A PROCESS USING BUILDING INFORMATION MODELING (BIM) FOR IMPROVING SELF-HELP HOUSING IN TEXAS COLONIAS

A Dissertation

by

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ABSTRACT

Colonias, as an example of informal settlement development along north of U.S. – Mexico Border, are comprised of low-cost, self-built and -managed houses with lack of access to basic services. These settlements often have four particular problems as a result of self-help construction of homes without expert consultation: (1) substandard and unsafe constructions that do not meet building standards, (2) higher than average cost for energy per unit area due to poor housing conditions and poor building performance, (3) poor access to capital due to incorrect valuation of their properties, and (4) inattention to best practices for sustainable community development. This research identifies a process for designing additions and improvements to the existing self-help structures in the colonias by utilizing Building Information Modeling (BIM) and building simulation tools to reduce energy consumption and improve sustainability.

This study employs a mixed-method research by combining survey research (qualitative), quasi-experimental research, and model-based research strategies (quantitative). This research comprises (1) survey of the literature review to build a logical framework and constitute a theoretical foundation for the research, (2) data collection including (a) interviews with residents in colonias and field survey of their houses to document existing architectural patterns in the colonias, and (b) focus groups with experts to identify best practices and low-cost, sustainable strategies that are appropriate for colonias residents, (3) development of a Colonias BIM Toolkit (CBT) to aid in creation of BIM models and calculation of their building performance, and (4) testing the strategies suggested by experts on designing an addition to two test cases by utilizing CBT. This study is limited to 30 self-help homes selected from three colonias located north of Highway 359 in Laredo, Texas which are referred to as Green Colonia, Red I and Red II.

Documentation of existing architectural design and construction patterns were used to develop a toolkit, CBT, to model existing colonias homes. The findings from the focus group comprise best practices and sustainable design strategies specific to colonias residents in Laredo, Texas. These are embedded in the CBT for best practices. CBT enables rapid modeling of the homes, and simulation of their building performance, to provide insights on energy use and cost while designing an addition to existing homes. Findings also show that the BIM models and simulation results of the 30 homes can be used to estimate the aggregate energy use of the three colonias. The most cost effective and energy efficient practices for two homes are identified. Based on these findings, the study confirms the benefits of utilizing BIM technology to model an informal settlement context to address sustainability and affordability.

DEDICATION

Lovingly dedicated to my son Batu and my husband Cengizhan Yenerim

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This dissertation is a product of five years of work at Texas A&M University and couldn't have been completed without the support of many astounding people.

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1 INTRODUCTION

1.1 Introduction: Problem Statement

The use of advanced software and processes for high performance architectural design and construction may enable creation of a process for improving houses in self-help communities, potentially increasing energy efficiency and value to the residents. In this research, colonias have been used as a test case for this hypothesis. Colonias are communities in the area north of the border between the United States and Mexico that consist largely of substandard housing often constructed outside regulatory practices and often lacking in basic services. The research may have implications to address challenges in other informal settlements across the globe.

Several studies show that three particular problems are direct consequences of the construction of residences without expert consultation on design or construction methods. A large number of informally constructed houses may fail to meet the building standards, and risk being substandard and unsafe. Due to poor housing conditions and building performance, residents may have higher than average costs for energy. As energy costs rise and homes are upgraded for mechanical services such as air conditioning, these costs can rise at an exponential rate. Finally, the self-help construction may not be correctly assessed in capital valuation of the home, and thus, owners may not have access to capital (Federal Reserve Bank of Dallas 1995; McKenzie 2002; SOS 2012; HUD 2008; Ward, Olmedo, et al. 2010; Ward, Sullivan, et al. 2010).

The colonias are largely overlooked by architectural practice and thus do not benefit from advances in design that have resulted from innovations in computing and sustainable construction. Building Information Modeling (BIM) and building simulation are new tools for building design that are being adopted in practice now, superseding paper and pencil methods and Computer-Aided Design. This research derives from the speculation that applying advanced design tools, such as BIM, and advanced construction methods to an under-served population could improve the welfare of its members as well as the society at large.

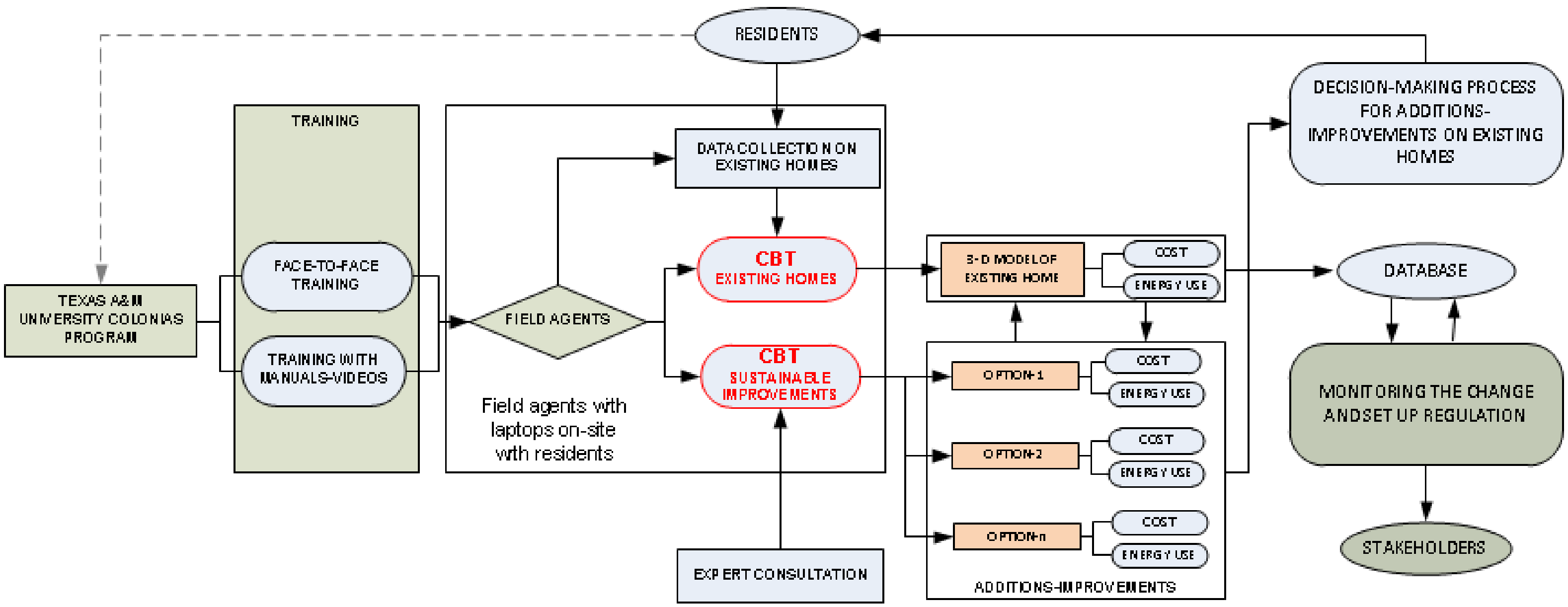

Figure 1: Process model of how Colonias BIM Toolkit (CBT) will be utilized to help colonias residents

