4 are better communicated by visual means. For this purpose, Toyota encourages the use of A3 reports. A3 reports are equivalent to an 11x17 in. sheet that follows the Deming cycle. It serves as a summarized guideline which leads the reader from problem identification to the implementation (Liker 2004).

**Principle 14: Become a learning organization through relentless reflection (Hansei) and continuous improvement (Kaizen).**

At the top of the pyramid model depicted in Figure 4-1 is one of the most important principles in the TPS. The core of the TPS is to encourage people to think, learn, and grow. According to Liker (2004), “the very learning capacity of the organization should be developing and growing over time, as it helps its members adapt to a continually changing competitive environment.”

A learning organization is capable of achieving Kaizen, which means continuous improvement involving all people at Toyota, from operators to top managers. Kaizen can’t be possible without Hansei. Hansei is a concept deeply embodied in the Japanese culture. It means reflection about weaknesses or mistakes, as well as envisioning of countermeasures to overcome them.

The Plan-Do-Check-Act (PDCA) is commonly mentioned in TPS as a tool to bring new knowledge to the organization (Liker 2004; Liker and Meier 2006; Rother 2010). According to Rother (2010,
p. 133) PDCA is a tool to test countermeasures by following a structured hypothesis formulation process:

1. Plan: Define what you expect to do and to happen. This is the hypothesis and prediction.
2. Do (or try out): Test the hypothesis. That is, try to run the process according to the plan. This is often made at a small scale (pilot projects).
3. Check (or study): Compare the actual outcome with the expected outcome.
4. Act (what’s next): Standardize and stabilize what works, or begin the PDCA again.

The PDCA model includes many of the TPS principles. Only after achieving a stable process comes continuous improvement. Only when the process is stabilized you can see its inefficiencies. When you have uncovered the problems you can implement countermeasures and learn about it. Learning means moving forward building on your past, including failures and successes. (Liker and Meier 2006).

4.3 Conclusions
Since the TPS played a fundamental role in the development of Lean Production and Lean Construction. Consequently, the author defines a research framework based on the fourteen TPS principles defined by Liker (2004). Based on the work of Liker (2004), Liker and Meier (2006), along with other relevant literature, this chapter described the fourteen TPS principles. Such description and understanding is the baseline for the Cross-case analysis that will be presented in Chapter 8.
CHAPTER 5 CASE STUDY VILLA HERMOSA

Chapter 5 describes the Case Study of Villa Hermosa, a private housing developer involved in designing and building a large project in Duran, Ecuador. The Case Study is appropriate for the framework of this research because the Developer is delivering a mix-income housing project in which approximately a half of housing units are targeted to low-income households awarded with DHS. The other portion of the project is targeted to middle-income families. This allows the integration of households with different socioeconomic backgrounds which avoids segregation by income.

Chapter 5 is organized as follows: Section 5.1 provides an overview of Ecuador and its housing policy context. Section 5.2 describes the Villa Hermosa project. Section 5.3 presents company’s business strategy. Section 5.4 describes the research methodology and introduces the Lean initiatives. Section 5.5, 5.6, and 5.7 describes Lean initiatives. Finally, section 5.7 presents the conclusions of the chapter.

5.1 Ecuador overview and housing policy context

Ecuador is a South American country of 14,483,499 inhabitants (according to the last national census, INEC 2010). In the last decade, the Ecuadorian Economy has been able to reduce poverty and inequality levels. Between 2006 and 2014, poverty measured by income declined from 37.6% to 22.5% and extreme poverty from 16.9% to 7.7%. (The World Bank 2015).

Housing needs in the country require to building or improving housing units for almost half of country’s population. In Table 5-1, as for 2010, Ecuador has a total housing shortage of 52% which is broken down into 33.1% of qualitative and 18.9% quantitative housing shortage. Similarly, to other countries in Latin America, the Ecuadorian government uses a housing policy based on DHS for new housing construction, enabling the participation of private developers in the provision of affordable housing (Bredenoord et al. 2014).

Table 5-1: Housing shortages in Ecuador, 2010 (Bredenoord et al. 2014, p. 287).

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</tbody>
</table>

Supported by a loan provided by the International Development Bank, the Ecuadorian government introduced in 1998 the “Sistema de Incentivos para Vivienda” (SIV, Housing Incentive System). SIV aims to decentralize the production of affordable housing so as to achieve three goals: 1) to expand participation of financial and construction sectors in housing construction, 2) to improve access to housing through subsidies, and 3) to improve transparency in the use of resources for housing programs (Klaufus 2010).
SIV has two components: one devoted to new housing construction and the other to improve the housing stock (Frank 2010). For new housing construction, the “Ministerio de Desarrollo Urbano de Vivienda de Ecuador” (MIDUVI, Ministry of Urban Development and Housing of Ecuador) provides grants up to $40,000 to qualified households for the purchase of new houses (MIDUVI 2016). The financing scheme is called ABC due its three components: Ahorro (savings), Bono (subsidy) and Credito (credit) (Klaufus 2010). Households are required to save for the initial down payment. After they have reached the savings threshold defined for the government, they can access to a mortgage credit in a government or private financing institution. Finally, the savings, mortgage, and subsidy add up the total housing cost (MIDUVI 2016).

5.2 Villa Hermosa project overview

In Figure 5-1, the project is located in Duran, Ecuador. Duran is a municipality of 235,769 inhabitants (INEC 2010) located approximately 20 kilometers (12.5 miles) east from Guayaquil, the biggest and most populous city in Ecuador (Villa Hermosa 2016).

![Figure 5-1: Project Location](image)

In Figure 5-2, the master plan of the project involves the design and construction of over 10,000 cast-in-place reinforced concrete single and multi-family housing units, constructed over the course of 8 years starting in 2014. Given the size of the project, it is divided into eight stages. The Case Study focuses on the design and construction of the first stage of the project, “La Merecida” (The Deserved), corresponding to 700 single housing units. The master plan includes commercial, service, and recreational areas (Villa Hermosa 2016).
5.3 Developer’s business strategy and DHS

Operating under the DHS, the Developer had the freedom to define the housing design and production system that best fits its business strategy.

In terms of design, the architecture of the project was based on Plaza Lagos Town Center which is one of the most highlighted developments of the Guayas region in Ecuador. It is inspired by colonial architecture combining residential and commercial areas in the master plan (Plaza Lagos 2016). Figure 5-3 and Figure 5-4 depict the style of architecture considered in this development.

In terms of production systems, in contrast to local trends in affordable housing provision, which includes building standard units, the Developer decided to customize housing design allowing customers to select some features of housing units. From the Developer’s perspective, this strategy
offers a competitive advantage because different housing models allow reaching a broader market segment. However, the Developer has to find the means to produce different housing configurations efficiently in order to maintain the competitiveness of the development in terms of cost and delivery times.

The Developer defined several housing models based on local market studies and customers’ feedback gathered during the exhibition of show houses. During the design stage, the definition of different models and the extent of customers’ choice were topics of debate inside the organization. On the one hand, the sales department wanted to maximize variation among models since more variety allows nearly everyone to find their preferred options, thus facilitating sales. On the other hand, the construction team aimed to reduce variation, since although valuable for an end user, it may increase operations complexity (Tommelein 2006).

Resulting from the debate, the Developer defined nine base models that customers can select from. In addition, customers can choose the number of bedrooms, types of interior and exterior finishes, including some add-ons (i.e., balcony), the stage of the project which is associated with a delivery date, and the location of the housing unit within the block. Table 5-2 provides insights about the different housing configurations offered. The gray cells are examples of customer choice. That is the “Hermosa” model with two bedrooms and basic finishes, located in an intermediate position of the block 1D, in the third stage of the project.

Table 5-2: Example of variation in housing model at Villa Hermosa (¹ Ten stages total. ² Every stage can have more than 50 blocks)

<table>
<thead>
<tr>
<th>Housing base model</th>
<th>Hermosa</th>
<th>Esplendida</th>
<th>Linda</th>
<th>Bonita</th>
<th>Divina</th>
<th>Bella</th>
<th>Grandiosa</th>
<th>Preciosa</th>
<th>Magnifica</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bedrooms</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior and exterior finishes</td>
<td>Basic</td>
<td>Medium</td>
<td>Premium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage of the project ¹</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Block ²</td>
<td>1A</td>
<td>1B</td>
<td>1C</td>
<td>1D</td>
<td>2A</td>
<td>2B</td>
<td>2C</td>
<td>3A</td>
<td>3B</td>
</tr>
<tr>
<td>Location within block</td>
<td>Corner (any of the four plots located on one of the block’s corners)</td>
<td>Intermediate (any plot that is not in the corners)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Developer acknowledged that delivering customized housing with the chosen architectural style requires the implementation of a flexible production system able to respond to customer preferences with efficiency. Thus, he decided to launch several Lean Construction initiatives. The following sections describe three of them.

5.4 Research methodology

The author used Case Study and Action Research to document the implementation of Lean Construction initiatives. For this purpose, the author became involved in Developer’s organization
from May 2014 to December 2015. The author spent ten months collecting data on the field in two stages, from May 2014 to August 2014 and from February 2015 to July 2015.

Figure 5-5 depicts the project delivery process and the Lean Construction initiatives. Lean Construction initiatives are linked with each other since all of them aims to facilitate the implementation of a customization strategy for housing construction. Because of the importance of concrete activities, this study focus on: Initiative 1 - selection of formwork system using Choosing By Advantages (section 5.5), Initiative 2 - formwork system standardization and production flow (section 5.6), and Initiative 3 - planning and controlling concrete related operations on the field using Information Technology (IT) tools (section 5.7). Further details about the research methodology used in each Initiative are provided in the corresponding section.

**Figure 5-5: Project delivery process and Lean Initiatives**

5.5 Initiative 1: Formwork selection using Choosing By Advantages (CBA) decision-making method

5.5.1 Project’s structural system

Deploying a customization strategy involves making crucial decisions at the design stage. During the early design stage of the project, the Developer evaluated the use of masonry and precast concrete construction. The characteristics of these type of construction techniques introduced barriers to implementing a customization strategy. Masonry construction is time-consuming and labor intensive (Hendry 2001). These disadvantages are exacerbated when pursuing a customization strategy becoming it inviable for the project. Precast concrete construction requires importing the equipment to fabricate concrete elements and the creation of the local capacity of production (Glass et al. 2000). Creating the capacity to produce variant precast concrete elements for customized housing required significant time and investment which became this option also unviable.

The best available option was cast-in-place concrete. Nevertheless, during the construction of show houses, the construction team realized that the formwork system used was inadequate to deliver the intended colonial architectural style and customized models. Figure 5-6 is a picture of show houses construction. Here, the numbered hatched rectangles represent the locally procured formwork system. At the left, the width of the standard formwork panel number one did not match the dimension of the wall. In this case, the team has to build wood formwork panels to solve the mismatch between house’s wall and formwork panel width. At the right, formwork panels number
two and three did not match the height of the wall. Figure 5-7 shows the masonry structure that the construction team built for the gable. These type of issues were intensified considering that the construction team built four different models (Figure 5-4) resulting in the impossibility to reuse some

![Mismatch in width](image1)

![Mismatch in height. Difficulties for the gable](image2)

![Standard formwork panels](image3)

Figure 5-6: Formwork system mismatch

Additionally, the construction team invested significant resources in building the molding details that provide the project its colonial architectural style. In Figure 5-8, skilled masons had to shape these type details after dismantling the formwork system.

![Mismatch in width](image4)

![Mismatch in height. Difficulties for the gable](image5)

![Standard formwork panels](image6)

![Molding details](image7)

Figure 5-7: Masonry in the gable (from the interior)

Figure 5-8: Additional molding operation
The developer realized that the correction these type of situations is crucial for the implementation of an efficient customization strategy, thus he wanted to use an engineered modular formwork system for cast-in-place concrete. The purpose was to have sets of formwork that can be easily arranged into different configurations to shape efficiently the concrete structure of the different housing models. In addition, the formwork system should be easily transported and installed on site.

The Developer asked formwork suppliers to bid a global price based on a set of preliminary housing designs. Formwork suppliers estimated the formwork components required for the project and offered a fixed price for engineering, manufacturing, and shipping the system. Since the Developer was asking for custom formwork system, he would be required to buy it, rather than rent it, as previously done for show houses formwork system. Thus, this fact made the up-front cost an important component of the selection process. Aiming to avoid the mismatch of the formwork system with housing design, the Developer wanted to engage the formwork supplier in the revision of preliminary housing designs. This, expecting to adapt housing designs according to the size of formwork panels marketed by the supplier. To sum up, suppliers’ technical support and willingness to participate in the collaborative design process and the total cost of the formwork system were important factors considered to award the contract.

The selection of the most suitable modular formwork system became a crucial decision for Developer’s customization strategy, schedule, and budget. Given the importance of such decision, the Developer explored decision-making methods, eventually leading to the selection of CBA.

5.5.2 Formwork use in Ecuador

The author visited several construction sites to see the type of formwork system used in the region. From Figure 5-9 to Figure 5-14, several projects were using wood formwork, suspension, and shoring systems. These systems are manually assembled on site using locally available materials. Nevertheless, in the last years, the tendency is to move towards the more industrialized systems. Ecuador and Latin America, in general, have experienced the introduction of several companies offering industrialized formworks and suspension systems to increase the productivity in construction activity (KHL group 2013).
5.5.3 Overview of formwork system selection

When using cast-in-place concrete, selecting an adequate formwork system is crucial for a project’s success. Formwork systems can represent up to 60% of the cost of a concrete structure (Hurd 2005) and affects safety, quality, and speed of construction (Hanna 1998). A fit-for-purpose formwork system enables a smooth production flow among construction trades since it releases work to subsequent activities like mechanical, electrical, and interior finishes (Hurd 2005). Selecting a suitable formwork system is also complex. Advances in formwork technology have resulted in a myriad of alternatives available in the market (Oberlender and Peurifoy 2010). Moreover, several factors must be considered in the decision. Hanna (1989) classified factors in four categories related to: (1) architectural and structural design (e.g., shape and size), (2) project specifications (e.g., concrete finish, speed of construction), (3) local conditions (e.g., site characteristics), and (4) supporting organizations, resources, and logistics (e.g., hoisting equipment).

Despite the importance and complexity of formwork system selection, contractors select systems based on experience and without using a defined decision-making method (Hanna et al. 1992; Kamarthi et al. 1992; Koo et al. 1992; Tam et al. 2005). Relying on experience, although valuable, does not guarantee that conditions will lead to consistent or the best results (Tam et al. 2005; Elbeltagi et al. 2012). Professionals are likely to have had different experiences dealing with formwork on past projects which may result in divergent outcomes (Koo et al. 1992). The
importance and complexity of formwork selection require the use of a sound decision-making method to support construction practitioners in the process.

Several numerical decision-making methods have been proposed for formwork selection. Here, the author first assesses the applicability of previous research in the context of selecting formwork for the Developer’s affordable housing project in Ecuador. He then justifies how this assessment led to the use of CBA. He explains the CBA implementation process on the Developer’s affordable housing project and debriefs information gathered from interviews with the professionals involved in it.

5.5.4 Research methodology

The author searched in selected journals for articles on decision-making methods used for formwork selection. For CBA implementation, he used Case Study research, a social science research methodology suited to document and analyze the implementation processes and outcomes of interventions (Yin 2014). After the implementation, each project participant engaged in semi-structured interviews to assess their experience with the CBA method. Interviews lasted twenty minutes on average and were audio-recorded for transcription and analysis. The author used the following questions to guide interviews:

- What is the decision-making method you would have used (if not CBA) to select formwork? Please describe the method.
- Based on this experience, what do you think about the CBA method?
- Please mention the positive aspects of CBA relative to the method you would have used, and vice versa.
- Would you use CBA for future decisions? Explain why or why not.

5.5.5 Review of formwork system selection methods

The author reviewed the literature on decision-making methods used for formwork system selection in the ASCE Journal of Construction Engineering and Management, Automation in Construction, and Construction Management and Economics, from January 1990 to December 2014. He found several papers.

Hanna et al. (1992) proposed using an expert system for the selection of vertical and horizontal formwork systems. The knowledge-base required by the expert system was built based on literature and information gathered from North American experts. The expert system was tested on hypothetical projects. Elazouni et al. (2005) proposed a hybrid approach of Neural-Networks (NNs) and the Analytic Hierarchy Process (AHP) to estimate acceptability of new horizontal formwork system in Egypt. The knowledge-base considered the literature and experience of 40 local experts. NNs aim to mimic the human brain’s cognitive capacities to assist in the selection process, while the AHP calculates the evaluation weights and acceptability values. The method was trained to produce values of acceptability for the formworks systems. Tam et al. (2005) proposed Probabilistic Neural-Networks (PNNs) for vertical formwork systems selection. Although their Case Study was in Hong Kong, they built their knowledge-base using 97 sets of data from high-rise building projects in Taiwan. The research included a practical application to test the method. Elbetagi et al. (2011) developed a knowledge-base to create a fuzzy logic model (FLM) for horizontal formwork system selection in Egypt. Based on literature and local conditions,
they identified 5 relevant factors for the selection: (1) speed of construction; (2) hoisting equipment; (3) available capital; (4) slab type; and (5) area of practice. They built the knowledge-base considering the experience of 37 local experts. Using MATLAB, the authors coded the model and then tested it based on information of 3 real-life projects. Similarly, Elbetagi et al. (2012) developed a FLM for vertical formwork system selection. They built the knowledge-base using a sample of 41 local experts. The authors conducted a Case Study testing the model on a 250,000 m² high-rise building. Their research suggested that in comparison to NNs, FLM are better at handling intangible information, thus allowing the use of linguistic inputs like words, phrases, or sentences (e.g., low cycle time). Shin et al. (2012) proposed boosted decision trees (BDTs) for the selection of tall building formwork systems in Korea. BDTs are multistage decision-making techniques built in advanced algorithms (known as ‘boosting’) that divide complex decisions into sets of simpler decisions. Eventually, the resolution of these sets will resemble the intended solution. The authors determined the rules for the method based on 75 projects. They defined the factors considering previous research and the experience of local experts. The authors tested the method in tall building projects and then compared it with Decision Trees and NNs. This research claimed superiority of the proposed model over the other two since it provided more accurate results and it was easier to implement.

Regrettably, the methods described could not be implemented in this Case Study in Ecuador because the knowledge domain in which they were developed did not fit the context of this project. A shortcoming of numerical methods for decision-making is their limited capacity to represent the context in which decisions are to be made (Riabacke et al. 2014). For instance, Shin et al. (2012) recognized that the BDTs method may perform satisfactorily in a given context. However, its accuracy can be affected by the quality, size, and reliability of the training dataset and the number of factors considered. Therefore, the direct application of a decision-making method without considering the context may lead to inaccurate results.

The methods discussed did not fit the context of this Case Study for several reasons. First, they considered local country conditions (North America, Egypt, Taiwan, Hong Kong, and Korea) that differ from this Ecuadorian Case Study. For instance, Elbetagi et al. (2012) considered vertical formwork systems available in Egypt but not in Ecuador (e.g., VARIO GT-24). Second, the information provided by local experts to build the knowledge-base inevitably is influenced by the local context. This is an important consideration because the inputs of these professionals are the major source of information to build the knowledge-base (Hanna et al. 1992). Proverbs et al.’s (1999) survey highlight the implications of local contexts when weighing the importance of factors in formwork selection. They found that UK contractors ranked the “relative cost” as the most important factor while their French counterparts were more concerned with the “quality of concrete.” Variances are attributable to historical and cultural differences between nations. Third, most of the revised methods were tested in high-rise building construction, while the Developer’s project involves housing construction. An important difference here is that the methods reviewed distinguish vertical from horizontal formwork systems. In contrast, the small size of housing units in the Ecuadorian Case Study makes it feasible to place concrete in walls and slabs simultaneously. Thus, the suitability of vertical and horizontal formwork systems must be evaluated accordingly.

