

ASSESSING DESIGN PRACTICES ON AFFORDABLE HOUSING PROJECTS IN MEXICO USING LEAN CONCEPTS

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ABSTRACT

This paper presents the results of a research project that investigated the level of knowledge and application of lean concepts and principles among the various stakeholders responsible for constructing affordable housing developments in the Southeast of Mexico. The project developed a conceptual framework with key lean parameters, based on the results from a survey among designers and developers.

There is substantial evidence showing that design can effectively be improved with the application of the lean production paradigm. Therefore the first objective was to explore whether there was any awareness of the existence of lean concepts: The survey particularly focused on lean design related terms, to explore (1) if they were indeed known by the various participants in affordable housing development projects; (2) whether lean construction concepts were applied in their organizations, and if so, if their application was restricted to senior management or had filtered down and incorporated within the design and production processes; and (3) the likelihood of lean concepts being adopted in the construction of affordable housing developments.

The survey revealed very limited knowledge of lean construction (and design) concepts at both management and operational levels. Consequently, the application of those concepts is almost inexistent within the various organizations involved in affordable housing developments. Two recommendations are made for future research to focus on furthering the understanding of the design process and thus eventually providing tools that will develop integrated solutions to the problem of design in affordable housing developments.

KEY WORDS

Lean design, lean construction, affordable housing.

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INTRODUCTION

This paper presents the results from a research project aimed to identify and document design practice during the delivery of affordable housing developments in Mexico. Specifically, the research pursued two objectives: (1) to identify the major issues impacting the design process of affordable housing developments in Mexico and how they interrelate, and (2) to identify if information flow principles are applied to the design process in affordable housing developments in Mexico, particularly in large developments. This paper discusses the results obtained for the first objective only.

AFFORDABLE HOUSING

There is not a common definition regarding affordable housing. Within the context of the investigation upon which this paper is based, affordable housing, or more properly an affordable house, was defined as housing that can be obtained without serious financing risk. But what can be considered serious financing risk? There is not a universal standard to measure it. However, it appears that most countries worldwide have set the 30% income limit as the basis to access financing for affordable housing, becoming so the reference for serious financing risk.

In United States of America, for instance, the HUD's (Housing and Urban Development) definition of affordability is for a household to pay no more than 30% of its annual income for housing (HUD 2002). Families who pay more than 30% of their income for housing are considered cost burdened and may have difficulty affording necessities such as food, clothing, transportation and medical care. In Mexico, though there is not a formal statement from the Mexican government, the related housing agencies consider a similar 30% household's income limit as the basis to finance social interest housing, or "*Vivienda de Interés Social - VIS*" (INFONAVIT 2001), a term that will be used as a synonym of affordable housing in this document⁴.

DELIVERY OF AFFORDABLE HOUSING IN MEXICO

The existing legal framework in Mexico allows *promotores de vivienda* (developers) to be responsible for the overall construction process, from feasibility studies to the delivery of the dwelling units to the households. According to several studies, having all responsibilities of the overall construction process under a sole entity facilitates teamwork, practice that promotes a better integration of the several stages in the total life cycle of a project (Dos Santos 1999, Ballard 2000, and Koskela, 2000).

Contrary to those findings, developers addressing the demand of affordable housing in Mexico appear to operate both fragmented and disintegrated (González et al. 2001). Some symptoms from such practice are the following: 90% of the dwelling units are inadequate in terms of comfort (García 1998, Gómez 2000), 5.7% of materials, in terms of weight, is

⁴ The reader should be aware that given the disparities of incomes between the two countries, houses of much lower cost need to be produced in Mexico. On the average, the selling prices for affordable houses in Mexico range from \$6,000 to \$20,000 US dollars.

wasted in construction (Marín 2000), waste represents, at least, 5% of direct cost of the unit (Marín 2000), and excessive regulation (SEDESOL 2001).

Several studies point out that the origins of such inefficiencies arise through decisions or actions during the design phase. Among others, Sverlinger (1996) found that the most frequent causes for severe deviations for design were deficient planning, deficient or missing information, and changes. In Latin American countries it is estimated that between 20 to 25% of the total construction period is lost as a result of design deficiencies (Undurraga 1996, Corona et al. 2000, González et al. 2001).

PROBLEM STATEMENT AND OBJECTIVES

In view of the above, a research problem was formulated as follows: The design process of affordable housing developments in Mexico (a) has characteristics of poor performance; and (b) is not properly documented, primarily because the major issues impacting the process and the flow of information have not been identified nor established.