The research strategy is to devise methods to provide increased knowledge on low-cost, sustainable design and construction techniques to the residents who perform self-help housing in the colonias. By utilizing advanced design software for modeling and simulation and best practices of construction, it may be possible to decrease energy use and cost of ownership, increase the production of equity and capital, and improve sustainability. The expectation is that the new model of practice can produce home designs that are more affordable, more sustainable, and more implementable and can help to identify best low-cost and energy effective solutions for self-help homes in the colonias (Figure 1). Figure 1 demonstrates the process model proposed in this study. This study foresees a model in which field agents take an active role in providing expert consultation on housing design and construction to the colonias residents. A field agent can be a colonias resident or an architecture student intern who is trained by Texas A&M University Colonias Program. Training session can be face-to-face or with manuals /videos on how to use Colonias BIM Toolkit (CBT) and BIM technology, and data collection on-site on homes. A field agent with a laptop can create a BIM of the existing home on-site after measuring the home with help of the residents. By using CBT for sustainable improvements including expert suggestions, he can help design a new home or an addition to an existing home by showing the residents the savings in energy consumption together with the cost of the improvements. However, integrating field agents is not the contribution of this study. The contribution of this study is the development of Colonias BIM Toolkit which can be utilized by field agents for both existing homes and sustainable strategies after on-site data collection on existing architectural patterns of the colonias homes.

The research is conducted with recognition that both the provision of housing and the increasing impact of energy use in informal settlements are acute challenges globally. Informal settlement inhabitants do not have access to the body of knowledge on low-cost, sustainable housing strategies. This study proposes sharing knowledge to empower the residents and provide options to them. Visualization of their homes and the design options together with cost and energy data would be beneficial for residents to participate in the design process. The research may have influence and application in many nations in addressing these challenges.

The research was limited to studying self-built homes in Texas colonias in Laredo, and modeling and energy analysis utilizing Autodesk Revit and Autodesk Green Building Studio (GBS) tools. The research did not assess the actual energy use of the homes. Comparison of results provide relative conclusions. It also did not provide conclusions on best solutions for designing additions for other colonias in U.S. However, the process developed in this study to assess energy use can be applicable to not only other colonias in the U.S. but also informal settlements around the world. The research with the same method can be repeated in other colonias homes to increase reliability and generalizability of the results.

1.2 Research Goals and Objectives

The overarching goal of the research is to increase the sustainability of the colonias through decreasing the energy footprint of the community as residents construct additions and new homes. This study focuses on the energy aspect of the concept of sustainability. Sustainability is considered at the two levels of community and individual residence. A model of a colonia can aid policy-makers, designers and home-owners in making decisions about interventions into the colonias and individual homes to increase satisfaction and decrease energy use. Energy usage of many colonias homes is very high and is likely to get higher as the residents start to install air conditioning systems in their houses. Aggregated across a community, this impact can affect regional and statewide ability to meet sustainability goals. A model of a particular residence can aid a home-owner to make better choices about improvements to the property to reduce costs and increase sustainability.

This study consists of the synthesis of two contributions to produce a third: (1) to identify preferences and patterns of construction and lifestyle of colonias residents through interview with 30 residents and field survey of their houses; (2) to identify best practices for low-cost, sustainable home design and construction through focus groups with experts on sustainable, low-cost residential design for colonias self-help homes in Laredo, Texas, and (3) to incorporate the rules and patterns for home design, construction techniques, and energy efficiency revealed from the previous steps into BIM software to aid design of additions that incorporate appropriate sustainable and low-cost residential design and construction techniques. This toolkit for designing homes in the colonias may enable residents to achieve lower cost and more energy efficient solutions to their housing needs.

1.3 Research Questions and Hypotheses

The study adopts a deductive research structure comprised of broad and general primary questions, more focused secondary questions, and narrower hypotheses. The idea is to elaborate the sweeping primary questions into narrower answerable secondary questions that suggest evidence for the more general primary questions. The research will address the following primary questions:

(1) What are the low-cost, sustainable design and construction strategies that can be adapted by residents in the colonias?
(2) Can advanced design software tools be used effectively to model homes and additions to homes in informal settlements, simulating design performance and improving sustainability of resulting designs?
(3) Can design and construction in the colonias be improved by use of advanced software design tools?

Secondary questions listed below operationalize the primary questions to allow for collection of measurable data:

(1) What are the existing building materials, construction methods, design patterns, technical knowledge and skills in the colonias?
(2) What are the sustainable and cost-effective design practices for houses suggested by experts?
(3) To what extent can the existing design patterns, and best practices for construction in the colonias be synthesized and encapsulated into guidelines and rules for sustainable design and construction appropriate to the region and social context?
(4) What BIM techniques are useful in developing a design toolkit for the colonias?
(5) Can a BIM toolkit for the colonias support rapid modeling and simulation of existing homes and possible additions to the homes?
(6) Can use of the BIM toolkit lead to better decisions for designing remodeling and additions to homes, increasing the sustainability of the homes and reducing energy costs?

Preliminary investigation of the questions has led to three testable hypotheses which are very narrow and focused:

(1) A BIM toolkit for informally produced housing units can establish a simulated performance for units and communities with respect to energy, construction cost and other criteria.

(2) Using a BIM toolkit, a colonias can be modeled rapidly.
(3) BIM can aid in design of improvements to homes in an informal settlement by reducing energy consumption and construction cost.

Although further research is necessary to reach definitive answers to the secondary and primary research questions, affirming these hypotheses constitute research conclusions that demonstrate that technology is sufficient to help solve the problems. The research thus has intellectual merit by extending the knowledge of architecture, sustainable communities, and the culture of informal settlements in ways that are general to many applications.

1.4 Research Significance

The significance of this investigation is listed below:

- It would examine the methods and approaches to improve the quality of housing in informal settlements.
- This system would provide a historic database of the houses that enable policy-makers to monitor the growth of a community.
- It will provide an adaptable process of sustainable upgrading by enabling field agency and empowering the world's poorest communities.
- The BIM toolkit may serve as an aid to collect data rapidly about buildings and how people use them, both in contemporary settings and historical contexts.
- The developed toolkit will help field agents with a moderate level of training model the existing houses with the BIM toolkit and suggest a number of low-cost strategies for the residents to reduce their utility bills through conducting cost and energy analyses.

1.5 Approaches and Methods

This research has employed mixed-method research to devise a new model for aiding residents of informal settlements to achieve greater sustainability in self-help housing. According to Creswell and Clark's framework (2011), I combined survey research (qualitative), quasi-experimental research and model-based research strategies (quantitative). Research involved both collecting and analyzing qualitative and quantitative data. The data collected by qualitative research strategies has served to perform quasi-experimental and model based research strategy, which can support causal conclusions (Shadish, Cook, and Campbell 2002).