Adapting or creating a numerical method that fits the context of this Case Study may have been an option but the development of a knowledge-based system consumes time (Yau and Yang 1998) and resources. Similarly, creating FLM requires substantial computational time (Pan 2008). In addition, the potential use of a new formwork technology imposed challenges for the creation of a
numerical decision-making method. Two of the four alternatives considered in this Case Study were never used in the region. Moreover, some alternatives considered engineering the formwork system particularly for the characteristics of this project. This results in insufficient prior data and experience about formwork usage to build the knowledge-base. Elazouni et al. (2005) acknowledged the complexity of collecting data of formwork systems that are not used on a large scale. In fact, the authors did not include in the research formwork systems that were used on a limited scale. Thus, creating a numerical decision method, in this case, would require a significant investment of time and resources. It may be valuable if several similar decisions of this kind have to be made in the near future on other projects in the region, but this was not the case on this project.

In order to support decision-makers, a decision-making method must be able to capture the context of the project. In defining the context, the participation of professionals involved in the project plays a fundamental role since they are familiar with local conditions and will be the end-users of the formwork system. Since decisions in the construction industry are often made by diverse professionals with different educational, social, and cultural backgrounds, in addition, to allowing the analysis of numerical data, the decision-making method must be capable of capturing the perspectives of decision-makers with different opinions. This manner of context representation results in a social process of human interaction in which debate, argumentation, and rhetoric play a pivotal role in the final resolution. These aspects of the decision-making process are difficult to model in numerical methods. Thus, a decision-making method like CBA appeared to best suit this Case Study.

5.5.6 Choosing By Advantages

CBA is a collaborative decision-making method that recognizes that decisions are subjective and must be based on the importance of advantages (IoA). Suhr (1999) developed CBA to support decision-making by the US Forest Service and the method has been used in many other domains and contexts since. Arroyo et al. (2014) and (2015) demonstrated CBA outperforms other decision-making methods such as WRC and AHP. When using CBA, decisions are not based on pros and cons, weighted factors, or disadvantages. Instead, CBA identifies the advantages of each alternative, attribute by attribute, anchored to the least preferred one in the context of concrete available alternatives, not by theoretical or obsolete ones. Collaboratively, decision-makers identify, compare, and assess the IoA. When IoA are identified, the decision-makers evaluate money data and eventually choose the most convenient alternative in terms of total IoA and cost.

One CBA approach is the Tabular Method which has five phases: (1) the Stage-Setting Phase, (2) the Innovation Phase, (3) the Decision-Making Phase, (4) the Reconsideration Phase and (5) the Implementation Phase (Suhr 1999). This section focuses on Phase 3 and follows the steps described in Figure 5-15.

![Figure 5-15: CBA Steps](image)

CBA stresses the importance of terminology and urges practitioners to be consistent in the use of language (Suhr 1999).
• **Factor:** An element, part, or component of a decision.
• **Criterion:** A decision rule, or guidance – usually, either a must or want.
• **Attribute:** A characteristic, quality, or consequence of one alternative.
• **Advantage:** A benefit, gain, improvement, or betterment. Specifically, an advantage is a beneficial difference between the attributes of two alternatives.

### 5.5.7 CBA implementation

The Participants in the decision-making process implemented the CBA step depicted in Figure 5-15 in four meetings over a span of two weeks. The team included 6 people: the author (acting as facilitator), the Project Manager, the Superintendent, the Leader of the Planning Department, and the Procurement and Budget Supervisors. Every meeting lasted on average one and a half hour.

**Meeting 1 - Training**

Since 4 of the 6 team members had no prior knowledge of CBA, this meeting was dedicated to training. The author and the Project Manager explained CBA to the participants. The team performed CBA exercises of different complexities to learn hands-on. They were also provided with readings covering the CBA language and implementation guidelines.

**Meeting 2 - Determining alternatives, factors, criteria, and attributes**

The alternatives included four formwork systems available in the region. Factors were determined in a brainstorming exercise. Each participant was asked to provide support for the consideration of proposed factors. Factors were listed and discussed. Participants decided the criteria for each factor. A team member was delegated to collect attribute data for each of the formwork systems. The team agreed to have all the information centralized in the CBA table (Table 5-3) for the next meeting.

![Figure 5-16: Explaining the CBA process](image1)

![Figure 5-17: Weighting IoA](image2)
<table>
<thead>
<tr>
<th>General information</th>
<th>System 1</th>
<th>IOA</th>
<th>System 2</th>
<th>IOA</th>
<th>System 3</th>
<th>IOA</th>
<th>System 4</th>
<th>IOA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor 1: Formwork Panels [m²]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: Less formwork is better because</td>
<td>693</td>
<td></td>
<td>931.41</td>
<td></td>
<td>916.94</td>
<td></td>
<td>916.94</td>
<td></td>
</tr>
<tr>
<td>inventory is reduced. It is related to modularity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and interchangeability of panels.</td>
<td>Advantage</td>
<td>238.41 more</td>
<td>100</td>
<td></td>
<td>0</td>
<td>14.47 m³ less</td>
<td>0</td>
<td>14.47 m³ less</td>
</tr>
<tr>
<td><strong>Factor 2: Reuses [Number]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: More reuses is better because offers</td>
<td>1200</td>
<td></td>
<td>1200</td>
<td></td>
<td>2000</td>
<td></td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>greater durability.</td>
<td>Advantage</td>
<td>Medium speed</td>
<td>50</td>
<td></td>
<td>Medium speed</td>
<td>0</td>
<td>Medium speed</td>
<td>75</td>
</tr>
<tr>
<td><strong>Factor 3: Erecting speed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: Higher is better because it enables a</td>
<td>Medium</td>
<td></td>
<td>Low</td>
<td></td>
<td>High</td>
<td></td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>faster construction cycle time.</td>
<td>Advantage</td>
<td>The fastest</td>
<td>60</td>
<td></td>
<td>The fastest</td>
<td>60</td>
<td>The fastest</td>
<td>60</td>
</tr>
<tr>
<td><strong>Factor 4: Stripping Speed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: Higher is better because it enables a</td>
<td>High</td>
<td></td>
<td>Medium</td>
<td></td>
<td>High</td>
<td></td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>faster construction cycle time.</td>
<td>Advantage</td>
<td>The fastest</td>
<td>60</td>
<td></td>
<td>The fastest</td>
<td>60</td>
<td>The fastest</td>
<td>60</td>
</tr>
<tr>
<td><strong>Factor 5: On-site training [Days]</strong></td>
<td>15</td>
<td></td>
<td>22</td>
<td></td>
<td>14</td>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Criterion: Longer is better because the labor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>force has more training time. This may increase labor</td>
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<td></td>
</tr>
<tr>
<td>efficiency using the system.</td>
<td>Advantage</td>
<td>3 more days</td>
<td>15</td>
<td>10 more days</td>
<td>30</td>
<td>2 more days</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td><strong>Factor 6: Lead time [Weeks]</strong></td>
<td>14</td>
<td></td>
<td>8</td>
<td></td>
<td>14</td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Criterion: Less time is better because it impacts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>formwork availability on site.</td>
<td>Advantage</td>
<td>6 weeks less</td>
<td>30</td>
<td></td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Factor 7: Largest possible panel weight [Kg]</strong></td>
<td>25.2</td>
<td></td>
<td>31.68</td>
<td></td>
<td>39</td>
<td></td>
<td>39</td>
<td></td>
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<tr>
<td>Criterion: Lighter is better because it eases</td>
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<td></td>
<td></td>
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<tr>
<td>transportation on site. The project does not</td>
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<tr>
<td>consider the use of cranes.</td>
<td>Advantage</td>
<td>13.8 kg lighter</td>
<td>25</td>
<td>7.32 kg lighter</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Factor 8: Largest possible panel size [m²]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: Bigger is better because it reduces visible</td>
<td>Panel 60x210 = 1.26 m²</td>
<td></td>
<td>Panel 60x240 = 1.44 m²</td>
<td></td>
<td>Panel 90x240 = 2.16 m²</td>
<td></td>
<td>Panel 90x240 = 2.16 m²</td>
<td></td>
</tr>
<tr>
<td>joints between panels on the finished concrete.</td>
<td>Advantage</td>
<td>0.18 m² bigger</td>
<td>35</td>
<td>0.9 m² bigger</td>
<td>45</td>
<td>0.9 m² bigger</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>**Factor 9: International experience of the</td>
<td>42</td>
<td></td>
<td>19</td>
<td></td>
<td>55</td>
<td></td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>formwork system supplier [Years]**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: More years is better because it means</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reliability and success in the market. The project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>considers customized formwork system.</td>
<td>Advantage</td>
<td>23 more years</td>
<td>50</td>
<td>0</td>
<td>36 more years</td>
<td>70</td>
<td>36 more years</td>
<td>70</td>
</tr>
<tr>
<td>**Factor 10: Sound exposure level resulting from</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hammering**</td>
<td>High</td>
<td></td>
<td>Medium</td>
<td></td>
<td>Low</td>
<td></td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Criterion: Low is better because workers are less</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>exposed to noise when hammering formwork components.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advantage</td>
<td>0</td>
<td></td>
<td>Medium exposure level</td>
<td>1</td>
<td>Low exposure level</td>
<td>2</td>
<td>Low exposure level</td>
<td>2</td>
</tr>
<tr>
<td>**Factor 11: Accessories [# of accessories /</td>
<td>12</td>
<td></td>
<td>7.5</td>
<td></td>
<td>2.31</td>
<td></td>
<td>2.31</td>
<td></td>
</tr>
<tr>
<td>Panels m²]**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion: Less is better because on-site inventory is</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduced.</td>
<td>Advantage</td>
<td>4.5 less</td>
<td>70</td>
<td>9.69 less</td>
<td>80</td>
<td>9.69 less</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td><strong>Factor 12: Transition plate in the first floor</strong></td>
<td><strong>Yes</strong></td>
<td></td>
<td><strong>No</strong></td>
<td></td>
<td><strong>Yes</strong></td>
<td></td>
<td><strong>Yes</strong></td>
<td></td>
</tr>
<tr>
<td>Criterion: Yes is better. The transition plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>allows the formwork system to be quickly erected in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the second floor. This enables a faster construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cycle time.</td>
<td>Advantage</td>
<td>Has the piece</td>
<td>40</td>
<td>0</td>
<td>Has the piece</td>
<td>40</td>
<td>Has the piece</td>
<td>40</td>
</tr>
<tr>
<td><strong>Factor 13: Inventory reposi[tion [Days]</strong></td>
<td>20</td>
<td></td>
<td>20</td>
<td></td>
<td>20</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Less time is better. Missing components of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>formwork must be replaced as fast as possible.</td>
<td>Advantage</td>
<td>All the same</td>
<td>0</td>
<td>All the same</td>
<td>0</td>
<td>All the same</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Factor 14: Quality of concrete finish</strong></td>
<td>Medium</td>
<td></td>
<td>Medium</td>
<td></td>
<td><strong>High</strong></td>
<td></td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Criterion: Higher is better because it avoids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rework on concrete surface.</td>
<td>Advantage</td>
<td>0</td>
<td>0</td>
<td>The best</td>
<td>15</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total IOA</strong></td>
<td>340</td>
<td></td>
<td>186</td>
<td></td>
<td>452</td>
<td></td>
<td>432</td>
<td></td>
</tr>
</tbody>
</table>
**Meeting 3: Weighing IoA**

Table 5-3 depicts the CBA table. The least preferred attribute for each criterion is underlined; it will serve as a baseline to define advantages. Similarly, the most preferred attribute is circled. Collaboratively, the team looked across the table at all most preferred attributes and selected one as the paramount advantage, giving it a 100 score in Importance of Advantage (IoA). Participants then assessed the other advantages (the beneficial difference between attributes) and weighed their IoA on a scale of 0 to 100. All advantages were written on sticky notes. Participants were tasked with determining IoA. Since participants offered different professional perspectives, they differed in opinion regarding the IoA values assigned to the advantages. Thus, several iterations were necessary to ensure all perspectives had been considered and some degree of consensus was reached.

**Meeting 4 - Cost analysis**

Figure 5-18 depicts the cost analysis. Cost is expressed as a percentage relative to a reference cost of $500,000 assigned as 100% to the cheapest option (system 4). For proper comparison, the total upfront cost of the equipment is divided by the expected number of reuses (Hurd 2005).

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Total IOA</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 1</td>
<td>340</td>
<td>528,585</td>
</tr>
<tr>
<td>System 2</td>
<td>186</td>
<td>766,191</td>
</tr>
<tr>
<td>System 3</td>
<td>452</td>
<td>535,526</td>
</tr>
<tr>
<td>System 4</td>
<td>432</td>
<td>500,000</td>
</tr>
</tbody>
</table>

System 4 is the most affordable alternative. The next affordable alternative is system 1. However, moving from system 4 to system 1 costs $28,585 but provides no additional IoA. The following affordable alternative is system 3. Moving from system 4 to system 3 costs $35,526 and provides 20 additional IoA. The question here for decision makers is whether or not they are willing and able to spend additional money to obtain the extra 20 IoA. Looking for the attributes in Table 5-3, the differences between these systems lie in the IoA assigned to factor 5 (on-site training) and 14 (quality of concrete finish). Certainly, narrowing the analysis to this level provides decision-makers specifics of the context that shapes their decision. Looking at the attributes, the differences are two extra days of training and a better quality of the concrete surface. This economic effort pays for itself in the short term since the formwork crews will receive more coaching about how
to better use the formwork on site and improved concrete finish will result in a reduction of unnecessary concrete hand rubbing activities. System 2 is the least preferred alternative because it has the lowest total IoA and the greatest cost. Accordingly, the team selected system 3.

5.5.8 Results

Ability of CBA to capture decision-making context

Through discussion at different meetings, CBA helped the team capture the context of their project leading them to select the formwork system best suited for their case. The exchange of experiences and perspectives that occurred during the meetings gradually led the team to articulate the context in which the decision should be made. CBA led the team to analyze the characteristics of the alternatives and to assess the advantages of them anchored to the uniqueness of the project. The context definition through CBA is evident when analyzing, for instance, factor 8 “largest possible panel size” with criterion “bigger is better” and factor 12 “transition plate in the first floor” with criterion “yes is better.” These factors and associated criteria matter because the project does not use a crane. Thus, smaller and lighter panels considerably ease the manual transportation of formwork. Factor 12, transition plate, is relevant in housing construction. This is a formwork component remains attached to the concrete structure after stripping the first floor, thereby easing the transition of formwork panels from the first to the second floor, which speeds up the construction cycle time (Figure 5-19).

![Figure 5-19: Section of transition plate (left) and the results on site (right)](image)

Participant interviews

Some of the social aspects of CBA were captured from the interviews:

Rhetoric: Previous studies discussed the importance of rhetoric in building design and in the decision-making process (Ballard and Koskela 2013; Arroyo 2014; Koskela 2015). In building design, decisions are influenced by arguments made by those involved. The degree of influence exercised is a result of the strength of the argument and the characteristics of the person supporting it. In this case, some participants mentioned how consistent points of view provided by seasoned professionals influenced their opinion about the importance of certain advantages. For example, when analyzing the effect of formwork modularity on construction cycle time, participants with limited knowledge of these areas concurred with arguments of more experienced professionals.
5.5.9 Conclusions

Decision-makers should use a sound decision-making method able to deal with complexities associated with selecting a formwork system. In order to assess the suitability of previous research in this Case Study, several decision-making methods were reviewed. Unfortunately, none of them could be implemented because the context in which they were developed did not resemble the decision-making context of this project. Based on literature the author argued that capturing the context in which decision-making takes place is crucial to selecting the most suitable alternative. In this aspect, CBA demonstrated to be superior to the other decision-making methods reviewed because it allowed decision-makers to represent the project's context collaboratively and to select the most preferred alternative accordingly.

The CBA method relies on the important social interaction between decision-makers that drives the decision-making process. This social process was captured from participants’ interviews. Team members emphasized the role played by rhetoric in the process. They also valued their inclusion in crucial project decisions. Nevertheless, this is an aspect that must be handled carefully. This section provides evidence that the interaction between professionals and their degree of participation is influenced by the level of authority and responsibility of team members. Further research is recommended on the social aspects of CBA.

5.6 Initiative 2: Formwork standardization and production flow

5.6.1 Background

Once the formwork system was selected, the Developer and the formwork supplier began a collaborative design process aiming to standardize some components of the formwork system. This, with the purpose to reduce inventory and to ease operations on the field.

In order to address increasing housing demand, The United Nations (1965) has long recommended standardizing and industrializing the house building industry. Arguably, the nature of the building process (i.e., uniqueness, uncertainty, and complexity of production systems) prevents mechanization of work. Despite the singularities of the building process, the housing construction sector is well-suited for the application of standard work (United Nations 1965; Bouillon 2012). Woetzel et al. (2014) estimated that by Lean approaches including standardization and industrialization, construction costs for affordable housing may be cut by 16%.

Standardization stands for the use of components, methods or processes enabling regularity and predictability (Gibb 2001). In this area, formwork suppliers have made significant progress in bringing automation to concrete related operations through the use of standard modules that can be easily transported and assembled on site (Oberlender and Peurifoy 2010). Nevertheless, several
factors must be taken into consideration when applying standardization practices in housing construction, e.g., an overuse of standardization may lead to design conflicts (Gibb 2001) and customer dissatisfaction (Dos Santos et al. 2014). This notwithstanding, excessive use of unique components may increase a project’s complexity, making it hard to manage (Tommelein 2006). Therefore, a balance between customization and standardization must be struck. In addition, key decisions made at the design stage impact the construction process. The use of standard products requires a comprehensive evaluation of the production system since excessive standardization may affect flexibility at the production stage (Barlow and Ozaki 2005; Jonsson and Rudberg 2015). In particular, the use of standard formwork modules requires advanced planning and coordination in design and construction (Oberlender and Peurifoy 2010). The link between product standardization and production process design must be analyzed in order to achieve a balanced production flow.

This initiative explores the use of standard formwork for the construction of reinforced concrete houses and its impacts on production flow. Based on observation, the author describes the design process for standardization, the challenges faced by the company during this process, and the results of this experience.

5.6.2 Overview of formwork standardization

Standardization is the extensive use of components, methods or processes which enable regularity, repetition and a background of successful practices and predictability (Gibb 2001). Component standardization specifically relates to the replacement of several components by a single one that can perform the functions of all of them (Perera et al. 1999). Among other benefits, the use of standard products or components shortens lead times, improves quality and eases operations at the construction stage (Gibb and Isack 2001; Pasquire and Gibb 2002).

The performance of concrete activities generally plays an important role in the overall performance of projects that use structural concrete (Dadi et al. 2012). Within concrete activities, formwork design has been noted as offering opportunities for standardization and industrialization (Shapira 1999). The conventional and still widely-used system of timber and plywood formwork built on-site has been set aside and replaced by more efficient modular systems. Formwork modular systems are fabricated in a shop and delivered to the construction site. On site, standard modules can be transported and assembled quickly. The use of standard formwork has several advantages over custom-built formwork (Oberlender and Peurifoy 2010):

- Simple installation that can be performed even by low-skilled workers.
- Reduced erection time.
- A Higher number of reuses that leads to reduced overall costs of equipment.
- Improved safety for the labor force.
- Better quality concrete surfaces which reduce further finishing work.
- Automation of formwork operations and improved productivity.

Nevertheless, the implementation of standardization highlights the conflict between uniformity and variation. The tension between standardization and flexibility may result in design impotence (Gibb 2001). In the context of housing design, the excessive use of standard products may cause customer dissatisfaction due to the variety of family profiles and the diversity of lifestyles in the population (Dos Santos et al. 2014). In contrast, excessive customization may prolong the length
of the construction process. The uniqueness of a facility may be valuable to the final customer, but using unique materials increases system complexity, making it more challenging to manage (Tommelein 2006). As a result, developers must strike a balance between standardization vs. customization in order to handle production systems efficiently while still meeting customers’ needs.