Therefore, the purpose of the research was to find out the major issues impacting affordable housing developments in Mexico, specifically during the design phase. In order to do so, it was necessary to identify and document current design practice.

RESEARCH METHODOLOGY

To address the problem, responses were sought in the following sources: documentation, archival records, and interviews, as shown in Table 1.

Table 1: Research Design: The Design Process

Question	Objectives	Units of Analysis	Sources of Evidence	Data Types
How is the design process currently done in the affordable housing sector in Mexico?	Identify type of firms involved in affordable housing, and ways they manage the design process. Thus, it requires to identify: 1- General characteristics of the firms 2- Current design process: - type of information - quality of information - who it is coming from 3- Knowledge of lean principles	<ul style="list-style-type: none"> •The firms •Embedded subunits: •Administrators •Designers 	<ul style="list-style-type: none"> •Interviews •Documentation •Archival records 	<ul style="list-style-type: none"> •Focused interviews •Design related communiqués from agencies •Newspaper clippings •Organizational charts •Service records (clients attended)

Documentation included administrative documents (projects proposals, design proposals, design layouts, and technical specifications), written reports of design related events, and newspapers' clippings and other articles appearing in the mass media. Archival records consisted of service records such as the number of projects submitted by contractors over a period of time, and interim records like organizational charts, to identify formal and informal communication flows. Finally, semi-structured interviews allowed data collection from key informants.

DATA COLLECTION

The first task was the detailed review of: related literature, documents from financing and regulating agencies, and archival records from four firms selected randomly, from the group of firms previously identified as performing affordable housing design, to participate in the pilot study. This task produced two results: (1) evaluated documents to be included in the database, and (2) the first version of the interview guide or questionnaire.

The first version of the interview guide included questions to investigate upon the application of lean production concepts to the design process, as suggested by the literature. However, while conducting the pilot study with the four firms selected, it was found that neither managers nor designers were consciously aware of most common lean terms, (i.e., variability, cycle time, transparency, flow, value-adding). They only knew one explicit lean term, waste, and other indirect lean terms such as: accuracy of information, flow of messages, and speed of information.

It is worth mentioning that none of the professionals interviewed during the pilot study knew the term “lean.” This is the first major issue found that impacts the design process. This actual condition forced the investigators to change the focus of the questionnaire because it did not fulfill its specific purpose. Instead of direct or explicit lean concepts and principles applied to the design process of affordable housing developments, that were originally sought, the most recurrent indirect lean parameters mentioned in the pilot study were considered to redesign the questionnaire. Therefore, the indirect lean parameters included in the second version were, for managers: (type of) communication, constructability, and waste generation; and for designers: modularization, constructability, and design errors. The questionnaire was revised by interviewees from two of the four firms that previously participated in the pilot study. After some minor clarifications and modifications, primarily grammar issues, the questionnaire was considered ready for use.

The interviewing phase at large scale consisted of 52 participants, 26 managers and 26 designers, from 33 different firms. Most data collected was primarily tabulated in spreadsheet files; comments and narratives were transcribed to text files. Both were included in the database. Preliminary analysis of data was conducted during data collection and it is discussed in the following section when necessary.

RESEARCH RESULTS

CHARACTERISTICS OF RESPONDENT FIRMS

The average age of participating companies is roughly 11 years; however, 58% of them have been in business for less than 10 years. The average size of the firms is small, both in terms of number of employees and annual production volume. Sixty five percent of them have between 1 and 10 full-time employees, for an average of 5 employees. They build annually an average of 125 dwelling units; however 54% of them only build 50 units per year or less.

It was also found that all respondents provide affordable housing design services. At the same time, 54% of the firms carry out residential design, 19% do industrial design, 15% do school facilities design, 12% perform commercial/business design, and 4% do storage/warehouses design. Concurrently to design, 73% of the respondents perform actual construction work, 46% realize supervision, and 12% do consulting. Thus, it can be inferred

that the traditionally project delivery option of design-build still counts as the preferred type of operations for most affordable housing developers.

TYPES OF COMMUNICATION IN THE FIRMS

Communication is primarily informal, since 54% do it verbally, and 8% do it over the phone. Only 27% of the firms communicate in writing.

Half the firms indicated that they communicate with households during the revision of the drawings, primarily focusing on the layout, and the proposed budget. Two major reasons for communicating with households are: (1) to sign the contract, and (2) due to policies established within the firms, such as providing better service to customers. This interaction, in all instances, should happen since it is mandated by INFONAVIT (Instituto del Fondo Nacional de la Vivienda para los Trabajadores – Institute of National Housing Fund for Workers), or the other financing agencies.