The reason for selecting model-based method research is that (a) model-based research strategy enables researchers to create an abstract model for a real environment/building and (b) it allows researcher to perform experiments on the model that are not affordable and feasible to conduct on the real buildings / environment itself. Model-based research strategy mostly is used in combination with other methodologies such as experimental methodology (Groat & Wang, 2002) to test variable scenarios.

Primary sources were the data collected from the field work, and focus groups, and generated by simulations. Secondary sources were:

- Aerial images and maps from Maps and GIS Collections and Services in Texas A&M University Library Collection and Google Earth,
- Information provided by theTexas A&M University Colonias Program,
- Information provided by the Texas Department of Housing and Community Affairs (TDHCA) about building standards and remodeling of self-help homes, including a systematic inspection and description of existing houses,
- Reimers-Arias dissertation (2009) for common interventions in the *colonias*,
- Ward, Olmeda, Rojas and Sullivan's study (2010) on an investigation of self-help housing conditions, and construction techniques in *colonias* in Central or South Texas,
- Ward, Sullivan and others (2010) and Sullivan and Ward (2012) on sustainable housing design and technology adoption in the *colonias*,
- UN-Habitat's and Architecture for Humanity's sources on best practices.

1.6 Scope and Limitations of the Study

The scope of this study is to develop a process to guide the design of self-help housing in informal communities for improved performance by utilizing BIM. The process was tested in this study. Although the process is claimed to be valid, high accuracy of the results is outside the scope of my research as it depends upon comparison to real building performance that was unavailable. BIM with integrated performance assessment tools can aid field agents to create affordable high performance buildings that meet building standards. Using BIM technology, the knowledge and ideas of experts can be modeled as a toolkit and field agents can assist a *colonia* resident to design a house or addition and understand the performance and the cost. This BIM aided design process with field agents may be a significant feature of technical advice centers, or housing support stations, in impoverished townships and informal settlements in other parts of the world. Although this study focuses on individual colonia homes, as a future implication, the proposed process may be used to estimate future energy consumption of a colonia.

Figure 2 demontsrates the overall process developed in this study. Several risks and limitations exist in the study due to sampling, and data collection methods illustrated in Figure 3. First**,** as the main focus of this study is self-help structures in the colonias, the sample is limited to 30 homes and includes only self-help homes and other types of structures that are partly built by its residents.[1] Since self-help structures are predominant in Green Colonia (89.5%), Red I (63%) and Red II Colonias (77%), the findings of the interviews and home inspections may provide explanations to the other self-help structures in these three communities.

Second**,** the home samples are selected from three out of many colonias in Laredo, Texas, which might not be big enough to generalize the results. Since climate is one of the major factors that impact the construction practices of these homes, findings can be generalizable to the self-help structures in other colonias located in the same climate division with Laredo, which is Texas Climate Division 9 (US Department of Commerce 2014a). However, they are not generalizable to the structures located in other parts of U.S. because climate conditions can differ significantly.

Third**,** as the permission from Texas A&M University Institutional Review Board let me inspect homes only from the outside, data gathered from on-site interviews with residents and home inspections lack some information, such as interior configuration of the structures, layers of construction materials on building components, tightness of the building envelope, and details about cooling and heating systems used. In order to overcome these challenges, other sources were consulted to enable me to make defensible assumptions.

Fourth**,** a risk was that residents might have prevented me from obtaining sensitive data from their houses during the field survey. To overcome this challenge, *promotoras* and employees from Texas A&M Colonias Program in Laredo assisted the on-site data collection process in Laredo.

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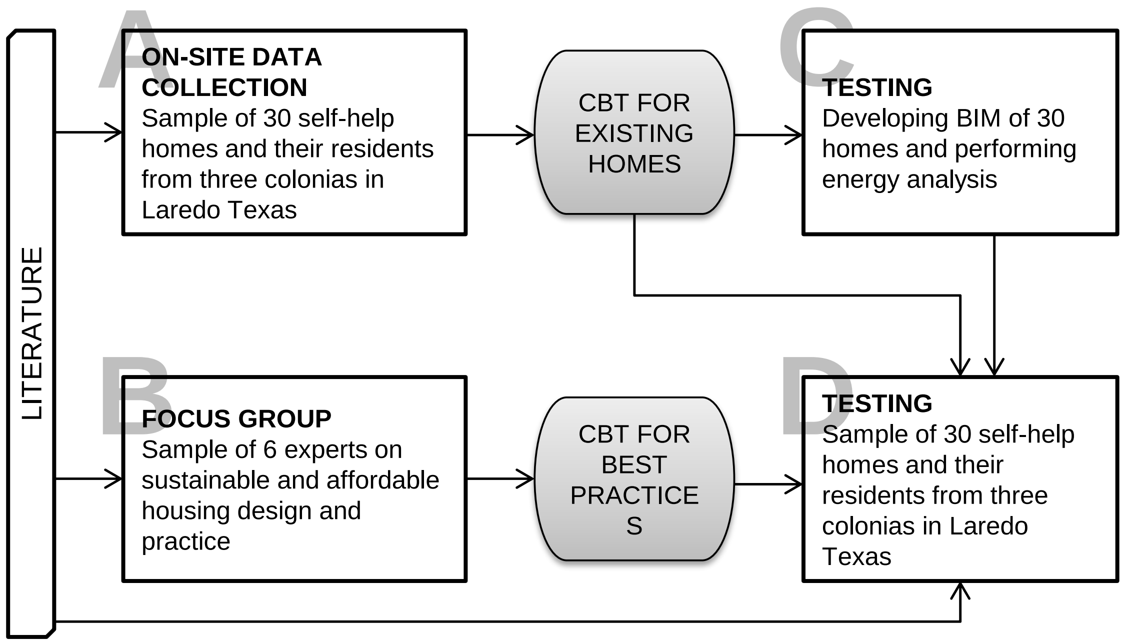
[1] The name of the selected three colonias are kept anonymous and referred as Green Colonia, Red I and Red II.



A: What are the existing building materials, construction methods, design patterns, technical knowledge and skills in the colonias?
B: What are the sustainable and cost-effective design practices for houses suggested by experts?
A&B: To what extent can the existing design patterns and best practices for construction in the colonias be synthesized and encapsulated into guidelines and rules for sustainable design and construction appropriate to the region and social context?
C&D: What BIM techniques are useful in developing a toolkit for the colonias?
C&D: Can a BIM toolkit for the colonias support rapid modeling and simulation of existing homes and possible additions to the homes?
D: Can use of the BIM toolkit lead to better decisions for designing remodeling and additions to homes, increasing the sustainability of the homes and reducing energy costs?

Figure 2: Process model of the research and related research questions

Fifth**,** a focus group on sustainable cost-effective strategies for colonias homes was conducted with six experts. Because it was a very small group, the reliability of the results might be questionable. However, all six experts have different background and different perspectives on the subject that enriches the results. Additionally, since the target of this focus group discussion was on colonias in Laredo, Texas, the findings cannot be generalizable to other colonias or informal settlements around the world. However, the questions can be utilized to conduct a study elsewhere.