In addition, the implementation of standard components must be evaluated beyond the design stage. It is recognized that the use of standard products must match the production system design (Jonsson and Rudberg 2015) since the incorporation of standard products may harm the flexibility of the production process (Barlow and Ozaki 2005). For this reason, the trade-off between productivity-related capabilities (e.g., cost and lead time) and flexibility (product and process) has to be carefully analyzed when designing the project’s production system (Nahmens and Bindroo 2011). In terms of production system design, success in using modular formwork can be achieved only by proper planning at the architectural design stage and then requires advanced planning and coordination at the construction stage. Work sequence, reuse scheme, allocation of formwork sets, cranes and crews must be considered (Oberlender and Peurifoy 2010). Consequently, it is crucial to evaluate the interface between the design of standard components and production capability in order to reach a balanced production flow.

5.6.3 Research methodology

The author uses Case Study research to document the formwork standardization process. Case Study research is suitable to investigate events in a real-life context when the boundaries between events and context are not clearly evident, and when it is assumed that contextual conditions may be relevant for the study (Yin 2014).

Being part of the Developer’s organization, the author became an observer of the formwork standardization process participating in discussion meetings with the formwork supplier. The author documented these interactions and accessed to data in order to portray the results of this experience.

5.6.4 First, run study

Based on local market studies, the Developer decided to design 20 preliminary house models, the smallest one being a 40 m² 1-bedroom and the largest one being an 80 m² 4-bedroom. As a first run study, the company built four demonstration houses. The purpose of this study was to assess the units’ constructability and to evaluate construction performance in terms of time and budget. After this experience, the team identified several constructability issues related to variation among unit models. For instance, the different dimensions of concrete elements impeded the reuse of formwork panels. The additional work required to adapt panels to different concrete elements’ dimensions resulted in a significant waste of resources. Moreover, the construction team noticed formwork activities demanded a significant amount of time and resources. After this experience, the company reevaluated the housing designs and decided to standardize the dimensions of concrete elements like rooms, walls, window- and door openings, and stairs.

5.6.5 Discussion of standardization versus customization

As described, excessive use of standardization may lead to customer dissatisfaction. In the Case Study, the level of standardization vs. customization in the models became an important topic of
discussion for Developer’s project team members. On one hand, the sales team wanted to maximize customization. More variation in housing models facilitates sales since it is easier for sales agents to find a model that meets specific customers’ needs. On the other hand, the construction team wanted to moderate variation. As experienced during the first run study, more variation considerably increased the complexity of operations on site.

After several iterations, the Developer decided to keep 12 base models. However, in order to offer more customization, they decided to include certain architectural “add-on” elements to satisfy a broader range of customers. By adding iconic elements to the 12 base models (i.e., balconies or different types of finishes), the design team was able to find a balance between standardization and customization. As a result, the 12 base models became 47 types of houses.

5.6.6 Formwork supplier selection

As described in Initiative 1 – Formwork selection using Choosing By Advantages, the team put special care into the selection of the formwork supplier. During this process, a bidder’s technical expertise and willingness to participate in a collaborative design process was of great importance in awarding the contract. Finally, the Developer selected a formwork provider with more than 50 years of experience in the market. This supplier would engineer and manufacture concrete forming systems according to Developer’s specific requirements.

5.6.7 Formwork standardization process

Developer’s customization strategy aimed to come up with a project that offered options for different customers’ profiles. At the same time, the Developer aimed to reduced variation and to optimized concrete related operations.

With this purpose, stakeholders’ interests were aligned in order to balance standardization vs. customization. Team members involved in the collaborative design process stacked two types of pre-existing designs up against each other. On one side were the preliminary designs of housing units made by Developer’s architectural team. On the other side were the standard panels marketed by the formwork supplier. In order to optimize formwork standardization, the existing models were adapted to the dimensions of standard panels. In doing so, the Developer and the formwork provider set the following goals:

- Reduce the number of formwork equipment on site – Reduce inventory.
- Standardize housing models for concrete operations – Reduce variation.
- Develop one LEGO set capable of building all models – Interchangeability.

Figure 5-20 shows how the design process proceeded for each group of housing models. Models were standardized in batches. The Developer sent the preliminary designs to the formwork supplier. The formwork supplier reviewed the design and proposed adjustment in the design. The Developer reviewed the proposed changes approving or discarding them. Finally, the Developer finished the design based on the formwork supplier’s feedback. The cycle depicted in Figure 5-20 repeated itself several times after all the shells of houses were completed. The design process lasted four months. At this point, two sets were used, each one flexible enough to build any of the twelve base models.
### Figure 5-20: Standardization process

<table>
<thead>
<tr>
<th>Assessment of original designs</th>
<th>Assessment of Changes</th>
<th>Final Drawings</th>
</tr>
</thead>
<tbody>
<tr>
<td>VillaHermosa</td>
<td>Formwork supplier</td>
<td></td>
</tr>
<tr>
<td>Send the current housing units’ drawings</td>
<td>Revision of drawings and standardization of main concrete elements (walls’ length, width and height; door/window openings)</td>
<td>Propose modifications for drawings</td>
</tr>
</tbody>
</table>

### Figure 5-21: Details of the standardization process

Figure 5-21 depicts the way this process was carried out in the practice. The blue and highlighted comments correspond to the design adjustments made by the formwork supplier (text in English). Several of these comments required moving dimensions from 10 up to 30 mm. These small changes allow the formwork supplier to arrange formwork with standard panels, avoiding...
manufacturing additional special components. The red comments (not highlighted) correspond to the reply of Developer’s design team regarding the acceptance or withdrawal of the changes proposed by the formwork supplier (text in Spanish).

5.6.8 Balancing production through design

Success in using standard formwork depends on proper design as well as adequate correlation with construction processes. In alignment with this statement, and considering the use of two flexible formwork sets, the Developer and the formwork provider simulated construction operations. Their objective was to optimize the use of each formwork set in order to achieve a balanced production rate that met sales.

In order to meet demand, the construction team had to produce 2 houses/day. This meant having two construction crews working simultaneously, each one capable of building any model. However, the size of the models and the setup of project lots affected the production flow. During the simulation, the team identified challenges and collaboratively implemented the following solutions.

Problem 1: Idle inventory: The initial production process design considered using two formwork sets, each one capable of building any base model. This solution was flexible since two crews working simultaneously could build any type of house. However, a typical block design has two lot sizes, one 67 m², and one 100 m² respectively with an average distribution of 30% and 70% per block accordingly. As shown in Figure 5-22, for each lot, only certain kinds of house models are allowed to be built. The 67 m² lot allows for the construction of small models while the 100 m² lot allows for the construction of big models. Since the project had small and big models, several inventory pieces (approximately 45%) would remain unused when building small models.

Solution 1: In collaboration with the formwork supplier, the Developer readapted the set’s configurations so as to have one set for small models and one for big models, thereby reducing the idle inventory considerably during the construction process.

Figure 5-22: Typical block setup and its corresponding house model
Problem 2: Unbalanced production per delivery zones: Given one formwork set for each type of house, two specialized crews are necessary to maximize inventory use and make production efficient.

![Diagram of unbalanced production flow](image)

Nevertheless, the specific distribution of different-sized lots (30/70) and the due dates for the completion of blocks imposed new challenges. Using two specialized crews with the 30/70 lot distribution resulted in an unbalanced production flow of small and big houses. By sharing only 30% of the work per block, the crew working on small models would work faster than the crew working on the big models. Schematically, Figure 5-23 shows construction progress at day 9. If each crew built 1 house/day, at day 9, the crew for small models would be working on block 3. However, block 2 would still be under construction because the big models would not be completed yet. Although the production rate would still meet the demand of 2 houses/day, the production flow per delivery zone would not be met. This was a relevant issue since the Developer is committed to delivering the project by block at specific dates.

Solution 2: In order to balance the production per block, the team included a specific house model in the design that could be built on either the 67 m² or 100 m² lot. This model can be used as a “wildcard” to achieve a balanced 50/50 distribution of small and big models per block. By adding a subtle design variation that indeed reduced the level of standardization in the original design, flexibility was obtained at the production level, enabling an even progression in the production flow.

Problem 3: Sales point coordination: By implementing this design change, the team set a balanced production system. However, the balanced distribution was based upon sales to customers since the sales representatives had to ensure that the wildcard house model was being sold in every block to keep the 50/50 distribution. Consequently, the project would require control over the sales per block or lose the balance in the production process.
Solution 3: In order to achieve control over the sales per block, Developer’s sales software set a counting system that calculates the percentage distribution for the different house models. Once the sale of big houses per block reaches over 50%, a restriction is set to only allow the sale of the wildcard house in the big lots. Thus far, this had not been a problem since the wildcard model has sold well, thereby allowing an equal distribution between crews without limitations to the sales representatives. Figure 5-24 schematically represents this new balanced production, which takes into account the wildcard house model and the sales point control.

Figure 5-24: Balanced production flow through delivery blocks resulting from the wildcard house model and sales point control

5.6.9 Results

In the first design iteration, the team standardized the houses’ concrete elements in order to have only two formwork sets capable of building any of the twelve models. However, this left 45% of formwork equipment idle when building small models. In response, the team designed two specialized sets, one for the small models and one for the big models. This alternative was efficient in terms of inventory use but inadequate when considering the balance of the production flow.

In a second design iteration, the team decided to include variation through a wildcard model that can be built with any formwork set. This design variation helped the team achieve a balanced flow of production between construction crews and allowed the team to meet project delivery dates per block. The team at this point realized that the balance in the production process could be achieved only at the sales point (Wardell, 2003) and to that effect set a subtle restriction at the sales point.

Through collaborative design and coordination among team members, the standardization process benefited the project. Table 5-4 shows the original setup cost $631,184. After completing the
design iterations, the final setup cost $501,597. The final setup also reduced inventory by 25%, which eased inventory management and operations on site.

<table>
<thead>
<tr>
<th>Item</th>
<th>Original setup</th>
<th>Final setup</th>
<th>Reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pieces</td>
<td>3,360</td>
<td>2,492</td>
<td>-25.8</td>
</tr>
<tr>
<td>SKUs/Items</td>
<td>944</td>
<td>687</td>
<td>-27.2</td>
</tr>
<tr>
<td>Total Cost USD</td>
<td>631,184</td>
<td>501,597</td>
<td>-20.5</td>
</tr>
</tbody>
</table>

5.6.10 Conclusions

This initiative describes a successful experience of formwork standardization in an affordable housing project in Ecuador. In the first stage, the formwork standardization process focused on design, aimed to reduce variation and facilitate construction operations. However, the design team realized that further involvement of other project stakeholders was needed to optimize standardization. The success of this experience relied on collaboration among project members, as well as planning and synchronization among different project delivery stages.

Key decisions made early in design were crucial to making the final solution efficient overall. The production process simulation performed by the team identified the imbalanced production flow resulting from the original design. To overcome this imbalance, the Developer’s construction, and sales teams helped find the solution. This Case Study demonstrated the link between design and production. Specifically, the use of standard components affected the flexibility in construction and production flow balance. Incorporation of the wildcard model added variation and reduced standardization, yet proved to be beneficial by helping the team achieve a balanced production flow. This improvement, in addition to modifications of sales procedures, facilitated the application of a solution that optimized the whole, not parts, of the production system.

The involvement of an experienced formwork supplier had a significant impact on this success. Nevertheless, professionals participating in this project agreed that involving the formwork provider earlier in the design process could have helped the team avoid initial design iteration, leading to the development of an even more efficient final solution. A barrier impeding the application of this improvement was the competitive bidding process required by the Developer in awarding contracts.

An aspect relevant for discussion relates to the type and scale of the project and its relation to standardization practices. In order to maximize affordability, developers in the affordable housing industry accept small profits per housing unit so they will aim to maximize the benefits of economies of scale (Lizarralde and Root 2008). In this context, the standardization of building components becomes crucial for the success of projects. Nevertheless, standardized house components do not mean standard architecture in the project. The different components can be arranged into different configuration shaping different housing styles which is the aim of the Developer. In the case of large projects, small profit margins achieved in the production of a single housing unit can be replicated in the following units, maximizing overall gains for the project.
5.7 Initiative 3: Implementation of Information Technologies (IT) for project planning and control

5.7.1 Background

The Developer selected a suitable formwork system for project’s context and standardize some of its components to facilitate the implementation of a house customization strategy. However, such strategy brought new challenges for project planning and controlling.

In terms of project planning, the 47 different housing configurations resulted in increased complexity to planning the construction work. Customer orders at the sales point had to be efficiently communicated to the construction team in order to develop the most appropriate execution plan. If the project had only one housing model, the construction team would know beforehand the house models that has to be built and their location within the project plan.

In terms of project controlling, the large and diverse number of housing units became the project hard to control. In the practice, each housing unit was like a small project composed by several tasks. If the project has to be constantly monitored, it requires significant effort to control the activities at the different locations of housing units.

Both phases, project planning and controlling are crucial for the success of the project. Nevertheless, doing this with pen and paper may be very ineffective.

The Developer took part in the creation of two tailored Information Technology tools to facilitate these phases; Interactive Plan for planning the construction work and Production Tracking app to track the progress of the project.

5.7.2 Trade-offs between efficiency and customization in housing construction

Custom builders tend to build on land owned by the customer and start designs from scratch spending more time on each project. On average, a custom builder work in less than 10 homes a year. In contrast, mass builders design their developments on land they have previously purchased and restricts the design to a group of preselected designs. They normally build a large number of homes in a year (NAHB 2015).

From the developers’ perspective, there are two main reasons to avoid customization in housing construction. First, it is not economically feasible to design every housing unit according to individual tastes. This may result in significant design information that will make the production process complicated to manage. Second, traditional manufacturing techniques require repetition to reduce costs based on the execution of repetitive work (Duarte 2001) and to take advantage of economies of scale (Ofori 2012). From the customer point of view, customization provides higher client’s value since the product meets individual customer needs (Nahmens 2007). Furthermore, as described in Chapter 2, evidence reveals that disregarding human motivational factors in the design and construction of housing, as commonly done in mass housing production, may result in social dissatisfaction and disorder (Zavei and Jusan 2012).

This results in a dilemma for developers. On the one side, they do not want to sacrifice productivity gains by deviating from traditional models. On the other side, they are required to meet the needs of clients demanding variety (Nahmens and Mullens 2009). This results in the operational challenge of how to provide the required customization with the efficiency in the production system. Nahmens and Bindroo (2011) found that developers offering a broader level of
customization should expect to face poorer labor productivity. They argue that the implementation of Lean Production and the IT that serves people and the production processes has the potential to facilitate a customization strategy and to lower efficiency losses.

5.7.3 Lean Production and IT to support a customization strategy

The implementation Lean Production in affordable housing construction may serve as a mean to deliver a variety of options to customers with an efficiency that makes housing still affordable. Such approach may also enhance the value and quality of the housing product delivered to customers. As discussed, such achievements resulting from Lean Production implementation have been already realized in the automotive industry (Krafcik 1988; Womack et al. 1991). Based on such principles of production, by 1992 Toyota was able to produce a total of one million variations, with an average of five vehicles per variant, including different of colors, trim, body style among others features (Johnson and Bröms 2000, p. 80).

Delivering variety in large housing projects results in increased flow of data making project hard to manage. In terms of planning, information regarding customer product configuration must be adequately captured by the company at the sales points (Nahmens 2007) and timely communicated to production units in order to efficiently respond to customer requirements (Ozaki 2003). In terms of project controlling, the wide and varied number of units makes project production tracking a cumbersome task since variation in housing models deprives the project controlling process to be standardized. Thus, developers aiming to deliver variety in house building industry must be able to efficiently manage large amounts of information among its different departments.

The integration of Lean Production and IT can help companies to enable a faster reaction to changing external requirements (Riezebos and Klingenberg 2009) as in a customization environment. IT tools may help the developers to align its operations towards the customers’ requirements. It may also serve as a powerful source of shared information in the supply chain, allowing the organization to avoid delays when managing product configuration information (Nahmens, 2007). Toyota, for instance, implemented an “e-Kanban” to enhance communication with its suppliers (Kotani 2007). The combination of Lean Production and IT has also helped several manufacturers to reduce customer lead times (Ward and Zhou 2006). Consequently, Lean Production and IT implementation can be considered as complementary parts of a production system intended to increase efficiency (Moyano-Fuentes et al. 2012).

Nevertheless, achieving such synergy between Lean production and IT may be challenging in the building industry. The construction industry is characterized by limited investment in Research and Development resulting in a lack of product and process innovation (Barlow and Ozaki 2003).

The following sections describe the experience of the Developer developing and implementing two tailored IT tools aimed to deploy its customization strategy in terms of project planning and controlling.

5.7.4 Research methodology

The author uses Action Research. Action Research contributes to addressing practical concerns of people in direct problematic situations by using social science based on joint collaboration within a mutually adequate ethical framework (Rapoport 1970). In order to address the practical issues, the researcher is involved in the process of change (Benbasat et al. 1987). Susman (1983) defined
five essential steps of action research: 1) diagnosis, 2) action planning, 3) action taking, 4) evaluating and 5) specifying learning.

Action Research has been identified as a proactive research method to address issues in the Construction Engineering and Management field (Azhar et al. 2010). It is also a suitable methodology to address productivity issues when Lean Construction is being implemented (Jang et al. 2011)

During the time the researcher was involved in Developer’s organization, he contributed to diagnose organizational issues and participated in the development of two tailored information IT tools intended to address organizational issues. The author was in charge of identifying organizational needs in order to translate them into IT tools’ specifications. He also contributed to creating prototypes of the IT tools and coordinated their proper implementation in the organization.

5.7.5 Project planning: Interactive Plan

5.7.5.1 Need for improved communication

Initially, customer requirements captured at the sales points were communicated to the construction team using spreadsheets. The large size of the project and the different options offered to customers resulted in a bulky document hard to manage. Upon this data, the planning and construction team plotted housing units in the project plan in order to proceed with the planning process. Every time an update in customers’ selection occurred (e.g. order cancellation, change in the model, type of finishes or location), the team had to review the planning process and adjust the plan accordingly. Unquestionably, under this system, the planning process was complex and time-consuming. The Developer identified the need to create an IT tool that captures customer orders in a project plan. In this way, the construction team can access to sales data in a way that facilitates the planning process and reduces construction team’s response to customer requirements.

5.7.5.2 Product configuration process

In housing customization, there are many choices a customer can make (e.g. house model, type of finishes and locations). As a result, builders limit the range of selection to customers in order to increase the efficiency of the construction process (Barlow et al. 2003). A strategy to reduce product complexity is to group choices in the configuration process (Fixson 2005).

Based on a similar strategy, the company allowed customers to select from any of the base 12 housing models. However, the finishes types were grouped and offered to customers as economic, medium and top quality packages. A similar approach was implemented for delivery dates and locations. Given the large size of the project (180,000 m²), it was divided into stages according to predefined delivery dates. In this way, customers’ selection regarding units’ location was restricted to an area within the project’s plan. The Developer aimed to avoid building units in a scattered fashion due to the construction system implemented and all the resources that transportation activities demand. Providing the customer with excessive alternatives resulted in significant product variation making the production system cumbersome to manage. The application of subtle restrictions in customers’ selection provided the Developer with more control over the production system. Figure 5-25 depicts product configuration process followed by customers at the sales point.
After defining the product configuration, the company focused on the planning of construction work, which was highly impacted by the customer’s choice. The delivery dates per zone were determined by the construction team prior to the sale. However, the final mix of housing units per block was unknown until the entire block was sold. This situation challenged project planning since many information needed for to plan depends on customers’ selection at different times.

Particularly in the housebuilding context, the delay in customer decision making (Cuperus 2003) and the risk to have doubtful customers (Andújar-Montoya et al. 2015) have been identified as inhibitors for a customization strategy.

The author argues these issues are especially relevant in the affordable housing market. Commonly, affordable housing buyers do not have a strong financial capability; they rely on governmental support and the willingness of financial institutions to lend them money. This situation had a significant impact on customer selection. For example, a customer may hold back a housing model expecting to qualify governmental and/or private financial support. If the application process for financial aid fails, the reservation is canceled. In other cases, if a customer selects a model and experiences unexpected financial events, he may want to change the original house model for a cheaper one. These conditions become the low-income customer hard to predict resulting in significant variability on sales and the production system.