Fifty percent of the respondents allow household's participation during design of the unit. However, households' participation is limited to the revision of several layouts and facades previously designed by the firm, considering primarily the household's income bracket, and, to a lesser degree, the actual needs for space.

Regarding other types of interaction that were specifically sought as an alternative type of communication, it was found that half the firms interact with future households. Specifically, the main type of interaction mentioned is to review and adjust dimensions of the layout to INFONAVIT's specifications, as well as to review some other design alternatives (minor variations of the layout) within the credit bracket assigned to a household. This shows consistency with the data mentioned in the previous paragraph.

Respondents indicated that they have limited interaction with households because they follow the firm's own design parameters, primarily based on the amount of credit assigned to the household, location of the unit, and credit type. This condition most respondents called "experience," while few others referred to that as "relying on historical records and/or performance of the firm on similar ventures."

The above are clear indicators about the limited input households have upon the design process. This, despite the dwelling unit is, supposedly, designed to satisfy their needs and requirements, and that such unit will be for most of them the only home for their entire life.

Several reasons hinder household's participation during design, namely: process restricted (predefined) by financing agencies, policy of the firm, and lack of funds from household. Other reasons managers mentioned include: marketing (offering large packages of units to union members, or the like, is only possible for the firms when they limit the options to only a few layouts), and household's income. Design requirements and needs from households are predetermined by only two groups: INFONAVIT (or other financing agency), and the firm itself.

Regarding communication with other parties (e.g., regulatory instances, suppliers), all respondents indicated that for daily operations they primarily communicate verbally. However, official interaction, particularly in anything dealing with financing agencies and city offices with agencies, is in written form, and when needed. The manager of a firm, however, indicated that he conducts all his business over the phone.

An interesting finding is that, young firms (e.g., up to ten years in business) appear to be more concerned about maintaining communication with households (Table 2).

Table 2: Relationship between Age of Firm and Communication Used

Time in business (years)	Type of communication with household				
	Oral	Telephone	Written	Sketch	Other
1-5	5	1	2		4
6-10	4		3		1
11-15	2	1	2		2
16-20	2				1
21-30	1				2
More than 30					1
Total	14	2	7	0	11

Data in Table 2 also reinforces that communication, and consequently information, among firms involved in housing design is definitively informal. Only seven firms responded to communicate on written form with households. This fact provided the investigators potential leads during the first phase of the research, to explore the flow of information in the process of affordable housing development design.

Several studies have documented that communication is one of two essential elements that should exist among design participants to achieve good quality design (Chan et al. 2001, Cleveland 1999, and Mendelsohn 1998). Teamwork is the other one, but neither one appears to be present in the participant firms.

CONSTRUCTABILITY APPLIED TO AFFORDABLE HOUSING DESIGN

In the first phase of the research, characterization and formalization of the design process, all 52 respondents (26 managers, responsible for construction operations, and 26 designers) acknowledged interaction with other professionals that provide them with input for design. Both groups mentioned interaction with the following professionals: architects, engineers, primarily civil engineers, consultants, supervisors, and subcontractors/builders (Table 3).

Table 3: Interaction with Other Professional During the Design Process

Professional	Managers		Designers	
	Frequency	Percentage	Frequency	Percentage
Architects	21	81	23	88
Engineers	20	77	26	100
Contractor/Builders	3	12	20	77
Consultants	4	15	5	19
Supervisors	4	15	15	58
Total number of respondents = 52, 26 managers and 26 designers				

However, Table 3 shows that managers and designers have different perceptions upon the participation of other professionals that provide input during the design phase. It appears that designers have higher expectations regarding such participation, particularly from engineers, contractors/builders, and supervisors. It could be inferred that designers expect better design performance by doing it with a teamwork approach.

Managers and designers were specifically asked to identify the type of input provided by other professionals. From the managers' perspective, the input provided is as follows: architects, suggesting layout configurations, and aesthetics related to facades; engineers, providing cost estimates and preparing construction schedules; consultants, suggesting marketing alternatives; field supervisors, facilitating alternatives for materials' control and handling during construction, and strategies for hiring labor force; contractors/builders, recommending construction methods, selection of materials.