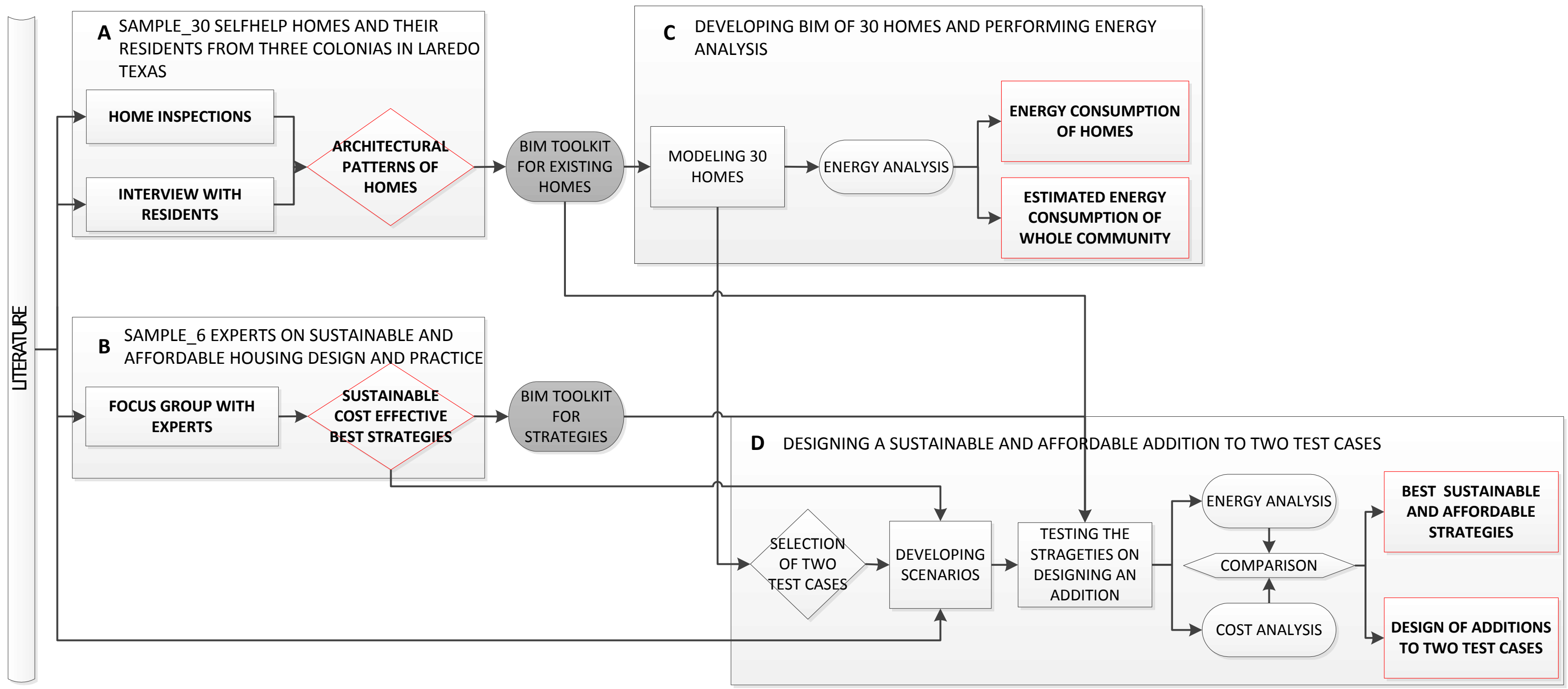


Figure 3: Detailed process model of the research

A sixth limitation is that questions may arise related to how precise are the results obtained by utilizing BIM design tool in conducting energy analyses. By utilizing BIM, energy analyses can be conducted for the expansions to the existing houses. BIM has been commonly used by designers to guide them on the form selection and material choice of their design (Bazjanac 2007; 2008; Krygiel and Nies 2008). My process has been tested as part of this research.

A final risk was that my expertise in using the software would be inadequate.For any problems related to using Autodesk Revit tools, our BIMSIM study group at Texas A&M University has the chance to work closely with Autodesk support.

The general process that I propose may be applied to other colonias and also other informal settlements around the world. It requires two phases of data collection (process A and B) and two phases of modeling and simulating energy use by utilizing BIM tool (process C and D) (Figure 3). The survey instruments for data collection were derived from the literature and can be utilized for investigations on other colonias in the U.S. and even other informal settlements around the world.

The proposed Colonias BIM Toolkit was developed parametrically to enable users to adapt it to various *colonias* in different contexts. After gathering adequate data on existing architecture of the homes, it is easy to input and develop the toolkit for other colonias or informal settlements. The precision of the findings can be increased by collecting data that lacking in this study.

1.7 Outlines of Sections

This dissertation is structured in eight sections.

1. Introduction introduces the research by describing the research problem, the research objectives, and research significance.

2. Literature Review: Background and Terminology introduces a general background on informal settlements as a global phenomenon and colonias as an American example of informal settlements. I identified the similarities and differences between colonias and other informal settlements around the world. It then presents low-cost, sustainable self-help house design strategies and introduces BIM technology to design high performance buildings.

3. Methodology of the study describes the research methods used in this study. It contains the study area and the criteria for selecting the sample of homes. It describes data gathering tasks: (1) focus group with experts and development of the instruments, and (2) fieldwork including interviews with residents and home inspections in colonias and development of their instruments. The section continues describing modeling and energy analysis tasks that utilized BIM.

4. Evaluation of existing architecture and construction patterns in Texas colonias presents the analysis of the data collected from a sample of 30 houses from Laredo, Texas. It expands in analysis on house form and construction, infrastructure and services, community and household. This section is organized as a report format.

5. Sustainable low-cost self-help housing design and construction techniques for Texas colonias describes the focus group and strategies for designing and building low-cost sustainable homes in colonias. The focus group developed suggestions on (1) Climatic Determinants, Orientation, and Passive Design, (2) Building Design and Construction including Housing Shape, Housing Fenestration/Aperture, Strategies for Placing Windows and Doors, controlling solar gain, Ventilation, and Housing Envelope: Construction Methods and Materials, (3) mechanical Systems-Sustainable Technologies & Techniques.

6. *Development of a Colonias BIM Toolkit (CBT)* describes a method for applying digital modeling to existing informal settlements to estimate building performance and establishes a part of the third contribution. It shows how BIM models of 30 homes have been created through acquisition of expertise in using Autodesk Revit and other BIM analysis tools and what assumptions have been made computer-aided modeling methods. It provides energy use results of 30 homes according to 20 scenarios.

7. *A BIM-based method for identifying best practices in low-cost energy efficient housing design* describes two test cases to establish the third contribution. It introduces a design process using the Colonias BIM Toolkit to determine the best options for designing an addition

to colonias homes. The strategies suggested by experts and literature have been tested on addition consisting of one bedroom and one bathroom.

8. Summary and Conclusions summarizes each contribution and the analysis that supports each contribution. It discusses the limitations of this study, and presents suggestions on the implications of research beyond the scope of this study.