Given this scenario, the implementation of suitable means to capture and communicate customer requirements across organizational levels is crucial to enable an efficient response of the construction team. Aiming to address these issues, the Developer took part in the development of Interactive Plan.

**5.7.5.4 Interactive Plan system architecture**

Interactive Plan is based on IDempiere, an open source Enterprise Resource Planning (ERP) platform (Wikipedia 2015). IDempiere is built on JAVA, it can be run in a physical or virtual infrastructure and accessed through an intranet or the internet. IDempiere’s flexibility and openness allow the companies to develop tailored applications to meet specific organizational needs. IDempiere does not require software installation in the operative systems; it can be accessed through the internet using any browser available online (BMLaurus 2015).
These features became IDempiere a suitable ERP platform for the Developer. Over IDempiere platform, the organization has developed several customized applications to facilitate business operations, including the Interactive Plan.

As shown in Figure 5-26, Interactive Plan centralizes customers’ selection information gathered at the sales points, builds a database on IDempiere and captures this information into a project plan. The data plotted in the project plan is accessible in real time by the different company’s divisions. In this way, the information regarding customers’ selection is instantly processed and communicated across different departments in the organization in a simple and visual way.

![Interactive Plan system architecture](image)

**Figure 5-26: Interactive Plan system architecture**

5.7.5.5 *From sales points to IDempiere*

In order to reach customers, the Developer’s sales force is strategically distributed in different locations. Using a customized IDempiere interface developed by the IT team (Figure 5-27), sales agents input data about customers’ selection in the system. This information is captured according to the product configuration process depicted in Figure 5-25. Through an internet connection, the information captured in the sales points is centralized in IDempiere’s database.

5.7.5.6 *From IDempiere to Interactive Plan*

The data stored in the IDempiere is plotted in the project plan through JAVA code. This process is made overlapping information of two layers of data.

As depicted in Figure 5-28, layer 1 corresponds to a high definition JPG picture of the project plan. Through JAVA code, every block and plot location is assigned with (X, Y) coordinates. In this project, housing units’ locations are identified using a “block-lot” convention. For instance, unit 5A-2 is located in the block 5A and lot number 2. For example, unit 5A-2 corresponds to coordinates (100, 250).
Layer 2 is programmed to translate customer selection into color and shape codes. In simple terms, layer 2 acts as a “transparent slide” that contains the same (X, Y) coordinates for units’ locations than layer 1. Once customer selection is translated into color/shape codes, the information enclosed in both layers is overlapped. Since both layers have the same (X, Y) designation, the final result corresponds to the project plan showing the different housing models in a visual way.

Interactive Plan can be consulted in real time through an internet connection. Every time the company receives a customer order, the information is promptly captured and depicted in the system. Figure 5-29 shows the user interface for Interactive Plan. Based on color and shape codes, the right side depicts the customer selection anchored to its corresponding location in the project plan. The left side shows the legend for the colors and shapes. Users are provided with custom filters allowing them to select the information of their interest. For instance, a user may want to
analyze only the information for a certain delivery date or to verify the locations where a specific model has been sold. In addition, Interactive Plan can be zoomed in or out according to the amount of information a user wants to display on the screen. By clicking in the colored codes, the user can access to a secondary window that deploys broader information for the selected location (Figure 5-30). For instance, users can check the size of the lot, the date when the order was placed, the name of the client, the cost of the transaction, among other information. These features of Interactive Plan make it valuable not only for the construction team but also for other departments in the organization.

Figure 5-29: Interactive Plan user interface

Figure 5-30: Interactive Plan secondary window
5.7.5.8 Results and discussion

Interactive Plan is able to communicate customer choices efficiently to the construction team by depicting sales data in a simple and visual way. As depicted in Figure 5-31, Interactive Plan allows the Developer to automate several steps in the planning process that used to be manually performed. This results in faster construction team response and reduced customer lead time.

![Figure 5-31: Interactive Plan process automation](image)

Interactive Plan is also a valuable source of shared information. The Developer discovered that by adding more layers of information to the system, this tool could be useful for other departments in the organization. For instance, the secondary window provides information about the clients and payment conditions which are beneficial for the sales and commercial department.

Relevant for discussion is the direction of the information transfer in the system and its impact on internal communications. In the beginning, Interactive Plan allowed only unidirectional information flow, from the sales points to the construction team. However, programming the Interactive Plan to handle multi-directional information flows expand its functionality. This means allowing to input information not only at the sales point, but also to receive information coming from other departments in the organization.

One application of this multidimensional information transfer is the “blocking system” implemented between the construction and sales team. One month before the start of the construction work of certain stage, the construction team is able to send a “blocking signal” to the sales department. This with the purpose of warning sales agents that changes on customer preferences are no longer allowed on that stage. This period of time beforehand allows the construction team to plan the construction work adequately. Otherwise, variability would increase,
thereby impacting the performance of the production system. In the case there are units not yet sold by the time, the sales department decides the type of model to be built in vacant lots based on sales statistics generated the same Interactive Plan system.

These type of practical situations exemplify that the aligning Developer’s operations towards customer requirements require enhanced coordination among every step in the project delivery process. At the same time, such communication is crucial to the success of a customization strategy and the implementation of IT contributed to facilitate it.

5.7.5.9 Limitations

The feedback provided by end-users contributes to identifying the limitations of Interactive Plan as well as the aspects where it can be improved.

First, the current version of the Interactive Plan only allows exporting the information in a JPG file. The JPG file has several limitations in terms of compatibility with other software commonly used in the construction industry. This situation restricts users’ ability to use Interactive Plan for other purposes. For example, exporting Interactive Plan in a DWG file could help the design team update project design according to customers’ selection (e.g. as-built drawings).

Second, the software is not able to receive inputs directly in Interactive Plan interface (Figure 5-29). Currently, information can be only inputted directly in IDempiere’s database. This shortcoming may limit its functionality. For example, the construction team may want to input information about the progress of the project allowing other departments in the organization receive feedback about the progress of the construction work.

5.7.5.10 Conclusions

This section presented the creation and implementation of a novel IT tool to the implementation of a customization strategy. The success in the development and implementation of Interactive Plan relied on two facts. First, the use of a flexible ERP open source that allowed the company to create tailored IT tools to address organization’s needs. Second, the availability of an internal Information Technology department capable of developing ERP based IT. Developer’s IT team worked closely with end-users which facilitate the translation of user needs into IT tools features. This scheme of work allowed IT developers to receive feedback directly from end user which enable improvements in Interactive Plan’s functionality.

Interactive Plan also serves as a tool for continuous improvement. The database allows the Developer to learn about customers’ preferences enabling the sophistication of the customization strategy for the following stages of the project. For instance, the Developer may evaluate to discontinue housing models ranked at the bottom of sales. Similarly, the database may provide the Developer with valuable information about the housing features that customer prefers. In future stages, the Developer can focus on such aspects in order to provide customer with enhanced value in housing construction.
5.7.6 Project controlling: Production Tracking Application

5.7.6.1 Background

Efficient construction project tracking is crucial to a project success. A production tracking system should provide feedback about the status of construction activity in order to allow the project team to detect deviations and to implement corrective actions accordingly. Despite the importance of this task, most contractors use manual tracking procedures that are time-consuming and prone to errors (Turkan et al. 2012).

In the practice, controlling the project based on pen and paper requires significant work and may take up to 4 hours of field engineers’ daily working time (McCullouch and Gunn 1993). When using manual approaches, field engineers may have to print control forms and get to the field for data collection. Second, they have to come back to the office and input this information into the computer. Third, this information has to be properly processed in order to compute the metrics illustrating the status of the project. Certainly, pen and paper is not the most efficient approach for project controlling (Hsie et al. 1995).

Taking advantage of advances in technology, researchers have contributed to bring automation to this process (McCullouch and Gunn 1993; Cox et al. 2002; Goodrum et al. 2006; Samir El-Omari and Moselhi 2009; Shahi et al. 2012; Turkan et al. 2012; Kim et al. 2013; Shahi et al. 2013). This section presents the development and implementation of a novel IT application intended to automate the process of collecting and processing data to track the progress of the construction work on a daily basis.

5.7.6.2 Developer’s needs

The company developed this IT application trying to fulfill the following organizational needs:

Daily Project tracking: The Developer wanted to track project’s progress on a daily basis and to consider each housing unit as a small project. The data collected must be anchored to the housing typology and its corresponding location. The large number of units, variety of models and multiple activities involved in housing construction resulted in significant data that must be properly managed for tracking purposes. Thus, the IT application must be able to facilitate data collection on the field and to report the status of the project efficiently.

Continuous improvement: At the moment to build the schedule for the first stage of the project, the Developer lacked proper information to estimate the sequence of work and activity durations. The Developer relied on information provided by subcontractors. Thus, the Developer identified the need to learn from experience in order to improve the accuracy of scheduling for the future stages. Thus, the IT application should also serve as a reliable database that enables learning from experience.

5.7.6.3 Product development process and main organizational needs

The Developer set a collaborative environment for the development of the IT tool that included the budget, planning and control, construction and IT departments of the organization in addition to subcontractors. The purpose of collaboration was to come up with a solution that serves the most people in the organization.
Through several meetings, team members captured the needs of the different departments and translated them into product specifications. The team also considered border conditions like the characteristics of the ERP system being used by the Developer and connectivity limitations for mobile devices in the field.

**Construction team:** The construction team wanted to use electronic devices for data collection. The electronic device must contain a list of the activities easy to control on a daily basis. They also wanted to avoid manual calculations to input data. For example, if the concrete for the first floor is completed, having broad activities in the list like “concreting work” required them to compute the percentage that the concreting first floor represents over the entire house. In contrast, they preferred more specific activities as “concreting first floor” or “concreting foundations,” which allows users to input progress data easily. In this way, they can mark activities simply as completed (100%) and not completed (0%) on a daily basis.

**Planning and control department:** The planning and control department wanted to avoid manual computing to estimate the progress of the project. They required having easy access to the construction progress updates in order to feed the master schedule and to facilitate the elaboration of project’s status reports. They also wanted to track the progress at different levels (i.e., activity level, block level, delivery group level, and project level).

**Budgeting Department:** They wanted to translate progress inputs in the field into the progress of budget items. This ensured that the progress on the field is correlated with payments made to suppliers and subcontractors. This information was also useful to have a database for cash flows and to forecast future payments.

**Project Managers:** Project managers wanted to access to online executive progress reports. They also wanted production tracking on a daily basis, so it serves as a source of learning to plan future stages of the project.

### 5.7.6.4 System architecture prototype

Based on organization’s needs, the team created a prototype system architecture in Excel. The most challenging aspect was to synchronize properly the Budget Breakdown Structure (BBS) used by the budgeting department and the Activity Breakdown Structure (ABS) desired by the construction team. For example, the BBS had the Rebar item merged in one line. In contrast, in the ACS the construction team preferred the Rebar item divided into different phases according to the sequence of the construction work (i.e., foundations, first floor and second floor). In addition, since the project had 47 variations, the BBS and the ABS were not necessarily identical for every housing typology. Consequently, the team standardized both breakdown structures, so they fit all housing models.

With the BBS and ABS standardized, the team developed a Relationship Matrix (RM) aiming to synchronize percentages of progress between both breakdowns structures. The purpose was that percentages of progress input by field engineers in the ACS are automatically translated into progress in the BBS.

Figure 5-32 depicts a portion of the RM for housing model “PRE_M_M”. The left side of the RM corresponds to the ACS while the top side to the BBS. In the BBS, the rebar item is consolidated in one column while in the ACS it is divided into four levels according to the sequence of work advised by field engineers. That is the foundation, first floor and slab, stair, and second floor. Each
of these levels was assigned with a percentage (21, 59, 7, and 13% accordingly) based on a representative unit of the activity. In this case, the chosen base unit was Kilograms of rebar.

Figure 5-32: Relationship matrix

These percentages in the RM defined the synchronization between the BBS and ABS. For example, if the activity ID 5: REBAR is marked as completed in the field, it represents a 21% of progress for the REBAR item in the BBS. Then, if the activity ID 11: REBAR is marked as completed, it represents an additional 59% of progress for the REBAR item in the BBS. That is a cumulative value of 80% (21 + 59 = 80%). This process of linking the BBS and ABS in the RM was performed for all the activities and items included in the budget.

The prototype was tested several times emulating the progress in different house models in order to ensure that the links between the ABS and BBS are accurate.

5.7.6.5 System architecture

Figure 5-33 depicts the system architecture.

Users

Field engineers collect data simultaneously using tablet or smartphone devices. For this purpose, the IT team created a tailored android application. An important challenge was the limited internet access on the field. In order to overcome this issue, the application included an off-line mode with
the capability to storage inputs on the field. Once the mobile device is connected to the internet, the stored information can be synchronized and sent to the IDempiere database.

Figure 5-33: System architecture

Figure 5-34 depicts the user interface in a smartphone. Here, users have to log in and select a housing model including its location on the project plan. Then, users can input the activity progresses in the ABS. The application uses color codes to help users to differentiate activities that are already completed from those that are not.

Figure 5-34: User interfaces. Login screen (left), house model and location selection (center), and progress input (right)

**Database IDempiere ERP**

To support operations, the Developer is using IDempiere ERP. IDempiere allows the Developer to create and implement tailored applications that can be integrated into the ERP system. This enables the Production Tracking Application to send and store information in IDempiere database. Using a web browser and given the required permissions, users can access to the IDempiere database to generate customized progress reports.
Customized Reports

Different users may want to see the information in different ways. For example, users at the top management level may want to check the overall status of the construction work without extensive details. In contrast, construction supervisors may want to access to detailed reports showing the progress of each activity so they can improve coordination among construction crews.

In order to elaborate the reports according to variant users’ requirements, the IT team used JAVA Code to mimic the calculations of the Relationship Matrix described in section 5.7.6.4. These reports were designed based on the requirements of the different organization in order to display only the information that is valuable for the people. Customized reports can be exported in two ways: 1) Activity Breakdown Structure form and 2) in a Budget Breakdown Structure form.

As depicted in Figure 5-35, the Activity Breakdown Structure indicates the progress of construction work based on the list of activities defined by field engineers. Here, the report shows the progress from an activity to the delivery group level.

As depicted in Figure 5-36, the Budget Breakdown Structure report convert the progress input of field engineers in budget items progress. This process is made based on the RM described in section 5.7.6.4.

![Figure 5-35: Activity Breakdown Structure report](image-url)
5.7.6.6 Direct export of database

The system architecture allows users to export IDempierre database to an Excel spreadsheet. In this way, users have access to raw data with the autonomy to process it according to their needs. For example, Figure 5-37 depicts the completion dates for concrete related operations: Foundations, walls and slab first floor, stairs, and walls second floor. The Y axis in the left shows housing models and its corresponding locations in the block-lot format. The X axis in the top corresponds to time in days. The beginning and end of the activities, as well as the progression of the crews through different locations, are shown in the chart allowing users to analyze the execution of construction work.

In another example, Figure 5-38 corresponds to the calculation of average activity durations which allows the Developer to improve forecasts for future schedules.
5.7.6.7 Results and discussion

As shown in Figure 5-39, the Production Tracking Application automates several tasks in the controlling process reducing the effort and time required to process the information. It is also a valuable source of information for the different department in the organization. The automatic translation of construction work input into progress in budget items increases the coordination between the planning, construction, and budgeting team. Furthermore, the IT tool serves as a historical database of project execution that can be used to improve the forecast of schedules of future stages of the project.
5.7.6.8 Limitations

The standardization of the BBS and ABS, and their following linkage through the RM contributed to set up the proper synchronization of the progress of activities in the field and budget items. However, at the same time, this became the main limitation of the IT tool.

Such level of standardization harmed the flexibility of the system to respond to changes in the list contained in the BBS and/or ABS. When there is a change in any of the lists, it is necessary to reevaluate the percentages included in the RM and to update the code in the JAVA code in the system. This means, updating the application installed on mobile devices and adjusting the code used in IDempiere to generate the reports. Nevertheless, this is part of the constant revision of procedures carried out by the Developer. As described by Liker and Meier (2006), standardization is part of an ongoing process of identifying problems, establishing effective methods, and defining the manner those methods are to be performed in order to achieve continuous improvement.

5.7.6.9 Conclusions

The delivery of variety and the large size of the project posed several challenges for project controlling. Tracking the progress of construction work on a daily basis, as aimed by the developer, resulted in significant amount of data that had to be accurately processed. The development and implementation of a tailored IT tool helped the Developer to overcome these issues.

The close collaboration of IT team with end user allowed the organization uses feedback to improve some shortcomings or limitations of the IT tool. For example, the incorporation of color codes for activities that are completed (or not completed) emerged as a requirement of field engineers. These small changes based on user experience increased the efficiency in data collection. This process of continuous improvement is an approach that is still being implemented by the Developer.

5.8 Conclusions of the Ecuadorian Case Study

The Ecuadorian Case Study described three Lean Production initiatives aimed to facilitate the implementation of a customization strategy in home building.

When analyzing Lean Production initiatives altogether, the author realized that the implementation complexity increases as the project progress in the delivery process. In Figure 5-40, the author believes that this has a direct link with the number of stakeholders involved in the project. The CBA experience, for example, was implemented early in the design stage of the project and it required the participation of five stakeholders within Developers’ organization. The fact participants of this experience belonged to the same organization facilitated the alignment of their interests towards a common goal, which eased the implementation process. The Formwork standardization experience brought a new stakeholder. Although in the standardization process both organizations (the Developer and formwork supplier) agreed to pursue common goals (see section 5.6.7), they still have their own internal interests inherent to their business and organizational strategies, which increased complexity in the implementation process. Similarly, the IT tools implementation, which was performed during project construction, required the involvement of more internal stakeholders as well as input from subcontractors. The development and proper implementation of the IT tools required increased coordination among all stakeholders, which increased complexity.
Since the Developer is operating under a DHS housing policy, it is important to analyze the links between the government and Developer’s production systems. Working in an environment of the DHS finance mechanism, the Developer has to comply with several regulations.

In terms of project design, the Developer has to obtain the approval of government agencies for all drawings and specification included in the development. This revision process has not been as fast as expected, thus impacting the timing of the project delivery process. These delays can be attributable to two causes. First, the expanded amount of information that has to be processed considering the variation of housing models resulting from a customization strategy. This is an aspect under the control of the Developer. If more resources are needed to process extra design information, the Developer can hire more personnel to speed up this process. Second, the capacity of the governmental agency in processing the information. This is an aspect which is out of the reach of the Developer. Moreover, governmental agencies may not be flexible enough to expand and/or reduce its capacity by adding or removing personal. State regulation, for example, may require an official procedure for personal management.

Similarly, in terms of construction, the government requires inspecting housing units when construction work at 70% of completion. Once this inspection is approved, the government takes two months to release the amount awarded in the DHS to the beneficiary. Thus, the Developer has no incentives to speed up the construction of the remaining 30% after the first inspection is done.

As depicted in Figure 5-41, directly or indirectly, the government becomes part of Developer’s production system and the dissimilar capacities between the public and private enterprise have a direct impact on Developer’s production system design. Developer’s operations may be flexible enough to adjust its capacity to meet its goals. However, the government may not have such flexibility. This unbalance produces bottlenecks in the production system that are more likely to be allocated on the governmental side.

This suggests that when designing production systems, private developers operating under the DHS must consider governmental agencies capabilities and accordingly adjust its own production capacities along the project delivery process. Despite housing provision is mainly a responsibility
of private developers, government operations can highly contribute to making housing construction more efficient and affordable.

Figure 5-41: Production system under DHS
CHAPTER 6 CASE STUDY QUINTA MONROY

Chapter 6 focuses on design. It analyzes the way beneficiaries’ needs are captured and incorporated into affordable housing design and provides illustrations from the Quinta Monroy Case Study. In terms of Lean, this chapter focuses on value generation. Quinta Monroy is suitable for this study because the project is delivered with the support of DHS. In this case, design and construction are not driven solely by the developer, as described in the Case Study of Villa Hermosa in Chapter 5. Instead, the Quinta Monroy project is the result of a collaborative process involving different stakeholders: the government, academia, the private sector and the beneficiaries. Thus, Quinta Monroy offers the opportunity to analyze an alternative approach that aims to address some of the shortcomings of centralized forms of affordable housing provision (including mass housing) in Latin America.