On the other hand, the type of input provided by other professionals, from the designers' perspective is as follows: engineers recommending construction methods and preparing cost estimates; architects determine design parameters and suggest layout configurations, contractors/builders participation focuses on scheduling, planning and control, and proper materials use; field supervisors provide feedback on design parameters, and adequacy of units selected based on income brackets; consultants primarily contribute suggesting a better selection of materials.

Managers and designers agreed that the input and knowledge provided by those professionals influence the overall process. However, their degrees of perception differ considerably (Table 4). It is important to point out that financing was not mentioned by managers as an issue impacting the process. This is because in Mexico financing agencies block the money aside when developers get their proposals approved. Proposals that were based on lists of clients previously ranked and qualified as subjects to credit by the same financing agency.

Table 4: Perception of Phases Influenced by Other Participants

Phase influenced	Managers		Designers	
	Frequency	Percentage	Frequency	Percentage
Schematic design	16	62	25	96
Working drawings	13	50	22	85
Specifications writing	8	31	16	62
Selection of materials	13	50	19	73
Final design	6	23	17	65
Cost analysis	15	58	19	73
Other	3	12	0	0
Total number of respondents = 52, 26 managers and 26 designers				

Managers and designers also differ upon the advantages achieved by the participation of other professionals (Table 5). For instance, managers perceived the following advantages: better quality of design 92%, better selection of materials 19%, and time reduction of the design process 8%. Rather, designers perceived: better quality of design 88%, time reduction of the design process 62%, better selection of materials 50%, and other 19%, including cost reduction and improvement of the design process (better planning). It becomes evident that managers focus on cost decrease while designers focus on better quality of design, specifically a more comprehensive design.

The results mentioned above are similar to the ones obtained in other studies by Arditi et al. (2002), and Uhlik and Lores (1998), showing that managers are less familiar with

constructability issues than designers, do not have formal constructability programs, nor did they take action toward the implementation programs.

Table 5: Advantages Achieved by the Participation of Other Professionals

Phase influenced	Managers		Designers	
	Frequency	Percentage	Frequency	Percentage
Better quality of design	24	92	23	88
Time reduction of design	2	8	16	62
Selection of materials	5	19	13	50
Other	1	4	5	19
Total number of respondents = 52, 26 managers and 26 designers				

MODULARIZATION AND USE OF MATERIALS

Two factors of constructability were specifically investigated in more detail among designers: modularization and use of materials, to further analyze their application to affordable housing design.

All designers were aware of the term modularization. Several definitions were provided for such term that can be summarized as: “working on a grid layout to achieve an efficient use of materials, primarily based on their dimensions, and trying to minimize waste purposefully.” However, only 15% of the respondents indicated that their design is realized according to existing materials’ dimensions.

Designers indicated two reasons for not considering modularization: (1) inclusion of a waste contingency factor for the construction phase, and (2) inclination by managers to provide the least expensive materials available. The waste contingency factor, be that recommended by the construction department or declared as a policy within the firm, ranges from 2% to 5% of the materials’ cost; based on experience or familiarity of the firm with similar projects. Instead of modularization, designers indicated they use multiple criteria to select materials, including: cost, quality, availability, reliability of supplier, delivery time, and durability and maintenance, in that order of importance.

SOURCES OF WASTE IN AFFORDABLE HOUSING DESIGN

The investigator approached the concept of waste, a major concern in lean processes, with subtle differences for the two groups of interviewees. For managers, the concept was explicitly treated, namely waste. Rather, for designers it was treated as design errors. This was purposely done given their different backgrounds and also based on the results obtained in the earlier pilot test. Managers were used to assess the concept of waste, primarily in money terms; rather, designers were more familiar to measure their performance in terms of design errors.

Managers

Most managers, 85%, responded that there is a link between design and waste, mentioning two main causes: (1) non-compliance of specifications at the site, and (2) poor selection of materials. Actually, from the suggested list of possible sources of waste generation, managers selected the following: bad planning, inefficient supervision, and incongruence on drawings.

Other sources of waste mentioned, not less important, were: lack of labor training, faulty construction methods, lack of knowledge and/or skills, and poor selection of materials.

Also, for managers, the following phases are responsible for the generation of waste: construction 50%, planning 42%, and design 12%. Causes identified were: inefficient supervision or lack of it, little interaction among participating parties, and untrained labor force. Remarkably, only 3 respondents considered design as the main cause of waste.

Last, for them, the impact of waste results in: cost increase 92%, environmental contamination 65%, environmental degradation 50%, shortage of materials 46%, and other causes 27%, including schedule overruns, health problems, and bad image. Outstandingly, cost increase was mentioned by 92% of the respondents.