2 LITERATURE REVIEW: BACKGROUND AND TERMINOLOGY

This chapter is a review of four bodies of literature relevant to this study. First, I provide an overview of issues of informal settlements, characteristics and types of informal settlements as a global phenomenon. Second, I introduce colonias as an example in U.S. and fit colonias in this global phenomenon. Further, colonias are reviewed on the light of housing typology and identifying the housing issues. Third, methods for energy efficient and affordable housing are reviewed and discussed. Fourth, as this research emphasizes delivering sustainable cost-effective solutions for colonias, I present an overview of the concepts of spatial agents and and contemporary advanced design tools of BIM.

2.1 Informal Settlements as a Global Phenomenon

2.1.1 Defining Informal Settlements

Informal settlements are a global phenomenon by which populations act outside of formal, regulatory authority to provide housing and communities for themselves, often out of desperation (UN-Habitat 2003). High immigration rates, limited economic growth,poverty, lack of affordable land, and lack of affordable or standard quality housing are the main triggering factors for informal settlement formation (Huchzermeyer 2004; UN-Habitat 2003). The informal settlement formation process starts with resident's unauthorized occupation of land outside the authority of land use and building regulations.

Different terms for informal developments are used in various nations and literature, including slums, townships, shacks, shanty towns, favelas, barrios, barracas, townships, squatters, nonformal settlements and illegal settlements. This variation in terms reflects important social, economic and physical distinctions among low-income settlements that underline different formation processes and important dimensions of housing problems (Beardsley and Werthmann 2008). Nonetheless, the following issues characterize all of these forms of urban communities: (1) clean water, sanitation and basic services alike are not easily accessible, (2) housing is below standards or building structures are illegal and deficient, (3) settlements are densely populated and usually overcrowded, (4) existing living conditions and locations of the settlements are hazardous to the health and wellbeing of the inhabitants, (5) security is low, (6) settlements are unevenly developed , (7) poverty and social exclusion are widely present, and (8) residence sizes are small (UN-Habitat 2003).

Since housing is a product of social, economic and physical processes; each feature is related and triggers each other. My investigations lead to a view that informal settlements are a group of improperly self-built houses without adequate basic infrastructure and without compliance to codes, regulation or standards that optimize the cost and quality by low-and very-low-income residents who cannot afford participation in formal sectors and are secluded from the rest of the society. Informal settlements risk causing and promulgating socio-economic and environmental problems.

2.1.2 Informal Settlement Types

Informal settlements are found in various countries irrespective of their development level: Brazil, South Africa, Turkey, China, India, Nigeria, Pakistan, Bangladesh, Indonesia, Iran, Philippines, Mexico, South Korea, Peru, USA, Egypt, Argentina, Tanzania, Ethiopia, Sudan, and Vietnam (Amis 2002; Burdett and Sudjic 2007; Davis 2006; Skinner and Rodell 1983; Turner 1977; UN-Habitat 2003).

In a global context, location (inner city or periphery), tenure (owner-occupied or rental), settlement types (authorized or unauthorized), size and scale, legality and development dynamics are the factors that lead to different territoriality and spatial formation (Davis 2006). “Pirate urbanism” and “squatting” are the two formation processes seen all over the world (Beardsley and Werthmann 2008; Davis 2006; UN-Habitat 2003).

The former includes occupation of abandoned structures in inner cities whose previous residents have moved to newer houses. For instance, in Buenos Aires, wood and sheet metal houses originally built for Italian immigrants are accommodated by low-income families living in one room of *inquilinatos* sharing kitchen and bathroom. In Mumbai, *chawls*, and in Lima, *callejones* are built by government to be rented by poor. Another example of “pirate urbanism” is in Hong Kong; a great number of people live on rooftops or in the structures filled in airwells in the center of buildings. Seoul has bed space apartments for renting a bed per day. In Asia, boats are also used for rent. In Sub-Saharan Africa, hostels are mostly used by single men, and township houses for families (Beardsley and Werthmann 2008; Davis 2006; UN-Habitat 2003).

The second type of informal settlement, “squatting,” is the phenomenon of building on illegally occupied land by a self-help process. It often leads to extensive communities such as *barrios, tugurios, favelas, bidonvilles, gecekondus, kampongs* (Davis 2006) and *colonias*. Self-help process refers to expedient construction by residents who follow regional constraints such as “site conditions, local knowledge, topography, the availability of tools and materials, technical skills and climate” (Mills 2012). This study focuses on colonias as an example of the squatting type that is developed north of the U.S.-Mexico border.

2.1.3 Critical Features of Informal Settlements: Physical and Socio-economic

Informal settlement formations for most of the cities have common problems, such as bad or even deplorable living conditions with living space deficiencies and lack of access to basic facilities and services, that have a negative impact on both quality of life and unpredictable growth that overwhelms resources (UN-Habitat 2003; 2008; 2009). Therefore, these settlements are different from formal ones in terms their physical and socio-economic features.

Physical features of informal settlements vary across cities according to income level of residents: mostly, they are located on illegal sites. For squatting, houses are often built (a) by residents themselves with help of friends or community through incremental changes, (b) by employing local building materials, design and construction skills without any expert or public assistance, and without compliance to formal codes, standards and regulations, and (c) without having adequate access to basic services. Consequently, high variation in types and in quality of construction and materials are observed. These features can cause health problems and may have impact socio-economic conditions. They may also lead to environmental pollution. Therefore, there is a need to guide residents to improve their houses (Wekesa, Steyn, and Otieno 2011).

In terms of socio-economic features, these settlements are formed by poor residents who cannot afford the formal housing option and thus build their own houses according to the needs and availability of money (Maliene, Howe, and Malys 2008). The variation in physical characteristics in houses is due to income levels of households. Mostly, residents belong to low- and very-low income group; however average household income level of some houses can be high due to several number of employees working in mostly informal sectors such as agriculture, manual labor, and construction with irregular income (Wekesa, Steyn, and Otieno 2011). Due to irregular income and unemployment rates, residents mostly do not have access to credit to upgrade or improve their houses (Ferguson and Navarrete 2003; Giusti and Estevez 2011). This situation causes seclusion from the rest of the city and social inequity. As mentioned in the literature, establishing community centers in informal settlements is a good way to improve the social features of the community (Wekesa, Steyn, and Otieno 2011). For economic features, several funding opportunities should be provided to these residents to improve their houses (Ferguson and Smets 2010; Giusti and Estevez 2011).

2.2 Colonias: An American Example of Informal Settlements

2.2.1 Defining Colonias in the Informal Settlement Universe: Formation Process and Upgrading Interventions

Informal settlements in different parts of the world vary in terms of its size, character, age, social and political standing and organizations of the communities. In the literature, various terms such as; slums, shacks, shanty towns, squatters, informal or non-formal settlements and illegal settlements, are used in order to encompass the important cultural, economic and spatial distinctions among low-income settlements (Beardsley and Werthmann 2008). Neither governmental organizations nor non-governmental organizations (NGOs) have come up with any common planning framework or method for upgrading these settlements (Abbott 2002).