This chapter is organized as follows: Section 6.1 introduces the chapter and Section 6.2 present the research methodology. Section 6.3 describes the “Chile Barrio” housing program and Section 6.4 provides insights into the architectural firm Elemental. Section 6.5 and Section 6.6 describe the Quinta Monroy project and its main challenges. Section 6.7 and Section 6.8 describe how stakeholders approached the project. Section 6.9 provides the conclusions of the chapter.

6.1 Introduction

DHS appears to have favored centralized forms of housing provision (Lizarralde 2015), like mass housing construction. Some of the problems related to the poor design and quality of the mass-produced housing may be a result of limited involvement beneficiaries in housing design.

According to Alexander et al. (1985), most decisions regarding housing design are made remotely by people who do not have to deal with the consequences of them. Developers make decisions about land they have never visited. State officers make decisions about roads connecting developments without having any type of human link with the place for which they are making decisions. Architects decide design attributes on behalf of people they don’t know and engineers design columns which they will never see materialized on site. Construction work is performed by workers who have no power of decision about the details they build. This results in housing developments without any kind of human bond with residents and unable to express the uniqueness of different families living in them. In most cases, poor people in need of shelter are approached as a whole, providing one standard for the “mass” (Hernández 2010). According to Turner (1968) governments “must give up on the idea that they can act unilaterally and effectively on behalf of the mass of people.” They should not work for them but with them.

Centralized forms of housing provision miss the potential benefits of delivering variant standards of housing. For instance, variant housing standards in the same development may respond to different target groups resulting in the integration of families with different social and economic backgrounds. Variant housing standards may also allow families to expand their housing units according to their building capacities (Lizarralde 2015, p. 194).

In recent decades, governments have started recognizing the value of community participation in slums rehabilitation and housing provision initiatives (UN-Habitat 2003, p. 132; Fay 2005). Incremental housing is an approach that has been used to address the problem of illegal settlements and is based on strong community participation in housing design and post-occupancy construction. This approach consists of a progressive construction process in which a core house is delivered with basic features and is upgraded later according to financial capabilities of the
families living in it (Greene and Rojas 2008). In fact, research has shown that incremental housing can be used to address some of the problems of subsidized mass housing developments such as the small size and poor quality of the housing units, lack of customization (Afshar 1991) and the lack of customer involvement in design decision making (Lizarralde 2011).

6.2 Research methodology

The author analyzes the Quinta Monroy project in retrospective. He selected Quinta Monroy because the project was financed through DHS which fits the framework of the research. In addition, the project has received significant recognition in terms of housing policy innovation and because of the quality of design. In fact, the main contributor to the project, Alejandro Aravena was recently recognized with The Pritzker Architecture Prize (The Pritzker Architecture Prize 2016).

The author uses literature review to analyze the housing policy context, and the design and construction process of Quinta Monroy. He also uses audiovisual materials available online that include interviews with key stakeholders involved in the project.

The focus of this analysis is on value generation. For this purpose, the author evaluates the adherence of Quinta Monroy practices to the fourteen Lean Production Principles described by Liker and Meier (2006). Nevertheless, this chapter only describes the case study. The adherence of Quinta Monroy to the Lean Principles is presented in Chapter 7 along with the other two case studies included in this research.

6.3 “Chile Barrio”: a new approach for housing provision

As part of an evolution of its housing policy, the government launched in 1997 the housing program called “Chile Barrio” (Chile neighborhood). The program aimed to improve the living conditions of 105,888 families (half a million people) occupying 972 illegal settlements around the country (Saborido 2005).

The Chile Barrio program addressed some of the shortcomings of DHS. First, DHS were not reaching the poorest families (Ruprah and Marcano 2007). Previous savings and access to mortgage credit required by housing programs placed a significant burden on them. Thus, many of families could not qualify for a subsidy or were defaulting on mortgage loans. In order to overcome those issues the government decided to 1) reduce the subsidy from $10,000 to $7,500, 2) lower the savings thresholds required for subsidies application, and 3) eliminate the mortgage component (Sinclair 2006). Although the amount of the subsidy was reduced, the government was able to reach more families (particularly the poorest) and to relieve them from mortgage debt.

Second, the government realized that the provision of a housing unit itself does not alleviate poverty issues. Thus, through Chile Barrio, the government addressed the problem of extreme poverty and illegal settlements with multidimensional interventions including the establishment of support networks before and after slum intervention. This includes, for instance, social integration of the community with its surrounding urban environment, and training and education programs aimed at integrating the community into productive activities (Morales et al. 2010). This approach required a decentralized strategy and enhanced collaboration among the central and regional governments, as well and participation of private industry and the community (Saborido 2005).
As part of the Chile Barrio implementation, in 2002 the Chilean government asked the architectural firm Elemental to design a solution for the illegal settlement Quinta Monroy (Aravena et al. 2004).

### 6.4 About Elemental housing

Elemental is a for-profit architectural firm that focuses on projects of public interest and social impact, including housing, public space, infrastructure, and transportation. The firm promotes participatory design with architects working collaboratively with communities and end users (Elemental 2016a). One of the main objectives of Elemental is to bring professional expertise and resources to affordable housing design and construction.

Elemental was conceived in 2000 by the Chilean architect Alejandro Aravena while working at Harvard University. Since 2006, the firm has worked in partnership with Chile’s Catholic University and private companies. This mix of professional expertise, academic excellence, corporate vision and entrepreneurship has helped Elemental to expand its scope of operation in several countries in Latin America (Aravena 2011).

The first project of elemental was Quinta Monroy (Elemental 2016b) which gave them international recognition because of its innovative approach to affordable housing provision (Arcspace 2016).

### 6.5 Quinta Monroy

Quinta Monroy is an illegal settlement located in downtown Iquique; a Chilean city situated 1,500 kilometers north of Santiago (Hernández 2010). Given the poor living conditions of the 97 families at Quinta Monroy, the Chilean government offered the community to move to a new housing development in Alto Hospicio, located at the periphery of the city (Figure 6-1 and Figure 6-2). The idea of relocation was influenced by the cost of land. Considering the little amount of the subsidy awarded by housing programs, the cheaper cost of land in Alto Hospicio became a new housing development economically feasible. Nevertheless, the community refused to relocate. After decades of living in the same place, they created strong social networks and felt empowered to remain permanently settled at the same site (MoMA 2016).

### 6.6 Project challenges

The goal was to build a structurally safe home for all the families in the current settlement (Sinclair 2006). The project had two main challenges. First, the size of the settlement: only 5,000 square meters (53,820 square feet) was available to build 97 homes. Second, the availability of resources: a subsidy of US$ 7,500 per family was awarded by the Chile Barrio program. This amount of money had to be used to cover the three main items of housing cost: (1) land, (2) connection to urban services (drinking water, sewer system, and electricity), and (3) the cost of the housing solution itself (Aravena et al. 2004). From those items, the cost of land took a significant portion of the available budget because of its location in downtown Iquique (MoMA 2016). That cost of land was three times more the amount that an affordable housing development could normally afford. Given budget constraints, in the best case scenario families could get a housing unit of maximum 30 square meters (323 square feet) (Aravena et al. 2004). In terms of available space for construction, the only way to accommodate all families at this site was through multistory family construction (MoMA 2016).
Figure 6-1: Quinta Monroy location in downtown Iquique (MoMA 2016)

Figure 6-2: Location of Quinta Monroy and Alto Hospicio (Google Maps, visited March 15, 2016)
6.7 Elemental approach: the first half of a good house

Elemental first informed the community of all project restrictions. The design team knew what they could not do but they were not sure about what they could do. In order to understand what they could do, Elemental asked the community of Quinta Monroy to embark in a participative design process. The intention was to deliver a project that meets the expectations of the community members (MoMA 2016). Elemental also wanted to address some shortcomings of massive housing developments. First, the inability to represent the uniqueness of each family, including their styles and preferences in house and neighborhood design. Second, the inability to consider the dynamic nature of families. For instance, by providing residents the opportunity to build extensions according to family’s growth (Aravena et al. 2004).

Elemental, in conjunction with graduate students of the Harvard Graduate School of Design and the Chilean Catholic University started a design iteration (Aravena and Iacobelli 2012). In Figure 6-3, option 1 considered one house per lot (detached houses). This approach was inefficient in terms of land use and could accommodate only 32 families (Aravena et al. 2004). The availability of cheaper land in the city border is the main reason why subsidized housing is located in unattractive locations far away from urban services, opportunities for work, education and health which creates significant social problems and inequality (ArchDaily 2008).

<table>
<thead>
<tr>
<th>Concept</th>
<th>Distribution on site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1 1 house = 1 lot</td>
<td>Option 2 (a = b = 3) meters (10 feet)</td>
</tr>
</tbody>
</table>

Figure 6-3: Design iterations (Aravena and Iacobelli 2012)

Option 2 considered making the width of the houses same as the width of the plot (row houses). However, this setup could accommodate nearly 60 families (Aravena et al. 2004). In addition, this configuration imposed several restrictions on the house’s interior design. House width equal to one room, around 3 meters) meant that any extension could hinder proper illumination and ventilation of adjacent rooms. Moreover, it could affect privacy because circulation has to be done
crossing rooms which led to overcrowding and promiscuity (ArchDaily 2008). The only way to make room for 97 families was through multi-story family buildings, as in option 3. Nevertheless, this option prevented families building extensions (Aravena et al. 2004). Multi-story buildings were highly rejected by the community. According to Aravena (2014), “the community threatened to go on a hunger strike if we even dare to offer this as a solution.”

In terms of housing design, the team knew that an appropriate interior space for a middle-class family is 80 square meters (861 square feet) and eventually set this design parameter as a target. Nevertheless, budget constraints forced them to reduce housing size to make it more affordable (i.e., 40 square meters or 430 square feet), as private housing developers may do (Aravena 2014). The project’s constraints led the design team to recognize that a “good full house” was impossible to build given all constraints. Thus, the team rephrased the problem: Why not to consider building half of a good one? (Aravena 2014). They had arrived at the half house concept (Figure 6-4) (Aravena and Iacobelli 2012).

Instead of providing a small house, the team decided to provide one-half of a middle-class house that can be enlarged later by the residents according to their own building capacities and priorities. The half house concept imposed new challenges on the team. When public money is available only for half of a house, which half should be built? The team decided to design and build the half that a family could never do on its own (Aravena 2014). That means all the difficult parts of the house as the kitchen, bathroom, partition walls and structural elements with a standard of a house of 80 square meters (ArchDaily 2008). The design included a set of details to guide and facilitate future expansions. External walls were made of concrete blocks but internal walls and other modifiable partitions were made of wood. Key structural elements such as foundations and internal bracing were made of cast-in-place concrete but staircases (external and internal) were made of wood and designed in a way that residents can replace them later either with concrete or metal (Hernández 2010).

![Figure 6-4: Half house concept (Aravena and Iacobelli 2012)](image_url)
The final model combines the half house concept with the design iterations depicted in Figure 6-3. In Figure 6-5, white cuboids represent the half house concept while the gray ones represent potential future expansions. By using this arrangement, the team addressed two project challenge. First, it increased land use efficiency thus allowing the 97 families to settle in the same site. Second, it provided families the opportunity to expand the house horizontally at ground level, and vertically over a solid construction (Aravena et al. 2004).

![Figure 6-5: Quinta Monroy's concept (ArchDaily 2008)](image)

Figure 6-6 depicts the final design through a series of 3D models. The last 3D model at the bottom right presents examples of extensions that the team expected families to build after moving into the development.

### 6.8 Community participation: the second half of a good house

The team established three ways to ensure community participation in design process (Aravena and Iacobelli 2012, p.106):

- **Communication of restrictions**: The team believed their professional responsibility was to inform families properly about the limits of their options and thereby avoid false expectations.
- **Joint decisions**: The team meticulously informed the families about the available alternatives and explained the consequences of their decisions. Decision making was made in conjunction with the community.
- **Bi-directional participation**: The team acted as a top-down (government → community) and bottom-up (community → government) channel of communication.

Making restrictions clear to the community served as a baseline to start the design process. The community was aware that they could decide some aspects of the house but always according to the available budget. According to one community member: “It was clear we could not ask for a palace.” Nevertheless, all the desires of the community could not be fulfilled. According to a community member, some people began “acting silly” and asked for things totally out of the scope budget (MoMA 2016).

Project constraints required making sacrifices. The team tried to explain clearly to the community the positive and negative aspects of the different alternatives leading them to make informed decisions. In the practice, decision making was executed in conjunction with the community. For example, they were asked if they favored the inclusion of water heater over more land for the
houses. They could have only one because resources were not enough to get both. These type of decisions were made by voting (Aravena and Iacobelli 2012)

Figure 6-6: 3D model of housing units at Quinta Monroy. Arrows represent enlargement built by the residents (MoMA 2016)

In Figure 6-7, illustrate the team’s decision to use a “U” shape to create four common spaces (or groups) that facilitate social interaction (Sinclair 2006; Hernández 2010) and allows control over access points (MoMA 2016). In order to deal with some issues in the decision-making process for
common areas, the team formed community groups based on the level communication among families and thereby the degree of consensus they can reach based on common interests (MoMA 2016). They were able to decide features like walkways, roads and parking spaces for their sub-neighborhoods.

![Figure 6-7: Quinta Monroy layout and four groups for decision making in common areas (MoMA 2016)](image)

Elemental communicated the residents the progress of the design process by presenting scaled models and plans (Figure 6-8). The work with the community also included several workshops to prepare them for the transition as well as to show them the collective aesthetic of their future neighborhood (MoMA 2016).

![Figure 6-8: Residents using paper housing models (MoMA 2016)](image)

The construction work took over a year and was completed by the end of 2014. Four months after moving in, residents started to enlarge their houses, fact that was seen as a signal of the project’s success by the design team (Sinclair 2006). Residents used the openings left in the design as guides for the extensions. These openings permitted the use of standard-size construction materials, such as plywood and sheetrock. Elemental estimated that by investing around $750 in construction materials, families could increase the value of their property by to around $20,000 (MoMA 2016).
Figure 6-9, distinguishes between the structure provided in the original design and the expansions built by residents. The half of house provided by the team ensures hygiene and order, while the enlargement performed by the community makes the project lively and ensures identity (Van Leuken 2013).

![Figure 6-9: Housing units as delivered (left) and extensions build by the community (right)](Swenarton 2009)

6.9 Conclusions

Quinta Monroy reflects an innovative approach to affordable housing provision that integrates the efforts of the government, private institutions, academia, and beneficiaries in addressing the problem of consolidated illegal settlements, while at the same time avoiding some of the shortcomings of centralized forms of housing provision like mass housing.

At the housing policy level, the Chile Barrio program set the policy framework adequate to enable collaboration among the actors involved in the project. The involvement of Elemental, graduate students of the Harvard Graduate School of Design and the Chilean Catholic University brought professional expertise to address a challenging design problem. The construction company in charge of the construction work contributed to use efficiently materials and improve work productivity that was key to keeping the costs low (Ramírez 2005). Finally, the participation of residents in decision making contributed to design a project that represents their lifestyles and priorities. According to Elemental’s architect Tomas Contese, the architectural model of Quinta Monroy is easy to replicate. What may be hard to repeat is creating the synergy between institutions and people that contributed to this project (MoMA 2016).

In comparison to traditional developer-driven approaches, incremental housing requires enhanced planning and collaboration among different stakeholders. In developer-driven approaches, housing design and construction relies on the private developer. The government’s role is restricted to managing resources for subsidies and to overseeing project’s design and construction according to affordable housing standards. Others actors such as the academia or beneficiaries have little or no participation in the project delivery process. In contrast, incremental housing depends on collaboration, which requires planning and managing stakeholders’ participation before, during and after the project delivery (Lizarralde 2011). This represents an evolution of the DHS policy. According to a housing agency officer, in the previous approach, the government role was only restricted to turning in the house keys. Now, the government understands that helping communities overcome poverty is more than providing a house (MoMA 2016).
Quinta Monroy approach also addressed some of the design and social shortcomings of mass housing production.

From a design perspective, the team was able to capture the community’s needs and to design a project that met their expectations. In addition, by incorporating in the original design the guidelines for future enlargement, the project benefits from resident’s ability to expand their units according to their building capacity and priorities. Furthermore, it enabled them to express their lifestyle in the neighborhood, providing them a sense of community and belonging to their environment. According to Tomas Contese, in the short term community’s progressive construction delays the consolidation of project’s urban image. Nevertheless, in the long run by progressively improving their own home, residents contribute to increasing the quality and value of their collective environment (MoMA 2016). This is a totally opposite effect that has been experienced in mass housing developments. Commonly multi-family mass housing does not consider units’ expansion. This rigidity in design forces families to build irregular extensions outside minimal standards. Their investment does not add any value to the property and the urban environment. In fact, it contributes to the degradation of the urban environment and thus the devaluation of the development (Rodríguez and Sugranyes 2005, p. 215).

From a social perspective, settling the community in the same central site, instead of pushing them to the city’s suburb allowed residents to keep their social networks and facilitated their access to urban services. It improved the life quality of the community since it allowed them to have better access to job opportunities, health and education.

Providing a good half house is a creative solution to address several constraints in the Quinta Monroy project. Nevertheless, it also reveals that resources to provide decent and affordable housing are not enough. According to Aravena (2014), the magnitude of the housing problem is so big that it cannot be addressed without people’s building capacity. In this aspect, Quinta Monroy is an example of how to properly channel people’s building capacity. Thus, under the adequate policy framework, sufficient planning, proper collaboration and innovative design, slums may not be part of the problem but part of the solution.
CHAPTER 7 CASE STUDY BUILD CHANGE

Chapter 7 focuses on value generation. It analyzes the way the local context of developing countries is captured and incorporated into affordable housing design and construction by analyzing and providing illustrations of the Build Change Case Study. The Build Change Case Study is suitable for this study because its working model relies on building local capacity for housing supply. This means educating homeowners about the importance of safe home construction and training local stakeholders to build (or retrofit) a disaster resistant housing stock. Build Change partners with local governments in order to encourage the use of subsidies and donor grants for safe housing construction.

Chapter 7 is organized as follows: Section 7.1 introduces the chapter and describes the importance of safe house construction to reduce the vulnerability of informal settlements. Section 7.2 corresponds to the research methodology. Section 7.3 and 7.4 describe the origins of Build Change and its purpose. Section 7.5 and 7.6 explain the working model of the organization and the way it is implemented. Section 7.7 describes challenges faced by the organization. Section 7.8 describes the results and impact of Build Change’s work. Section 7.9 focuses on describing the organization’s work in Colombia and Section 7.10 corresponds to the conclusions.

7.1 Introduction

The occurrence of natural disasters is increasing. The reason is not necessarily that natural hazards are happening more frequently but rather that communities are becoming more vulnerable. Particularly, the poorest people are the most vulnerable because the development of their settlements is not properly planned and built, which contributes to magnify the scale of impact of any natural disaster. Furthermore, when governmental relief and reconstruction efforts fail, the vulnerability of the poorest increases (Schilderman 2004). Effective post-disaster recovery and housing reconstruction are fundamental to restore affected communities (Barenstein 2006) and to break this vicious cycle (Schilderman 2004).

The possibility of occurrence of natural disasters impacts housing policies. The level of damage to the housing stock results in a recalculation of qualitative and quantitative deficits, and thus a redefinition of housing strategies (UN-Habitat 2015). The quantitative deficits, which may result from significant destruction of the housing stock, is commonly addressed by means of new housing construction. The qualitative deficit, which may result from partial damage to the housing stock, is approached by retrofitting strategies. In Chile, for example, the occurrence of earthquakes results in frequent recalculations of housing needs, which drives the way in which resources are spent in housing construction (Allard et al. 2012, p. 90-94).