Designers

Working drawings are an essential element of construction, bridging the gap between the design set forth in the specifications and the details necessary to fabricate material and install the work in the field. Any faults or ambiguity in working drawings can lead to cost overruns, delays, disruption of construction progress, and, eventually, to litigation between the parties involved in the process.

Faulty, ambiguous, or defective working drawings and incomplete specifications were found to be two major factors that cause design problems.

Thirty five percent respondents indicated that, despite the participation of other professionals, they still find out incongruence and/or errors in design. Ardity et al. (2002) found similar results in the USA, 33% errors in design documents.

The type of errors identified by designers included: location and height of hooks on the walls⁵ 35%, discrepancy between drawings and specification 23%, and space functionality, faulty plumbing installations, structural failures, and poor quality of materials, all of them 11%.

But discrepancies and errors are also due to management pressures, namely: competition (e.g., developers pushing too hard to offer the maximum amount of space for the least expensive price), and lack of familiarity with household's needs and requirements. These are clear symptoms derived from the lack of communication with end users, as found by several authors (Hicks et al. 2002, Björk 2002, and Carneiro et al. 2002).

Designers also indicated that, once incongruence or errors were detected, design changes did occur, primarily in the use of materials, in maintaining quality but cutting down cost; looking for better space distribution; and relocating plumbing and electrical installations.

This finding was categorically proved during the second phase of the research. Detailed revision and comparison of drawings and specifications showed an average of 41 errors per drawing. Far too many from any standard considered.

With the rising costs of construction and the increased demand of time constraints on schedules, few members of the construction industry can afford to waste, be that resources, time, errors, incongruence, or ineffective work practice.

⁵ Due to the hot climate, most people sleep on hammocks, which are swinging couches or beds usually made of netting or canvas and slung by cords from supports at each end.

On the flip side of the coin, contrary to errors, designers selected the following factors that enhance good design: (natural) air ventilation 100%, natural lighting 92%, space distribution 73%, location of unit 65%, and functionality 50%.

CONCLUSIONS

ISSUES IMPACTING THE DESIGN PROCESS OF AFFORDABLE HOUSING DEVELOPMENTS

The findings of the research indicate that the design process of affordable housing developments in Mexico has the following characteristics: is primarily performed by small, young firms that prefer the design-build option for project delivery, relies on informal channels of communication, does not promote participation from end users (households), and other professionals that should be involved in the process, does not incorporate constructability concepts, and evidences symptoms of errors and generation of waste. In summary, the design process of affordable housing is highly informal and based on experience, and there is not significant participation from the end users of the dwelling unit.

FUTURE RESEARCH EXTENSIONS

The intent of this research has been to begin to uncover an understanding about the design skills behind the creation of solutions to specific affordable housing developments design problems. As such, two recommendations are made for future research to focus on furthering this understanding and thus eventually providing tools that will provide for integrated solutions to the problem of design in affordable housing developments allowing it to be solved from the bottom up at the same time it is being solved from the top down.

Developing of National Standards for the Classification of Design Information

Different types of information are exchanged between the various parties for the purpose of communicating design, construction and contractual matters. Individual firms have developed their own means of classifying and disseminating information to facilitate this process. However, as there is no standardized system in Mexico of classifying and sharing of such information, much of the data is lost along the way.

The development of classification systems in the UK, America, and Canada began some 30 years ago. The Swedish system, SfB, has been in existence for more than 50 years. However, in Mexico, efforts in this direction have not surfaced yet. There is an evident need for information standardization in order to facilitate communication. Some of the approaches that could be addressed to develop and establish a standardized system of classifying information could cover the following aspects: a) Written reports, b) CAD drawings, c) Specifications, d) Cost information, and e) Product information.

Implementation of Constructability Programs

Constructability programs in the design phase could be implemented following the framework proposed by Ardity et al. (2002). Such model focuses on five areas identified as having significant impact upon constructability, namely (1) organizational issues, (2) techniques used during constructability reviews, (3) timing of constructability reviews, (4)

factors that enhance constructability, and (5) factors that constrain constructability. The model can be easily adapted for the design of affordable housing developments in Mexico, particularly for areas 1, 4 and 5. For instance, a first step would be a survey to identify and rate factors such as: for organizational issues, design practice, project delivery, project size, project type, client type, and project location. Other factors that could be investigated are: working drawings, specifications, budget limitations, and client satisfaction. However, we should be aware that these factors could either constrain or benefit constructability, depending upon how they are applied to the design process.

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