Colonias are examples of self-help informal settlements in the U.S. which can be categorized under "squatting" informal settlement formation type. Colonias are the communities developed north of the U.S. border with Mexico in the states of Texas (1,800 colonias), New Mexico (142 colonias), Arizona (86 colonias), and California (15 colonias) (HUD 2003). Although colonias are not almost always urban settlements, unemployment, and lack of access to legal housing are the main factors that lead low-income families to prefer colonias as an option. Even though some residents can access formal financing, they prefer the colonias option since it is more flexible in financing, they can affod more space, there are few restrictions in construction, and it provides a the ability to live close to kin. Accessible technology, materials, and resources shape these residential structures and settlements in the colonias (Arizmendi, Arizmendi, and Donelson 2010).The downside of this situation is lack of access to social services, infrastructure, and living away from city centers resulting in inadequate public transportation (Ward and Peters 2007).

According to current practices and research, self-help housing approach is a better alternative to the non-affordable, non-sustainable method of constructing apartment blocks after forced eviction that is common in informal settlements other parts of the world (Bredenoord and Verkoren 2010; Goethert and Hamdi 1988; Joshi and Sohail Khan 2010; Kowaltowski et al. 2006; Sengupta 2010; Turner 1972; 1977; UN-Habitat 2003; Yap and De Wandeler 2010). To that end, colonias are based on autonomy in design and construction of their homes which mean residents design, construct and manage these homes by themselves. Therefore, the self-help housing of the colonias may provide lessons to other planning and development about informal settlements.

2.2.2 Defining Colonias in U.S.

Colonias is not a term from the U.S. In fact, it has stemmed from the other side of the border: Mexico (Esparza and Donelson 2009). The term *colonias* is a Spanish word meaning 'neighborhood' or 'community'. In the literature, scholars have pointed out the diversity in the definition for colonias developed by public agencies in U.S. (Parcher and Humberson 2007; Martinez 2010; Reimers-Arias 2009). Each agency establishes a definition for colonias that fit in their scope in assisting these settlements, which has led to a dramatic expansion of the definition and sometimes inconsistencies in meaning (Arosemena and Hartzell 2006)

The oldest definitions of the colonias emphasized "Classic border colonias" that are developed outside the city limits on the rural borderland. However, colonias are found and developed not only in the border counties but also away from the border region. These are called "non-border colonias" (Arosemena and Hartzell 2006; Ward and Peters 2007). Indeed, Ward and Peters (Ward and Peters 2007; Ward 2007) argue that these housing types are not restricted to the borderland; in many urban hinterlands of the U.S., very similar kind of housing subdivisions have emerged, such as in Austin, Dallas/ Fort Worth, and Lubbock in central and north Texas, Albuquerque and Santa Fe in New Mexico, Tucson and Phoenix in Arizona, Charlotte and Greensboro in North Carolina, and Dalton and Atlanta in Georgia. They called these settlements "non-border peri-urban informal subdivision".

The colonias and informal subdivision found in metropolitan areas serve people of similar low economic level who are excluded from mortgage market. They fulfill their shelter needs by reducing the cost of owning a home through self-help construction, owner-financing of very small scale construction, and quasi-legal land and property ownership.

2.2.3 Characteristics of the Colonias Settlements

Colonias are defined as communities developed along the north of the US border with Mexico in the states of Texas, New Mexico, Arizona , and California (HUD 2003). Identifying similarities and differences among informal settlements is important to fit colonias within the informal settlements universe.

Literature states that colonias share many characteristics with other informal settlements around the world (OAG 2011; SOS 2012; HUD 2003; Ward 1999; Ward and Peters 2007). They are developed on mostly unincorporated towns and cities, built by using improper materials and construction methods, with inadequate regulation, and lack of access to services such as running water, sewage system, public safety, and a proper electricity installation. Many homes are composed of a mixture of trailer and self-built structures. On the other hand, colonias are distinguished from other informal housing around the world as most of the time they are constructed on legal lands and larger lots which leads to a lower population density (Arizmendi, Arizmendi, and Donelson 2010).

2.2.4 Characteristics of Colonias Residents

Culture is one of the features that influences the morphology of a neighborhood. Culture is defined as a way of living influenced by race, ethnicity or other social characteristics (Bodley 1994). It focuses on traditions, norms, values, habits and daily relationships between people and selection of places; these factors are the important determinants for spatial choices of people and their “sense of place” based on physical, personal and familial relations (Johnson and Zipperer 2007). Therefore, it also influence sthe selection of houses and neighborhoods by considering housing prices, level of supply of consumer services, quality of landscapes, and social composition of neighborhoods (Faust et al. 2000; Geoghegan, Wainger, and Bockstael 1997; Leggett and Bockstael 2000; Mertens et al. 2000).

The characteristics of colonias residents also show differences from the rest of U.S. population. According to U.S. Census Bureau, 66.9% of households in the U.S. are homeowners and 65.3% in Texas (U.S. Census Bureau 2010). People living below the poverty line are most likely to rent instead of own a house; 65% are renters. According to Durst (2014), there is a growing population of renters in Texas colonias. Race and ethnicity influence the tenure type due to culture. For instance, within the Hispanic population, even the poorest section prefers to be a homeowner in comparison to African Americans (Ward and Peters 2007). However, they do not always have access to legally developed lands with adequate infrastructure and services.

Herzog suggests that people living in the border colonias are part of a "transnational community" which is an integration of two cultures, Mexico and the United States (Herzog 1999). Residents of the colonias also share similar characteristics such as low-income levels with 60% of the population in colonias living below official poverty line, low education level, and language difficulties which have led to both physical and social isolation (Davies and Holz 1992; Donelson and Esparza 2010; May et al. 2003; Mier et al. 2008). Income level of colonias residents are significantly lower than national income standard in U.S.; according to the U.S. census data, (a) the median income level of colonias residents is one-third of the median household income in the U.S. and one-fourth of Texas, (b) the average family size is larger than the national level, and (c) a great proportion of Hispanic population than the rest of U.S. (U.S. Census Bureau 2010; Martinez 2010).

Colonias consist of primarily Hispanic population with larger family size than the average in U.S., and colonias residents' median household income is $14,458 less than the U.S. average ($44,334) (Martinez 2010). Residents in the colonias generally work in agriculture, construction and manufacturing, usually as seasonal workers. The wages of the residents in Texas colonias range from $12 to $14 which means they cannot afford more than a $60,000 to $70,000 house built by homebuilders (TDCHA 2011). When considering the additional costs of land acquisition and development, with that budget it is not realistic to build a home. Moreover, colonias residents are not accepted as credit worthy because of their temporary and low-wage jobs (Giusti and Estevez 2011).

Housing is one of the most critical issues in the colonias. Colonias have a growing population and increased demand for cost-effective housing (Federal Reserve Bank of Dallas 1995). Considering the level of income of colonias residents, in the past the only feasible way of home ownership has often been the Contract for Deed arrangement (Ward et al. 2011). In this arrangement, residents buy land on the border with a low down payment and at a low price.

However, legal title of the land stays with the developer until all the payments are made. A conventional mortgage transfers the title to the purchaser immediately and thus enables the purchasers to build equity.