Chang et al. (2010) classify post-disaster housing reconstruction approaches according to the influence that different stakeholders have over resources and the project delivery process. In the government/donor-driven resourcing approach resource availability and spending are driven by governmental or donor agents. In the market-driven resourcing approach, the forces and rules of the construction market have a significant influence on resource availability. The construction work is performed by private construction companies. In the owner-driven approach, homeowners receive cash and have the responsibility for building their own houses.

Disregarding the approach adopted, post-disaster reconstruction projects usually fail. In some cases, international organizations have reported more than 50% of failure rate (Ika et al. 2012). Causes of failure are related to financial problems, inappropriate assessment of local needs,
inadequate communication, coordination, resource procurement, ineffective strategy’s design, and corruption (Ismail et al. 2014). Some argue that the root cause of these problems is the centralized way in which governments and relieve agencies manage reconstruction (Schilderman 2004). The traditional way to rebuild has been hiring professional construction companies to build houses for the people. Nevertheless, the experience has shown some limitations and risks associated with this approach leading to the adoption of more participatory strategies (Barenstein 2006).

Decentralized forms of housing reconstruction require involving local communities in needs’ assessments, prioritization, planning and execution (Lyons 2009). It also involves educating the community and building local capacity (Schilderman 2004). Governments and agencies may benefit from community involvement in the process because in many cases the best solutions can be developed in the local environment and using community’s capacity (Özden 2006).

Many organizations have started implementing homeowner-driven approaches for reconstruction (Barenstein 2006). In this approach, the government or donor agency provides funding but is the homeowner or the community who take control of the reconstruction process. In many cases, homeowners work with the support of external financial and technical assistance organizations (Karunasena and Rameezdeen 2010). This is the case of Build Change, a non-profit organization that empowers community participation for safe housing construction.

7.2 Research methodology

The author uses literature review to analyze the housing construction approach implemented by Build Change. He also uses documents, brochures and audiovisual materials available on the organization’s website.

As in the case of Chapter 6, the objective of analyzing the Build Change’s Case Study is to evaluate its adherence to the fourteen Lean Production Principles (Liker 2004). in terms of value generation. Nevertheless, this chapter only describes the Case Study. The adherence of Build Change to the Lean Principles is presented in Chapter 7 along with the other two Cases Studies included in this research.

7.3 Origins of Build Change

In the event of an earthquake, the poorest are the most affected people (Schilderman 2004). Since most housing stock of poor communities is built in the informal sector, the majority of houses do not withstand an earthquake. In the informal sector, houses are built with simple and traditional technology, and residents use their own labor and materials (Hausler 2010). Despite residents having strong control over the design and construction process, the lack of adherence to building codes and regulations (Klaufus and van Lindert 2012) results in unsafe homes. Thus, many lives can be saved and significant economic losses can be avoided by improving the way houses are built in the informal sector. What can be done to help people living in poor communities to build safe houses? (Hausler 2010).

Having this question in mind, Elizabeth Hausler, founder, and CEO of Build Change observed the reconstruction of places that were devastated by the 1993 earthquake in Maharashtra, India (Hausler 2015a). By interviewing homeowners, builders and government officials, she realized many shortcomings of the donor-driven approach used to shelter people (Hausler 2010). Despite housing solutions being structurally safe, the majority of them did not meet the needs and perspectives of the families (Hausler 2015a). For instance, some housing models did not have
windows, thus impeding proper illumination and ventilation. In other cases, housing units had an inflexible design which did not allow residents to make extensions according to family size or style. Even ten years after the earthquake, people were still living outside in improvised structures attached to their property because they did not trust the structural safety of their house. This was the situation because they did not participate in the design and construction process, and did not trust the construction procedures used by the contractor (Hausler 2010; Hausler 2015a).

Convinced that increased homeowner participation may result in safer homes and greater residents’ satisfaction, Hausler progressively developed, implemented and tested a homeowner-driven model for housing construction. In 2004, aiming to scale up her initiative, she founded Build Change (Hausler 2010).

7.4 About Build Change

Build change is a non-profit social enterprise that works with people in developing countries to build houses and schools that do not collapse in the event of earthquakes and typhoons (Hausler 2015b).

According to Hausler (2015b), the organization tries to address two main issues. The first issue was to reduce the number of deaths and economic losses resulting from natural disasters. The belief is that it is not the natural disaster that produces the deaths, but the collapse of a poorly built and unsafe buildings. The second issue was to improve the way governments and agencies approach post-disaster reconstruction. Commonly, the donor-driven approach uses subcontractors who build a large number of houses for people, leaving little room to build local skills or improve the local economy. Furthermore, this approach does not consider homeowners in the design and construction process.

7.5 Working model

Hausler summarizes Build Change’s working model as “teaching how to fish instead of giving away fishes.” In other words, instead of building houses for people, Build Change works with homeowners during the process, supporting them in the process of designing and building their own safe home (Hausler 2015a). Thus, Build Change does not build houses on behalf of people, nor it does provide financing for people. Financing usually comes from the communities or owners themselves, from loans, from government subsidies, or from donor grants. The role of the Build Change organization is to ensure that funds are used for buildings that meet code requirements (Wesseler 2015), creating a demand for safe home construction that must be satisfied by the private sector (Hausler 2015b).

Figure 7-1 illustrates that, after more than a decade of experience working in developing countries in Asia and Latin America, the organization has discovered three aspects that are crucial for the well-functioning of its homeowner-driven approach (Hausler 2010):

Technology: The housing solution must use a technology that is locally available. The architecture style and specifications must be in alignment with the local context. It should take into account, for instance, the local culture, builders’ capabilities and availability of materials.

Money: The housing solution must be affordable by the poorest. Homeowners will build a safe house only if they have enough resources to do so. In this aspect, proper accesses to financing and financial incentives to encourage safe housing construction are key in the model.
People: Someone has to want a house safe in order to create a demand for safe construction. In this aspect, the model includes education people, builders, and governmental agencies about the importance and implications of safe house building. In addition, the design of housing solutions should have a connection with people’s needs.

Figure 7-1: Build Change model (Wesseler 2015)

7.6 Implementation steps

Build Change’s working model touches the ground by following seven steps (Hausler 2010):

Step 1: Learn first.

The organization researches buildings affected by earthquakes, aiming to understand the reasons for their collapse. The purpose is to use this learning to improve the design of future houses. The organization has conducted 12 post-earthquake studies in 6 developing countries. Based on this data, the organization concluded that safe construction depends on three main aspects.

1) Configuration. It has to be simple, square and symmetric.
2) Connections. Foundations have to be properly connected to the upper structure and the roof. Similarly, confining elements must be properly tied.
3) Construction quality. Concrete blocks must be fabricated with proper materials and contain enough cement. They have to be properly cured in order to be a resistant final product. In the construction process, masons must totally fill the joints between blocks. Figure 7-2 is an example of this type of assessment.

Step 2: Research and design for earthquake-resistant houses.

Build Change realized that it is easier to improve a well-known existing construction technology than introducing a new one. For this purpose, the organization develops local sub-sector studies in order to work with a housing technology and design that best fit the local context. The solution should be disaster-resistant, sustainable and affordable.
Step 3: Build local capacity.

The construction of safe homes involves the coordination of many stakeholders and the generation of local capacity. This is mainly achieved by education people. Local engineers should learn how to design a safe house. Local suppliers should learn how to produce high-quality materials and builders should know to materialize the project properly. For instance, Build Change’s local engineers and master masons conduct workshops for homeowners and builders on the site. They also work with local material producers in order to help them to improve the quality of their products while sustaining their profits. In Figure 7-3, they also developed design and construction manuals that are tailored to local practices and are easy to understand.

| Confined masonry house under construction, insufficient connections | Zoom-in view of ring beam – column connection |
| Zoom-in view of beam without connection | Insufficient connection between column and beam |

Figure 7-2: Observations of the effect on houses of the 2006 Central Java earthquake (Build Change 2006)

Step 4: Stimulate Local Demand.

Homeowners should want the house to be earthquake resistant. Nevertheless, how to convince a rural homeowner with limited resources to invest more in the construction of a safe house? Thereby, the approach should be affordable and easy to implement on the field. In order to make it easier and affordable, Build Change creates simple building guidelines, develops training seminars, and inspection systems that can be implemented in regions with limited infrastructure, budget, and personnel.
Step 5: Facilitate access to capital.

The role of Build Change is not to build houses or pay for materials, equipment, and labor. In most cases, funding for the projects comes in the form of grants from governments or relief agencies. In the case those funds are insufficient, Build Change partners with financial institutions so homeowners have sufficient funding to build safely. The main role of the organization is to encourage the spending of these resources for safe home construction.

Step 6: Measure the change.

Build Change field staff monitors and evaluates the projects in different ways. They document, for instance, the changes required by homeowners and their recommendations. This allows the organization to have detailed records of customer preferences that can be used for future designs. For training programs, they use tests to assess how people’s skills have changed after training programs. The ultimate test will be an earthquake in the area where they have worked.

7.7 Challenges

The working model developed by Build Change is a result of more than ten years of experience (Hausler 2004; Hausler 2005; USAID 2012). In this process, the organization has identified and addressed several challenges for the implementation of its working model.

7.7.1 Design standards

Designing and building safe homes require the enforcement of building codes and standards. Nevertheless, in some developing countries, this code does not exist or may not be relevant for the type of construction used for single family housing. For instance, regulations may exist for multi-story buildings, but the application of such criteria to single family housing may result in a conservative and thus expensive design (USAID 2012). In addition, if the code is hard to change,
it may prevent the implementation of small modifications that can make houses more affordable while keeping safety standards (Hausler 2015a).

In the absence of local code, it is recommendable to adopt international regulations (USAID 2012). However, the adaptation of international codes should consider the local context. The code may assume certain conditions that are hard to achieve in the field. For example, in Indonesia, the weather is extremely hot and during bricklaying, the high temperature of bricks tends to absorb the humidity of the mortar before it has achieved its required resistance. This results in a structural element in which bricks are not tight together. The resistance of the structural elements also depends on the resistance of bricks. In some cases, because of quality issues in the production process, bricks or cement blocks do not have the resistance required by the code (Hausler 2015a).

Consequently, the application or adaptation of building codes and standards in many developing countries requires the use of judgment. Such judgment should be based on a first-hand assessment of site conditions. A small change in design criteria and construction guidelines can make a significant difference for safe home construction. For example, in the Indonesian case, teaching local masons to soak the bricks before laying them out may result in significant improvement in the resistance of a structural element (Hausler 2015a).

### 7.7.2 Suppliers and quality of materials

An important aspect of Build Change’s working model is the creation of local capacity which includes encouraging the demand and supply of quality construction materials for safe home construction. For example, in Haiti, the standard set a minimum compressive strength of 10 megapascals for cement blocks. Nevertheless, randomly tested blocks only reached an average of 4.45 megapascal. Experience in the field revealed that with little investment, local producers can significantly improve the quality of blocks at an affordable price (Build Change 2012).

The first step in creating a proper supply of quality materials is encouraging demand for them. Thus, Build Change educates the consumer in order to convince them to buy higher quality, more expensive materials (Hausler 2015a).

In terms of demand, in many cases, local providers do not have the capacity to produce quality materials. Local providers produce at a low scale and work with limited cash flow. Such working conditions impose barriers for the production of high-quality materials (Hausler 2015a). For instance, in order to create a good bond between cement and aggregates particles, cement blocks require more than eighteen days of curing (Build Change 2012). In other words, small producers are required to hold inventories for almost a month before they can sell it. This is a challenge because, with limited cash flow, small businesses are unable to start producing a new batch until they have sold the previous one. In order to produce quality cement blocks, they need access to capital, but they cannot access to financing because they don’t have the collateral required by financing institutions (Hausler 2015a).

It is also important to create a consistent demand for quality materials. For instance, a producer may know how to produce high-quality blocks but may choose not to produce them because of low demand (Build Change 2012). In other experiences of reconstruction in Indonesia, Build Change’s projects rejected materials that did not meet quality criteria. Nevertheless, the demand was so high that instead of fixing the quality of materials, suppliers decided to deliver them to projects managed by other agencies with less strict quality controls (Hausler 2010, p. 99).
7.7.3 People and construction

In many developing countries there is not enough enforcement of building codes or standards; one reason is that governmental agencies do not have enough capacity to oversee all projects (Pazdon 2016). This is the reason why educating local people in safe construction is key. For a small project in rural areas, for example, it may be hard to implement a testing facility. Thus, Build Change trains homeowners and builders to perform quality tests on their own. In Figure 7-4, Build Change instructs people about how to visually recognize adequate material for construction. Similarly, at the bottom, they show how to test the resistance of brick and cement blocks quickly (Build Change 2016b). In practice, these small onsite quality controls can push the providers to improve the quality of their products (Hausler 2015a).

7.8 Results and impact

In the ten years since its creation, Build Change has worked in 10 countries helping to build more than 46,000 safer houses and schools improving the welfare of 230,000 people (Build Change 2016c). Build Change mitigates risk but also promotes safe construction activity and promotes local growth (Build Change 2015). Build Change’s staff has trained more than 23,000 people and created around 10,500 jobs. They have been able to partner with 17 governments and 67 others NGOs (Build Change 2016c)

7.9 Colombia: the evolution of the model

The working model used by Build Change has evolved over time. It shifted from a direct service approach to a system change approach (Hausler 2015a). The organization has also started
implementing retrofitting strategies to reduce the vulnerability of the housing stock before a natural hazard happens. This is the case of the work Build Change started in Colombia.

In Colombia, as in many other Latin American countries, irregular settlements have spread everywhere. In this country, 60% of new homes are built in the informal market (Hauser and Caballero 2015). Since most of this stock was built without considering building codes or standards, most likely it will not withstand an earthquake. This situation puts nearly 15 million people in a very vulnerable situation in the occurrence of a natural disaster (Swisscontact Colombia 2016)

In order to address this issue, Build Change partnered with SwissContact and Colombia’s “Servicio Nacional de Aprendizaje” (SENA: National Learning Service) to train local labor and builders in retrofitting methods (Build Change 2016d). The work focuses on following areas (Swisscontact Colombia 2016):

1. Identify good practices and develop technical solutions.
2. Increase the population’s and interest groups’ awareness about the importance of safe construction.
3. Develop local capacities of the labor force in the informal sector.
4. Develop partnerships for the replication of this experience in other settlements.

Build Change focuses on providing technical assistance to agencies that distribute government subsidies for housing improvements. The homeowner receives the subsidy and it is up to him or her to buy the materials and to select a builder from for safe home construction within Build Change’s program framework (Wesseler 2015).

The Colombian government awards a $5,000 subsidy to homeowners. The most difficult part is to convince low-income homeowners to spend this money on safe construction. They are tempted to improve their house, for example, by building an extension or improving finishes. If they have to use $5,000 for retrofit, most probably they will not see any aesthetic or architectural improvement in the house, but it will make it more resilient in the event of a natural disaster (Gerdes 2014).

7.10 Conclusions

Build Change deploys an innovative homeowner-driven housing provision and upgrading model that integrates the capacity of communities into the project delivery process. Communities are integrated into this model not only at the design stage but also in procurement and construction activities. Thus, the model has a double impact. First, it enables low-income people to have access to an affordable and safe housing stock that meets their needs. Second, it contributes to boosting the local economy by using resources (DHS or donor grants) to hire local suppliers and labor force.

From a housing policy perspective, resources for housing construction are put in the hands of the homeowners instead of private developers. This is a significant difference with typical developer-driven approaches used under the DHS policy. Having the homeowner drive the design and construction process may result in a longer or unfinished project. This usually happens when funds are not enough for a disaster resistant home. For large scale relocation projects a more developer-driven approach may be recommended. However, this approach should consider some type of homeowner participation in the design and construction process (USAID 2012).
Build Change’s working model addresses some of the shortcomings of mass housing production, first, by enabling beneficiaries’ involvement in housing design, and second, by favoring construction in the same site over relocation. In terms of efficiency, one may assume that customer involvement and increased customization of housing solution may affect the affordability of this approach. Nevertheless, surveys conducted by the organization demonstrate that this approach is cheaper than new housing construction and transitional shelters (Build Change 2014a).
CHAPTER 8 CROSS-CASE ANALYSIS

Chapter 8 presents the Cross-case Analysis based on the fourteen TPS principle. It is organized as follows: Section 8.1 presents the considerations for the Cross-case Analysis. Section 8.2, 8.3, and 8.4 examine the Case of Villa Hermosa, Quinta Monroy, and Build Change respectively. Section 8.5 presents the summary and conclusions of the chapter.

8.1 Considerations

In this chapter, the author links the Case Studies to the fourteen TPS principles by describing the way the practices adhere to the principles. This section includes concise examples of these practices but further details can be found in their corresponding chapters 5, 6 and 7. If a Lean Principle is not listed, it means the author could not find a reasonable connection between the Case Study’s practices and that principle.

8.2 Villa Hermosa

Principle 1: Base your management decisions on a long-term philosophy.

Villa Hermosa aimed to deviate from traditional mass housing construction by avoiding excessive standardization and architectural monotony. The owner and initiator of the Villa Hermosa project wanted to deliver a mixed-income housing project while meeting two main goals: 1) to design a project with a beautiful architecture and identity, and 2) to allow customers to select some features of housing units according to their budget (Ernesto Weisson, personal communication, March 15, 2014).

Having a broader variety of housing models allows the developer to reach a broader range of customers with different socio-economic backgrounds (only some receiving a housing subsidy) which avoids segregation by income. Customers may benefit from an improved housing design and customization while the same time Villa Hermosa takes a competitive advantage in the local housing market.

These goals drove key organizational decisions. Providing an improved architecture and enabling customization at an affordable price require the implementation of an efficient production system. Affordability is important for two reasons. First, the price of housing units targeted to low-income households should be below the threshold of “affordability” defined by the government. Only units below this threshold (or target cost) can participate in government housing programs. In other words, beneficiaries of subsidies are allowed only to purchase houses which are below the target cost. Second, in terms of competition, the company is aware of many other projects targeting the same market segment but using a mass production approach. Thus maintaining prices as if they were mass producing houses is fundamental for keep the company competitive.

An example of long-term thinking is in the implementation of CBA for formwork selection. In this case, the developer favored acquiring a more expensive formwork system, choosing a long-term partnership with the formwork supplier over short-term cost savings.

Principle 2: Create continuous process flow to bring problems to the surface

The reduction of non-value added activities from the production system is fundamental to create a continuous flow (Ohno 1988). By implementing Interactive Plan and the Production Tracking Application, the developer automated some tasks that were initially performed manually without
adding value to the process. For example, by reducing non-value added activities Interactive Plan speeded up the flow of information regarding customer orders from sales points to the construction team which favors a continuous process flow. For the construction work, the Production Tracking Application allowed the team to visualize the production flow of construction crews serving as the baseline to identify areas in which this flow can be improved.

**Principle 3: Use “pull” systems to avoid overproduction.**

By allowing customization, the developer favored the implementation of pull systems. This means producing housing models based on customer orders, or Build to Order (BTO). This approach is the opposite of the Build to Stock (BTS) approach commonly used in mass housing construction. For example, Villa Hermosa uses Interactive Plan to capture and manage customer orders which facilitate the implementation of a “pull” system.

**Principle 4: Level out the workload (heijunka).**

The construction team uses information from Interactive Plan to define the sequence of the construction work and to balance production. The construction work is planned based on the mix of housing models per block, availability of crews and formwork sets.

In Figure 8-1, every square represents a lot number within a block, the color of a square reflects the corresponding housing models, and the red arrow outlines the sequence defined for construction crews. In Figure 8-2, the pattern of the construction sequence changes after completion of lot number 12. After lot 12, the construction team decided to continue in the order 06 → 11 → 10 → 09 → 07 → 08 (instead of the expected 11 → 06 → 07 → 10 → 09 → 08), favoring the execution of three consecutive housing models (the light blue squares marked 11, 10, and 09 correspond to the “Linda” model), that is: “batching” them.

![Figure 8-1: Planning board](image)
Nevertheless, this judgment is followed only inside blocks but not among blocks. For instance, blocks 5A and 5B have several yellow models (“Hermosa” model) but the construction team, in this case, does not favor the production of yellow models because it requires moving tools and material back and forth from one block to another, which is perceived to not be an efficient strategy.

Principle 6: Standardized tasks and processes are the foundations for continuous improvement and employee empowerment.

The developer standardized the formwork system thus reducing the time required for construction crews to erect and dismantle different housing configurations. Furthermore, this reduced the number of processes steps in the concrete operations. However, aiming to build houses that resemble the local colonial architecture, the developer also designed each house’s facade with concrete molding details (see the arrows in Figure 8-3). Such architectural details add beauty but at the same time, extra process steps to the construction work. During the construction of show houses, the construction team had to execute molding work after placing the concrete and assigned an extra crew, especially for this purpose which was time-consuming and costly. To limit the process cost of this product design, formwork components were incorporated into formwork design using molding details. Figure 8-4 shows those molding details and the results after placing concrete. As a result, molding work is performed at the same time as placing concrete on walls and slabs. Molding activities are thus reduced to quality control after formwork dismantling. In some cases, they require minor plastering work to improve surface finish.
**Figure 8-3: Molding in facades**

<table>
<thead>
<tr>
<th>Formwork system components for molding details</th>
<th>Molding in a wall’s side</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Formwork system components" /></td>
<td><img src="image2" alt="Molding in a wall’s side" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Molding in a corner</th>
<th>Molding below window opening</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Molding in a corner" /></td>
<td><img src="image4" alt="Molding below window opening" /></td>
</tr>
</tbody>
</table>

**Figure 8-4: Molding incorporated in the formwork system**

**Principle 7: Use visual controls so no problems are hidden.**

The developer uses visual controls for project planning and control. For planning, Interactive Plan depicts houses models according to color codes. This information is used in weekly planning meetings (Figure 8-1 and Figure 8-2).
Figure 8-5 depicts boards implemented in the construction site for planning and control urban infrastructure work (i.e., potable water and sewer systems). The project site is divided into sectors (black marker) in order to plan the location in which different crews should work without interfering with each other. Sheets of transparent acrylic and non-permanent markers are used to plan and track the progress of activities. Green represents completed work and blue corresponds to activities that must be executed during the week.

![Figure 8-5: Example of visual controls for planning](image)

In Figure 8-6, completed work is updated on a weekly basis before planning meetings. Using the boards, the construction team assigns work to the different crews based on the locations.

![Figure 8-6: Weekly planning meetings (left) and team members updating information on boards (right)](image)

The construction team also uses color codes to ease formwork operations. In Figure 8-7, formwork sets are labeled with different colors. Blue on the left and red on the right help workers to recognize panels that belong to one or another set thereby avoiding mixing the inventory.
Similarly, in Figure 8-8 internal and external formwork panels are distinguished by red and blue color code correspondingly. Workers are aware that the red colored panels should go in the interior and blue in the exterior. This helps formwork crews to identify the correct position of panels and to avoid mistakes while erecting formwork.
Moreover, in the Production Tracking Application, construction activities and data collection procedures are standardized in order to capture data from the field by locations on a daily basis. This serves as a reliable source of data to visualize the flow of production and to compute average production times for activities. The consistency in data collection is considered as a baseline to measure the impact of future countermeasures to improve the production system based on Plan-Do-Check-Act cycles.

**Principle 8: Use only reliable, thoroughly tested technology that serves your people and process.**

The company developed two IT tools that facilitate the implementation of a customization strategy. During the development of these tools, members of different departments were invited to participate in order to include their inputs in the features and capabilities of the IT tools. It was the belief of the organization that the IT tools should facilitate organizational processes but also have a connection with the people who will use them.

**Principle 13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.**

The CBA implementation for formwork system selection involved several stakeholders in the decision-making process. The purpose was to consider as many perspectives as possible in the decision-making process in order to select an alternative that best suits the context of the project. The team was able to reach some degree of consensus and selected an alternative that benefited the project in many aspects. Cost savings, reduction of formwork inventory, and the incorporation of molding details into formwork design are some examples of the benefits of making decisions collaboratively.

Similarly, the development of the IT tools relied on the participation of end-users which also required making decisions collaboratively. For example, the list of activities considered in the Production Tracking Application as well as the features of its interface for mobile devices was a matter of significant debate among team members. In this process, it was necessary to balance the prerequisites required by the IT tools to suffice the process against the features and functions desired by different team members. Such balance was achieved by exploring the advantages of different alternatives and by reaching consensus among team members.

**Principle 14: Become a learning organization through relentless reflection (Hansei) and continuous improvement (Kaizen).**

The CBA implementation allowed the team to document the decision-making process for formwork selection. Such documentation allows the organization to learn from the decision-making process and to revisit the CBA table to assess if the selected alternative performs according to the expectations. For example, the team may decide to check if the attribute for Factor 8: “number of accessories per m2” matches what is being experienced at the construction site.

Interactive Plan collects significant data about customers’ preferences in housing configuration which offers the developer a great opportunity to learn. For instance, the developers can evaluate to stop offering models that are not selling well, or to replace them with new ones according to customers’ preferences. Figure 8-9 depicts a sample of nearly 500 transactions in Interactive Plan that shows the popularity of some houses models (i.e., model “Casa Hermosa”) and the unpopularity of others (i.e., “Casa Radiante”).

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Figure 8-9: Sales by house model

8.3 Quinta Monroy

**Principle 1: Base your management decisions on a long-term philosophy.**

Many management and design decisions in the affordable housing market are driven by the trade-off between affordability and profitability. Developers should deliver housing at an affordable price for low-income buyers while at the same time maintain profitability. In some cases, communities living in irregular settlements get displaced to the periphery of their city where land is cheaper, separating them from urban services. In other cases, the size of housing units is reduced, leading to overcrowding conditions.

In terms of location, residents can’t do too much to improve their situation. Nevertheless, in order to increase their living space, families tend to build their own expansions modifying and adapting housing designs (Aravena and Iacobelli 2012). The proliferation of irregular settlements and the examples shown in Figure 8-10 demonstrate that low-income communities have the capacity and creativity to build their own space.
Incorporating the building capacity of the community into the project delivery process required making organizational- as well as design decisions based on long-term thinking.

In terms of organization management, the government created the adequate housing policy framework that facilitates coordination among stakeholders and expands the support to the community beyond solely house provision. For example, the government extended its network of support to the community by providing assistance to potential buyers needing to obtain low-interest loans to purchase construction materials to build the extensions after delivering the core house. In terms of design, the Quinta Monroy design team considered short and long term objectives. In the short term, they considered delivering a core house within a target cost of $7,500 per house. In the long term, they included guidelines and standards for post-construction that allows residents to build extensions incrementally according to their needs and without damaging the urban environment.

**Principle 6: Standardized tasks and processes are the foundations for continuous improvement and employee empowerment.**

Since houses would eventually double in their original size, the design of the project included different standards to guide residents in performing expansions harmoniously without damaging their urban environment.

Key structural elements of the core house were built with solid materials such as reinforced concrete and cement blocks. In contrast, modifiable divisions like internal walls were built with less solid materials like wood panels. The use of solid concrete elements in façades in which the design does not consider expansions discourages expansion in that direction. Although not impossible, in terms of cost and effort it will be infeasible for residents to demolish these walls for expansion purposes. In contrast, wood panels are easier to remove thus, residents are more likely to follow this direction to build expansions, plus they may even reuse these materials.

Since expansions should be safe and affordable, the design also included some considerations of economy. The original design of the “second half” included key structural elements thus, the budget for expansions minimizes the inclusion of expensive items like reinforced concrete or steel. Furthermore, lengths and widths of the spaces designed for expansion are intended to match...
standard sizes of common construction materials like wood and gypsum board. This allows residents to maximize their efficiency in construction material use.

**Principle 10: Develop exceptional people and teams who follow your company’s philosophy.**

Commonly, affordable housing is associated with lack of resources, bureaucracy, lack of options and thus, bad projects. This results in the limited interest of design and construction professionals to work in this field. Most professionals working in affordable projects perceive what they do as “charity work.” Elemental wanted to change that perception by expanding the spectrum of reasons why professionals should be interested in affordable housing. They began disseminating the idea that producing high-quality architecture and construction projects under limited resources is one of the hardest challenges for a professional in this area. Thus, it requires talent and capacity instead of merely generosity (Aravena and Iacobelli 2012). For example, the Quinta Monroy project had an exceptional professional team with an educational background from the Catholic University of Chile and Harvard University.

**Principle 11: Respect your extended network of partners and suppliers by challenging them and helping them to improve.**

Illegal settlements are commonly seen as urban malformations that should be totally eradicated from cities. This notwithstanding, the community at Quinta Monroy—instead of being evicted—was considered a valuable stakeholder in the project delivery process.

The project started by respecting the desire of the community to settle on the same site. In fact, many of the project constraints arose because of the high cost of this well-located site. Respect for the community was also reflected in the design team’s efforts to consider their ideas and perspectives and incorporate them in the project’s design.

At the same time, the community was challenged to improve their living conditions. They were required to deploy their construction capacity and creativity to eventually build the “second half” of the development by following the directives included in the design. Thus, the community is incorporated in the project delivery as an extension of the production system.

**Principle 12: Go and see for yourself to thoroughly understand the situation.**

In order to assess community needs, the Quinta Monroy design team conducted several workshops on the site. One of the best examples of the outcome of this work is the definition of courtyards’ distribution and size. The original design considered building the houses on the perimeter of the site with one centered common courtyard for all the community (Aravena and Iacobelli 2012). Through several workshops and design meetings the community transmitted that, instead of being a community of 97 families, they were actually better organized into four smaller groups. By capturing this information, the design team was able to come up with a solution that included four sub-neighborhoods and the families were grouped according to their common interests.

**Principle 13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.**

Most of the decisions at the design stage were made in conjunction with the community by voting. Community members were informed about the benefits of the different alternatives during the decision-making process. For example, community members had to choose from including a water
system in housing design and the location of the development. The cost of including a water heater reduced the availability of money to pay for land, which endangered the possibility to build the project on the same well-located site (Aravena and Iacobelli 2012). Staying on the same site allowed community members to keep their jobs which may provide them the financial stability to buy and install a water heater in the future. In contrast, if they move to another site (i.e., Alto Hospicio) and get a water heater, they may lose their jobs or spend more money on transportation so that they would not have enough income to pay for the energy required to operate the water heater. The design team helped to inform the community about the consequences of their decisions and encouraged them to make them based on long-term thinking. In this example, the community unanimously favored buying the land.

8.4 Build Change

**Principle 1: Base your management decisions on a long-term philosophy.**

Built Change aims to reduce the number of deaths and economic losses resulting from natural disasters and to improve the way governments and relief agencies approach reconstruction.

The belief is that the scale of natural disasters is amplified because of the poor design and construction of the housing stock. Thus, the organization intends to tackle the root cause of the problem by introducing positive changes in construction practices that favor safe home construction.

The philosophy of the organization is that introducing positive and permanent changes in construction practices relies on educating house building stakeholders about the importance of safe home construction, as well as the generation and use local communities’ capacity to build a disaster-resistant housing stock.

**Principle 3: Use “pull” systems to avoid overproduction.**

Build Change realized that one of the reasons of the lack of supply of material with proper standards for safe housing construction was the lack of demand for them. For this reason, Build Change educates homeowners about safe housing construction which create the necessary “pull” to incentivize suppliers to produce higher quality materials.

**Principle 5: Build a culture of stopping to fix problems to get quality right the first time.**

Build Change teaches homeowners to identify quality defects in construction materials. This allows them to build houses only with material that meet the required quality standards. With this approach, homeowners are empowered to stop the construction process when material do not meet the required standard.

**Principle 6: Standardized tasks and processes are the foundations for continuous improvement and employee empowerment.**

Build Change may face dissimilar conditions and challenges in the different countries where they work. Despite such differences in conditions, based on many years of experience the organization has developed a standardized step by step working plan that serves as a guideline to consistently implement intervention plans in different locations (Hausler 2010, p. 108 - 109). Build Change has grown over time and the lack of a standardized working plan may lead team members working in
different locations to approach reconstruction in dissimilar ways. The working plan serves as a roadmap for operations as well as a baseline to identify the causes of success and failures or to identify aspects in which it can be improved.

**Principle 7: Use visual controls so no problems are hidden.**

In order to educate stakeholders about safe home construction, Build Change distributes various posters and brochures. For example, some of these materials help homeowners to identify the quality of construction materials by performing visual inspections. In other cases, visual aids aim to address the lack of technology to perform quality controls. For instance, some brochures instruct people to test the resistance of concrete blocks by dropping them from a certain height and based on a simple break-or-not-break outcome. Several videos, booklets, and posters created by the organization for different developing countries are available in organization’s website (www.buildchange.org).

**Principle 8: Use only reliable, thoroughly tested technology that serves your people and process.**

The organization has to handle a significant amount of information including photographs, training programs data, and homeowner’s preferences and compliance rates. Build Change uses this information in order to measure its impact as well as to learn from the communities. Collecting and processing data in a small project could be easy but the growth and globalization of the organization have significantly increased the amount of data that has to be collected, centralized, and analyzed. In order to facilitate this process, the organization is switching to digital data collection supported by electronic devices (Build Change 2014b).

**Principle 9: Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others**

The Build Change working model has evolved over time. The organization shifted from assisting people in reconstruction projects to acting as a system-change driver. Driving change is complex and it requires the deployment of professionals with significant expertise and knowledge about their fields. The organization has learned that in order to drive changes, expertise should be combined with leadership and courage. Thus, the organization’s working model requires the development of people with outstanding expertise, leadership, and courage that follows and exercise organization’s philosophy at all levels, from regional managers till construction foremen and workers (Build Change 2016e).

**Principle 10: Develop exceptional people and teams who follow your company’s philosophy.**

Build Change’s working model relies on the creation of internal and external teams that follows and practice their organization’s philosophy. Internally, the organization works with engineers, architects, and seasoned masons and carpenters with technical excellence to design and implement safe construction approaches. Through training programs, the internal team transfers the organization’s philosophy and practices to the external team, namely the local community that acts as an extension of Build Change working model. The transfer of knowledge from the internal to the external team allows the organization to drive a long-lasting change in construction practices. For example, Build Change engineers and seasoned masons conduct training season in the field to teach the local community about safe home construction. Once Build Change intervention is over, the learned skills and knowledge remain in the community.
There is a significant difference between this approach vs. the centralized mass housing construction approach. In the mass approach, construction companies build houses for the people. Once they leave, the community has a roof, but no skills, nor learning. In contrast, the Build Change approach provides the roofs, skills, and knowledge at the same time, resulting in a multidimensional and long-lasting impact on local communities.

**Principle 11: Respect your extended network of partners and suppliers by challenging them and helping them to improve.**

Building safe homes creates a demand for high-quality materials. Build Changes realized that in some cases, the local economy is not able to provide materials that meet standards for safe home construction. For example, local suppliers in rural areas do not have the knowledge to produce resistant cement blocks. In other cases, suppliers may have the knowledge but lack proper funding to run a factory with higher production standards.

How can a homeowner build a safe home if the required materials are not available or not affordable? Build Change realized that introducing positive change in construction practices requires the contribution of the local network of stakeholders, including suppliers, the private sector, and the government. For instance, the financial sector can offer loans at affordable interest rates to small materials suppliers so they can improve their operations producing higher quality materials. Similarly, the government can participate in this model by helping Build Change to scale up safe construction initiatives.

**Principle 12: Go and see for yourself to thoroughly understand the situation.**

The creation and evolution of Build Change’s working model is a result of significant field experience. Before founding Build Change, Elizabeth Hausler traveled to areas affected by natural hazards in order to work with local communities in reconstruction projects. In those experiences, she talked directly to the affected communities, government officers, and relief agencies which provided her a deep understanding of the situation. Resulting from these experiences, she developed and tested a reconstruction working model that addresses the shortcomings she identified by direct observation. In addition, she is a skillful bricklayer. Her hands-on experience in conjunction with her expertise in civil engineering contributed to developing a working model that addresses practical issues in masonry construction, which is a widely used construction technology, especially in developing countries.

**Principle 13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.**

Before making any decision about the approach for retrofitting or reconstruction, the Build Change team researchers design for disaster-resistant houses. They analyze the local construction sector and communities in order to implement a solution that best fits the context. For example, in West Sumatra, the organization first asked the community if they wanted to count on the assistance of Build Change (Hausler 2010, p. 101). Furthermore, in some cases, decisions about housing architecture and structure are made in conjunction with the community. In West Sumatra, homeowners were asked about the type of structure they preferred for their houses based on the available local construction technology.
**Principle 14: Become a learning organization through relentless reflection (Hansei) and continuous improvement (Kaizen).**

Learning is part of Build Change because its working model starts with “learn first” and finalizes with “measure the change.” In the learn first step, the organization research the structures post-disaster in order to discover the main causes that led them to fail or withstand the impact that occurred. They use this information to improve the design of the houses they offer to homeowners. Furthermore, when they finish working on a project, the organization collects data about the community’s preferences regarding housing style, structure, and architecture in order to improve future designs. Likewise, they use tests to measure the impact of training programs by assessing how people’s skills have changed from before to after the intervention.

**8.5 Summary and conclusions**

Table 8-1 summarizes the results of the Cross-case Analysis. The Villa Hermosa Case Study focuses on the process while Quinta Monroy and Build Change focus on people and partners. These results are convergent with what has been discussed about centralized and decentralized approaches to affordable housing provision.

On the one hand, Villa Hermosa adopts a centralized approach. Although the developer involves the customer in project design by allowing customization, the input of residents comes nearly at the end of the design process. On the other hand, Quinta Monroy and Build Change adopt decentralized approaches. Here, the customer (or resident) is involved in project design from project conception. In addition, it is interesting to see how residents take part in the production process by being directly involved in construction activities. Particularly in the Case of Build Change, local stakeholders, including material suppliers are also integrated into the model trying to maximize the use of the local economy and having an effect the goes beyond the sole provision of housing.