This economic and social context has led to patterns of land development, construction, and ownership that are outside the standards and norms of formal, government authorized development. In many cases, residents of colonias purchase small lots and build their homes incrementally with help of their family members and friends based on their changing needs over time and availability of money (Ward et al. 2011; Giusti and Estevez 2011). The lots are often outside municipal jurisdiction and within county jurisdictions that do not provide services or enforce regulations. Subdivision of the land by the seller into parcels may be informal or poorly documented. This context has led to uneven quality of construction, ad hoc provision of water, electricity, and sewage services, poor roads and transportation, inadequate security, and inconvenient schools and economic markets.

2.2.5 Classification of Colonias

U.S. Geographical Survey (USGS) developed a three level classification criteria for colonias represented by colors: red, yellow and green by CHIPS method (Parcher and Humberson 2007) (Figure 4). Red denotes colonias with highest health risk due to having inadequate wastewater disposal, not having potable water supply or lacking plats. Yellow, on the other hand, symbolizes communities with medium health risk because they have access to basic services and infrastructure such as water supply, sewage systems, paved and passable roads but are at risk of flooding during a precipitation event. Green colonias have also access to basic services but they are not exposed to flood. The three selected colonias in this study are coded according to USGS's three levels of classification of colonias as being either red or green. For the purpose of this study, they will be referred to as Green Colonia, Red I and Red II.

The sample population in this study consisted of the colonias residents in Webb County, Texas, who are performing self-help upgrading interventions to their informal houses. Webb County Self-Help Center in Laredo is one of the six centers established in 1995 by Office of Colonia Initiatives (Vargas 2012). These centers assist colonias residents in "housing and community development services, infrastructure improvements and outreach and educational services" (Vargas 2012).

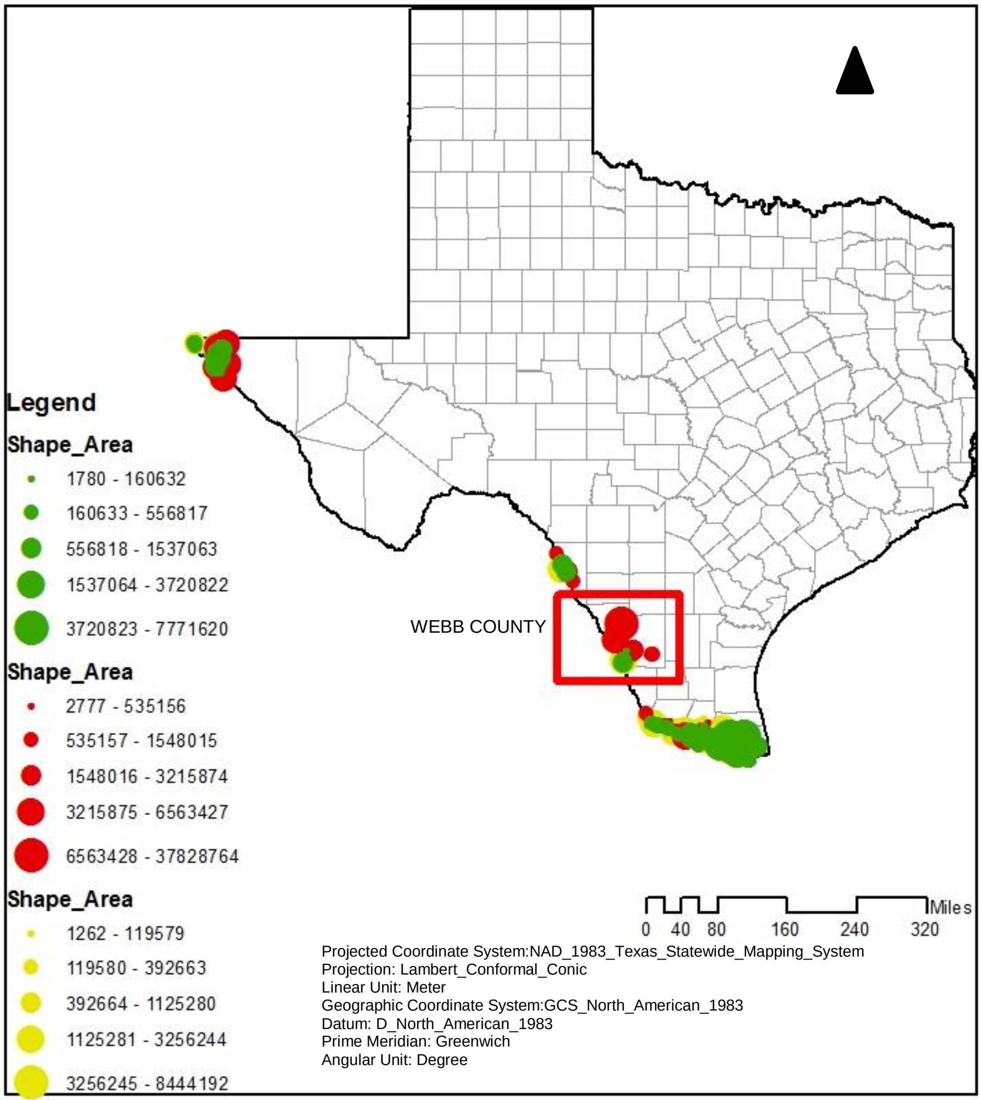


Figure 4: Map of Texas colonias: Size of circles represents the colonia shape-area in square meter

2.2.6 House Typology in the Colonias

The major house types on the U.S.- Mexico border include (a) self-help border houses with additions built incrementally through a long period, (b) manufactured homes (single or double wide trailers, or modular manufactured homes), and (c) recreational vehicles and campers (Sullivan and Ward 2012; Ward, Olmedo, et al. 2010) (Table 1).

Table 1: Housing types in colonias

Classic Self-Help Border Houses	Manufactured Homes	Recreational Vehicles and Campers
		
		

Self-help border houses are the structures that are built by the residents themselves over time to meet their changing needs according to the availability of money. This method of home construction results in a variety of form, materials, construction techniques, and standards. Due to the proximity to Mexico, colonias have a diffuse architectural tradition (Herzog 1999). Therefore, these houses exhibit different architectural styles from conventional U.S. or Mexican residential architecture (Méndez Sáinz and Banister 2003).

Manufactured homes are structures that are assembled off site and moved onto the lot. After the wheels are removed, they are placed on piers or concrete blocks. They are mostly *single* or *double wide trailers* showing a great variety in terms of form, materials, construction techniques and standards due to their production date. On the other hand, they show a great deal of standardization in terms of dimensions as all of them are 12 feet wide and 50 feet long due to highway considerations. Although *modular homes* are included as manufactured homes, they lack a wheelbase.

Recreational Vehicles and Campers are designed for regular towing and repositioning as temporary structures. They often provide residents temporary accommodation during self-built home construction process or serve for additional sleeping space for residents or guests. They may also be incorporated into the permanent structure.