The Quinta Monroy and Build Change models would be hard to implement in large scale projects. However, it would be interesting to develop a model in which centralized and decentralized approaches for affordable housing construction can be combined, aiming to maximize the positive aspects of all of them. For example, Quinta Monroy and Build Change may benefit from the efficiency gained in the production process at Villa Hermosa. Likewise, Villa Hermosa may benefit from using the building capacity of their clients and better developing and using local partners. Villa Hermosa could include extensions in their designs, so residents can take over after project completion. Especially the empty cells in Table 8-1 serve to promote new thinking to improve the delivery of affordable housing.
Table 8-1: Summary

<table>
<thead>
<tr>
<th>Philosophy</th>
<th>Villa Hermosa</th>
<th>Quinta Monroy</th>
<th>Build Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P1</strong></td>
<td><strong>Base your management decisions on a long-term philosophy.</strong></td>
<td><strong>Incorporates the creativity and building capacity of the community in the project delivery process to address the constraints in terms of time and money in affordable housing provision.</strong></td>
<td><strong>Improves design and construction quality of housing stock in order to reduce the impact of natural disasters by introducing positive change in construction practices which are based on the use of local knowledge and capacity.</strong></td>
</tr>
<tr>
<td></td>
<td>Delivers a mix-income housing project with improved architecture and allows customers to select some features of housing design.</td>
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<td></td>
</tr>
<tr>
<td><strong>P2</strong></td>
<td><strong>Create continuous process flow to bring problems to the surface.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uses Interactive Plan to improve coordination among different departments which favors a faster response to variant customer requirements. Uses Production Tracking Application to visualize the flow of production and to measure activity durations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P3</strong></td>
<td><strong>Use “pull” systems to avoid overproduction.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Implements pull systems to support a customization strategy. The developer produces according to customer orders.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P4</strong></td>
<td><strong>Level out the workload (heijunka).</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plans and the sequence of work and balances the workload according to house model sales mixes per block and the capacity and availability of crews.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P5</strong></td>
<td><strong>Build a culture of stopping to fix problems to get quality right the first time.</strong></td>
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</tbody>
</table>

**Notes:**
- P1: Base your management decisions on a long-term philosophy.
- P2: Create continuous process flow to bring problems to the surface.
- P3: Use “pull” systems to avoid overproduction.
- P4: Level out the workload (heijunka).
- P5: Build a culture of stopping to fix problems to get quality right the first time.
<table>
<thead>
<tr>
<th>People and partners</th>
<th>Villa Hermosa</th>
<th>Quinta Monroy</th>
<th>Build Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>P10: Develop exceptional people and teams who follow your company’s philosophy.</td>
<td>Brings exceptional professionals to address challenging problems in affordable housing design and construction.</td>
<td></td>
<td>Organization’s beliefs and philosophy are transferred to the local community in order to generate a local capacity that supports permanent change.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Villa Hermosa</th>
<th>Quinta Monroy</th>
<th>Build Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>P6: Standardized tasks and processes are the foundations for continuous improvement and employee empowerment.</td>
<td>Standardizes the formwork system in order to ease operations on the site. Standardizes construction activities in the Production Tracking Application enabling consist data collection which serves as a baseline to measure future improvements.</td>
<td>Incorporates different material standards and specification into housing design in order to guide residents to perform extensions at an affordable price and without damaging their urban environment.</td>
<td>Develops a standardized working model which allows the organization to deploy intervention plans consistently in different developing countries and to identify opportunities for improvement.</td>
</tr>
<tr>
<td>P7: Use visual controls so no problems are hidden.</td>
<td>Uses visual controls for planning and control. Color codes formwork components to ease operations and to avoid mistakes.</td>
<td></td>
<td>Uses visual controls to educate the community about safe home construction and to help them perform quality control.</td>
</tr>
<tr>
<td>P8: Use only reliable, thoroughly tested technology that serves your people and process.</td>
<td>Develops tailored IT tools using the input of the people who use it. Uses IT tools to improve processes.</td>
<td></td>
<td>Uses technology to facilitate data collection and processing to measure the Build Change organization’s impact.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>People and partners</th>
<th>Villa Hermosa</th>
<th>Quinta Monroy</th>
<th>Build Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>P9: Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.</td>
<td></td>
<td></td>
<td>The organizational model relies on professionals with strong professional background, leadership and courage to drive changes in construction practices.</td>
</tr>
<tr>
<td>People and partners</td>
<td>Villa Hermosa</td>
<td>Quinta Monroy</td>
<td>Build Change</td>
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</tr>
<tr>
<td><strong>P11: Respect your extended network of partners and suppliers by challenging them and helping them to improve.</strong></td>
<td>Tries to incorporate the perspectives and desires of the community in project design. Recognizes the building capacity of the community and uses it as an extension of the production system.</td>
<td>Tries to incorporate the perspectives and desires of the community in project design. Recognizes the value of local knowledge and capacity by integrating local communities and stakeholders in the production system.</td>
<td></td>
</tr>
<tr>
<td><strong>P12: Go and see for yourself to thoroughly understand the situation.</strong></td>
<td>Assesses the needs of the community by working with them on the field. Translates such needs into project design and specifications.</td>
<td>Organization's working model tries to address reconstruction approaches issues identified through direct observation and interaction with stakeholders.</td>
<td></td>
</tr>
<tr>
<td><strong>P13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.</strong></td>
<td>Makes decisions collaboratively considering the perspectives of different team members and tries to reach a consensus based on a long-term thinking (i.e., formwork system selection).</td>
<td>Informs the community about the pros and cons of alternatives. Makes decisions in conjunction with the community based on a long-term philosophy and considering project's constraints</td>
<td>Tries to integrate the desires of communities in housing design.</td>
</tr>
<tr>
<td><strong>Problem solving</strong></td>
<td>Plans to use information about sales and customer preferences captured in Interactive Plan database to improve housing design in future stages of the project. Analyzes data captured in the field using Production Tracking Application to improve production processes.</td>
<td>Investigates common structural failures in houses to improve the design and to create safe home construction guidelines. Uses homeowners’ data to improve its working model. For training programs uses tests to evaluate how people skills have changed.</td>
<td></td>
</tr>
<tr>
<td><strong>P14: Become a learning organization through relentless reflection (Hansei) and continuous improvement (Kaizen).</strong></td>
<td></td>
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</tbody>
</table>
CHAPTER 9 CONCLUSIONS

The final chapter presents the conclusions of the research and is organized as follows: Section 9.1 answers the research questions. Section 9.2 corresponds to the research findings. Section 9.3 presents the contributions to knowledge and Section 9.4 the generalizability and limitations of the findings. Section 9.5 presents research questions for future work. Section 9.6 proposes a housing provision model and Section 9.7 offers the final remarks.

9.1 Research questions and answers

9.1.1 In terms of value delivery

Q1.1: Is the implementation of a production system for affordable housing construction based on Lean Principles feasible?

In terms of value delivery, this research suggests that the implementation of a production system aimed to deliver customized housing based on the Lean Principles in the context of DHS is feasible.

In the Case Study of Villa Hermosa, Lean initiatives focus on addressing organizational issues resulting from delivering variety (i.e., coordination among departments in terms of planning and control) but the People and Partners dimension of the Lean Principles is not addressed, which is pointed out as a limitation of this part of the research.

The Case Study of Quinta Monroy and Build Change address the People and Partners dimension. These cases provide examples of how the community and local stakeholders can be incorporated into the production system, not only for value generation at the design stage but also as a part of the value delivery process in construction activities. In these cases, it is interesting how customers become co-production agents in the process, collaborating in different stages of the project delivery process, from design to construction, situation that is not seen in the case of Villa Hermosa.

Q1.2: How does the implementation of the Lean Principles contribute (or not) to deliver variety with efficiency in housing production?

The implementation of Lean Principles in housing construction helps to alleviate the negative effect that offering variety has on production systems efficiency; this alleviating effect may have benefits it terms of housing affordability.

In the Villa Hermosa Case Study, the collaborative decision making using CBA facilitates the selection of a formwork system that fits the local context of the project. Subsequently, the standardization process contributes to line up the formwork system and housing design in order to ease concrete-related operations on site. This also reduces the number of formwork system inventory pieces and its upfront cost. Similarly, the implementation of IT tools for planning and control reduces the developer's response time to variant customer orders and the effort required for planning and control activities.

In the Quinta Monroy Case Study, customization occurs by capturing residents’ needs at the design stage and post-occupancy when they build the extensions. The incorporation of some elements in
the design of extensions helps residents to build such extensions more efficiently and at an affordable price.

In the Build Change Case Study, the use of local people and partners (residents and local stakeholders involved in housing production) contributes to delivering affordable housing solutions that fit the local context.

9.1.2 In terms of value generation

Q2.1: How can Lean Principles be used in the design of affordable housing in order to fit the needs of the customers?

In terms of value generation, Lean Principles can be used to capture customer needs or requirements and to translate them into features of housing design that fit customers and the local context.

In the Case Study of Villa Hermosa, value generation is enabled by allowing residents to select some features of housing design. For instance, based on their financial capability residents can decide between more interior space (one to four bedrooms) and improved finishes (basic, medium, or premium features). Thus, residents have some control over design and pay for what they want from the production process.

In the Case Study of Quinta Monroy and Build Change, value generation is enabled by the early involvement of customers in the design process which contributes to design housing solutions aligned with their needs. Particularly in the case of Build Change, value generation also occurs through the study of the local context which enables the design of housing solutions that take advantage of the local economy by integrating local suppliers and newly-skilled builders into the production process.

Q2.2: What are the potential benefits of delivering customized housing for the customers?

Delivering customized housing results in increased residents satisfaction and connection with their home.

In the Case Study of Villa Hermosa, allowing the residents to select housing options may increase their sense of belonging to a place where they will spend a significant part of their lives.

In the Quinta Monroy Case Study, in a survey conducted after eighteen months of project delivery (Aravena and Iacobelli 2012, p. 189) residents evaluated housing features on average with 5.7 out of 7.0 with 7.0 being the best score (i.e., size, built quality, ventilation). The survey also showed that residents were even more satisfied with the expansions than with their core house. This demonstrates that increased resident involvement in the design and/or construction process results in increased satisfaction.

Similarly, four years after its post-earthquake work in Haiti, Build Change highlighted homeowners participation in the design process as one of the greatest contributors to the residents’ satisfaction (Build Change 2014a).

The benefits of resident involvement in housing delivery go beyond their increased satisfaction. In many cases, the disconnection between residents and affordable housing development design results in the degradation of living conditions and of the overall urban environment. This
progressive degradation led a significant portion of the affordable housing stock to decrease its value over time (Rodríguez and Sugranyes 2005). This effect is totally the opposite of what any resident investing in housing would hope for and may expect. Housing subsidies may be one of the biggest contributions a government provides to enable low-income households to access housing. Thus, if the housing stock acquired with government subsidies loses its value, both the government and the households are not benefiting to the extent possible of such investment. In the case of Quinta Monroy, customer involvement in the design and post-project delivery construction contributed to increasing the value of the development and thus the value of the government and customer investment in housing.

9.2 Research findings

Through the analysis of the different Case Studies, the author demonstrated the feasibility and described outcomes of the implementation of Lean Principles while delivering affordable housing construction with DHS in Latin America. Through the Cross-Case analysis, the author compared the Case Studies, highlighting similarities and differences in the housing policy context as well as enablers and inhibitors of Lean implementation.

9.2.1 Housing policy context may help or hinder Lean implementations

The analysis of the different Case Studies demonstrates that the housing policy context can facilitate or hinder the implementation of housing provision models based on Lean Principles.

In the case of Villa Hermosa, dissimilarities in production capacities between the private and public enterprise may hamper the efforts of developers pursuing a Lean strategy. Delays in the approval and revision of project documents or extended time to perform inspections may become inhibitors of continuous flow. The intention is not to exclude governmental oversight but to adapt it, so it facilitates the implementation of Lean. In the case of Quinta Monroy, the implementation of a new approach for housing production with increased resident participation required changes in housing policy. Thus, in this case, it became an enabler for value generation.

9.2.2 Excessive industry fragmentation bars Lean initiatives

The case of Villa Hermosa demonstrates that the integration of the housing design, production system, and supply chain contributes to delivering variety with efficiency. Nevertheless, the reliance of the developer on subcontractors and their competitive relationship hinders the possibility to deploy Lean initiatives that involve people and partners. Since the majority of the construction work is performed by subcontractors, the developer loses governance over resources on site. The developer’s field engineers are mainly overseeing the quality of the construction work but have little power to coordinate human resources or equipment, which hampers the nurturing of a Lean labor force. Developing a skilled construction labor force and creating a context in which laborers can pursue construction as a career, are of long-term importance to improving overall industry performance.

During the fieldwork, the author saw significant opportunities for improvement that can be achieved with little effort and investment, by influencing workers’ behavior or by using better tools or equipment to support the construction work. The author believes that with little investment in this area, significant gains in productivity and overall project success can be achieved.
9.2.3 More stakeholders imply more complexity

This research demonstrates that collaboration among individuals and stakeholders is fundamental to the success of Lean initiatives. Nevertheless, the experience reveals that engaging more stakeholders increases complexity in Lean initiative implementation. The alignment of perspectives towards a superior goal is required to reach some degree of consensus among stakeholders that facilitates Lean implementation.

9.2.4 Engagement of resident and local supplier capacity in housing production

The Case Studies demonstrate that resident involvement in design contributes to delivering housing solutions that better fit their contextual needs. Furthermore, the Case Study of Quinta Monroy and Build Change demonstrate that under an appropriate housing policy framework, residents can take part in construction activities. Residents acting in a co-production role in the delivery of affordable housing may contribute to addressing resources constraints for affordable housing in the region. This is an innovative approach that should be evaluated for scalability.

9.3 Contributions to knowledge

Table 9-1 summarizes the contributions to knowledge of this research by their corresponding chapter.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Reveals issues in affordable housing provision in Chile in terms of the housing product and production processes.</td>
</tr>
<tr>
<td>2</td>
<td>Provides insights about issues revealed in Chile that can be generalized to other Latin American countries.</td>
</tr>
<tr>
<td>3</td>
<td>Provides a rational connection between issues in affordable housing provision in Latin American countries and the potential benefits of using Lean Principles.</td>
</tr>
<tr>
<td>3</td>
<td>Synthesizes literature on the use of Lean Principles and Practices for affordable housing.</td>
</tr>
<tr>
<td>4</td>
<td>Documents Case Studies on the use of Lean Principles to deliver customized affordable housing.</td>
</tr>
<tr>
<td>4</td>
<td>Describes and proposes a novel Information Technology tool aimed to reduce a developer’s response time to variant customer requirements in a housing customization strategy.</td>
</tr>
<tr>
<td>4</td>
<td>Describes and proposes a novel Information Technology tool aimed to facilitate the process of tracking construction progress of customized housing.</td>
</tr>
<tr>
<td>5 and 6</td>
<td>Describes innovative approaches for affordable housing delivery from a Lean Perspective.</td>
</tr>
<tr>
<td>4, 5, and 6</td>
<td>Reveals opportunities and challenges for implementing Lean in the context of Latin America and contributes to understanding how these can improve the efficiency of housing design and construction in the region.</td>
</tr>
<tr>
<td>7</td>
<td>Provides an analysis of how Lean Principles may be implemented in affordable housing in Latin America.</td>
</tr>
<tr>
<td>8</td>
<td>Provides topics for future research.</td>
</tr>
<tr>
<td>8</td>
<td>Proposes a new model of housing provision in Latin America that aims to combine the positive aspects of the Case Studies covered in this research.</td>
</tr>
</tbody>
</table>

### 9.4 Generalizability and limitations of findings

The provision of affordable housing is a worldwide issue. Although this study focuses on Latin America, many of the issues described may also be found in other developing countries. Thus, the findings and contributions to knowledge of this study may be useful for researchers and practitioners outside Latin America.

The author believes that the scale of projects (i.e., the number of houses to be built in a limited amount of time) affects the replicability of the housing provision approaches described in this research. A large-scale project may tend to encourage the implementation of Lean initiatives for value delivery but discourage those for value generation. In terms of value delivery, the large scale of the project in the case of Villa Hermosa facilitates Lean initiatives since it encourages the developer to use long term thinking when making project decisions. For instance, the developer believes that investing more resources in the formwork system or creating IT tools will produce returns in the long-term. In contrast, the initiatives for value generation used in the Case Study of Quinta Monroy may be hard to replicate on a large scale (especially in a short amount of time). Reaching consensus about development and housing design considering a large number of households may be very difficult. Similarly, in the case of Build Change, managing different housing designs for several homeowners may result in substantial design information and variation hard to manage at a large scale. For such value generation initiatives to become scalable, new management approaches may have to be developed and deployed.

### 9.5 Future work

In the course of this research, the author identified areas that require further research.

- What is the scale of projects that enables a positive synergy between value generation and value delivery initiatives?
  - large-scale projects encourage the implementation of value delivery initiatives but may increase the complexity of implementing value generation initiatives.
- How can value generation initiatives be implemented on a larger scale?
  - value generation complexity appears to increase with the scale of the project. Exploring models for efficient value generation may be valuable in this context.
• Who benefits from Lean implementations? The customer? The government? The developer?
  o Value generation (design) and value delivery (construction) generate different outcomes. For example, in value delivery efficiency gains may result in cost savings. Who benefits from those savings?

• How can Lean be implemented for workers in the developing world?
  o Considering the low level of education of the labor force in Latin America, focusing Lean initiatives on educating the labor force has great potential. What are the main challenges and opportunities in this area?

• How do beneficiaries of subsidies prioritize choosing design features for housing customization?
  o When residents have to choose features of housing design, they have to evaluate tradeoffs between alternatives. What do they prioritize? Do they prefer more housing space over improved finishes? Understanding resident preferences may help developers to offer housing sub-assemblies, components, or features that better fit customer needs.

• How can affordable housing developers be encouraged to generate and deliver increased value to the customer in a DHS policy framework?
  o In the search for efficiency gains in production systems, affordable housing developers tend to simplify design or to mass produce housing. Can developers be incentivized to improve housing design or to offer customization? For example, the concept of Target Value Design (TVD) could be explored for affordable housing delivery. TVD aims to make a client’s value such as specific design criteria, cost, schedule and constructability the drivers of the design. In this way, designer work collaboratively in order to reduce waste and satisfying or even surpassing the expectations customers/clients (Zimina et al. 2012).

9.6 Opportunity in co-construction

Based on the results of this research and aiming to start discussing some of the questions posed for future work, the author proposes a housing provision model that combines the positive aspects of the three Case Studies included in this research.

The model depicted in Figure 9-1 describes the way housing developers, the government, funding institutions, and residents interact in a co-construction model that aims to integrate the efforts of developer customization strategies and the building capacity of residents at a larger scale.

On the left side of the model, housing developers are required to submit a project proposal to government agencies for an evaluation based on a scoring system. The government evaluates the project proposal and assigns it points according to predefined features, that reflect national or regional priorities in terms of location, type of housing, or quality of the project. For example, if the intention is to deviate from mass housing construction, the scoring system may award extra points to those developments that allow the customer to select some housing unit features. Extra points may also be assigned to developments embracing the concept of progressive housing or to those favoring integration among families with different economic and social backgrounds. According to the score, projects get to access financial incentives. One incentive could be to allow projects with higher scores to receive financing with lower interest rates and payment options.
Another incentive could be the increase of the amount granted in subsidies for projects with higher scores. This scoring system may encourage value generation since developers have to compete for financial incentives based on the quality of housing development designs.

The right side of the model incorporates the building capacity of residents based on the half house concept described in the Quinta Monroy Case Study. Housing development design may include customized core houses along with the structural elements and guidelines for future extensions in alignment with building codes. The government can support the harmonious growth of the development by offering financing plans for residents who follow the developer’s expansion guidelines. Guidelines for enlargement may be stricter for exterior than for interior design. This encourages the construction of extensions that do not compromise the urban environment of the development while at the same time offers residents the flexibility to manage interior design and space according to their needs.

One of the biggest challenges of this approach is the consistent application of building codes. During design and construction, the developer may adhere to building regulations (the core house). The governmental agency has more control in this part of the process because it has governability over construction permit approvals. Nevertheless, the situation may change when residents get involved in the construction process (the second half of the house). As depicted in Figure 8-10, residents may build extensions without considering building codes, which endangers the urban environment and the safety of the housing solution. In this case, government oversight over the construction of the “second half” is key to ensuring that work is done according to code. For example, this can be implemented in part by licensing qualified contractors but it will also require inspection. Although the government implements measures to ensure the quality and safety of
progressive housing construction, contextual situation of developing countries such as corruption may hamper governmental efforts.

This model may contribute to addressing housing constraints in the region in many ways.

In terms of housing design, the scoring system may encourage value generation since developers have to improve housing design based on a target cost. Residents are allowed to participate in housing design in two stages. First, when they select features of the core house, including the potential extensions. Second, when they build extensions according to their needs and priorities. Although residents must follow guidelines, they have some control over the design and construction which allows some personalization.

In terms of affordability, developers have the capability and expertise to build the “hardest” parts of the house more efficiently than residents. The implementation of this approach on a larger scale may reduce construction costs. For extensions, residents can use the local labor force, suppliers, and subcontractors which may result in more affordable solutions while at the same time stimulating the local economy.

9.7 Final remarks

The aim of this research is to explore the potential benefits of using Lean Principles to address issues in affordable housing provision in Latin America.

Through the analysis of three Case Studies, the research describes some of the benefits of using Lean in this context as well as implementation challenges and opportunities. This research may serve as a starting point for practitioners and researchers who are interested in improving the way affordable housing is produced in the region. The research also provides insights into a new housing provision model aimed to combine the positive aspects of the three Case Studies discussed in this research.

Affordable housing is a topic that involves many areas of expertise including housing policy, urban development, and construction. Since these areas are interrelated, Lean implementation can have the greatest impacts if different fields of expertise are aligned towards a common goal. Individual efforts in Lean initiatives may be hindered if housing policy or urban development directives do not support such efforts. Finally, several research questions have been posed for future research. The author hopes that these inquiries encourage colleagues to conduct research in this area.
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