Within these three types of houses in the colonias, there is a great variety of value, ranging from $500 trailers to half constructed homes to formal middle-class houses (Coronado 2003). Most occupants still live in unfinished houses; residents continue to upgrade their homes through self-help practices by using their savings and sometimes small loans provided by NGOs (Durst and Ward 2014). Davis and Holz (1992) surveyed three colonias in Texas and the results of their research indicates that the frequency of housing types ranges from 15% concrete block structures, 65% wood frame structures, 15% buses or trailers, and 23% shacks or campers.

According to the study of Ward (2001) which surveys 261 structures in 14 Texas colonias, 64% of the residents live in a self-managed home which includes self-built structures, mobile homes and manufactured homes, 16% of the residents live in trailers, whereas 3% lives in campers or shacks. 20% of the residents, on the other hand, own a structure which is comprised of several of these housing options.

Various combinations of these three types of homes are also common. However, common building materials in colonias vary according to their availability and affordability and include wood, cardboard, concrete blocks or other materials (Federal Reserve Bank of Dallas 1995; SOS 2012), or recycled materials such as cardboard and crates, dilapidated trailers, or campers (McKenzie 2002).As these houses are built by their residents according to their own needs, traditions and availability of money, they exhibit a great variety in terms of form, materials, and construction techniques.

2.2.7 The Major Challenges of the Housing in the Colonias

According to the literature, these settlements often have deficiencies as individual homes and the aggregation of many homes into a community:

(1) *Unsafe and Substandard Housing built through Unregulated Design and Construction.* Informal settlements are usually built using methods that scarcely meet the regional and local building standards because the standards reduce affordability due to the high initial capital needs (Bradshaw et al. 2005). However, in the long term, the substandard construction increases the maintenance and operational costs and may harm the good health and safety of residents (Davidhizar and Bechtel 1999; Donelson and Esparza 2010; Govender, Barnes, and Pieper 2011; Keall et al. 2010; Lawrence 2004; Parcher and Humberson 2009). In colonias, the building process may occur over years using available materials without any assistance from professional builders. This can lead to variation in quality within a single homestead. Furthermore, the colonias contain a wide variety in housing quality spanning from very high quality builder-constructed houses to shacks and trailer homes.

A number of studies performed in different colonias in Texas emphasize the severe housing conditions: 33% of colonias residents live in moderately to severely substandard housing, 80% of 1,000 houses in the Cameron Park colonias are identified as substandard (HUD 2008), and the results from Rancho Vista and Redwood colonias show that roof leaks, poor insulation, and extreme indoor temperature in summer are the major severe housing conditions to address (Ward, Olmedo, et al. 2010).

(2) *Poor Building Performance and Increasing Energy Consumption.* The impacts of informal settlements upon energy consumption are often very high as a result of the lack of precautions and practices to provide sustainable use of energy (UN-Habitat 2008; 2010). Several studies demonstrate that a low-income family spends more in dollars for energy for heating, cooling, lighting, and appliances than does an average U.S. family living in better houses and neighboring areas (Gharaibeh et al. 2009; Machado 2006). A study focusing on electricity bills of colonias' residents in El Paso county in the state of Texas shows that the average monthly electricity payments of residents in colonias (82.5 $/mo) is 40% more than the average payments in El Paso county (59.7 $/mo) (Machado 2006).

The difference in energy consumption is a result of both lack of infrastructure systems and poor housing conditions. According to Ward, Olmedo and others' study (2010), in colonias houses, the major problems are leaking roofs, unstable foundations and footings, poor and dangerous electrical systems, poor insulation and improperly closing doors and windows, poor ventilation, and inadequate cooling and heating. They also find a negative correlation between the age and the quality of insulation and a positive correlation between the cost of house and quality of insulation. Therefore, the common upgrading interventions on houses in the colonias are installation of air conditioning systems, and due to the lack of insulation, improvements on roof and floor materials (Giusti and Estevez 2011). When aggregated into the entire community, the potential impacts of these houses upon energy consumption may increase exponentially as residents adopt air conditioning and other energy intensive practices (UN-Habitat 2008; 2010).

(3) *Low Recognition of Equity Creation and Poor Access to Capital.* Since the values of the homes are not recognized and residents have poor credit history, residents are often not able to finance improvements without collateral (TDHCA 2012). Without access to a mortgage,, houses in the colonias are most of the time bought and sold with a contract for deed (Durst 2014; Durst and Ward 2014; Ward et al. 2011; Giusti and Estevez 2011; Ward, de Souza, and Giusti 2004). Contract for deed are a financial arrangement in which the seller holds the title until the loan is totally paid and often carry high interest rates (Federal Reserve Bank of Dallas 1995). This arrangement can lead to economic inequity due to three reasons: (1) the contract is not recorded by a county clerk, and thus may be difficult to enforce, (2) the homeowner does not obtain a title until all payments are finished and may lose all rights if one payment is missed, and (3) the homeowner cannot acquire equity until the title is transferred, leading to poor access to capital (Federal Reserve Bank of Dallas 1995).

(4) *Inattention to Best Practices for Sustainable Community Development.* The community in general suffers from unsustainable community development due to lack of awareness on the part of the residents (Galster 1987; Rohe, Van Zandt, and McCarthy 2002). The knowledge of residents about sustainability and sustainable housing practices is found to be very limited and a careful examination of the sustainability of low-income homeownership is not well-established in the literature (Van Zandt and Rohe 2011; Ward, Sullivan, et al. 2010; Sullivan and Ward 2012).

Inevitably, populations expand, communities become formalized and incorporate higher standards of living, and energy resources become scarce. These pressures add to the urgency and importance of achieving greater energy efficiency and sustainability in informal settlements. Resolving this situation may become an acute challenge.

Introducing sustainable and energy-efficient design and construction solutions may play an important role in reducing escalating impact on resources. However, social considerations can be a barrier to acceptance of the suggested strategies by colonias residents. In a phenomenon known as “transitional architecture”, the houses in the colonias incorporate different architectural styles and patterns than conventional U.S. and Mexican residential architecture due to incorporation of two cultures (Méndez Sáinz and Banister 2003). Some materials and methods are avoided due to being stigmatized by associations to poverty while others represent aspirations to raised social class (Donelson and Esparza 2010). Therefore, a barrier to adoption of improved building methods is that they may not align with social and cultural factors of the residents. It is important to understand and document the existing houses and residents’ attitudes prior to proposing sustainable improvement strategies for these settlements. To that end, understanding and documenting the existing housing design and construction patterns is crucial.

2.2.8 Assistance on Colonias Housing Conditions and Building Performance

For colonias, several standards have been established to improve housing conditions and building performance. HUD and Federal Housing Agency (FHA) have developed a set of minimum standards for structure, materials and building performance for housing in the colonias called Colonia Housing Standards (CHS) (TDHCA 2012). Additionally, HUD and Department of Energy (DOE) have provided construction, safety and codes and standards for manufactured homes entitled Manufactured Home Codes and Standards (HUD 2012).

At state-level, Texas Department of Housing and Community Affairs (TDHCA) has developed the Colonias Self-Help Center (SHC) program according to the 74th Legislature in 1995 and has established centers in several counties of Texas such as Cameron/Willacy, Hidalgo, Starr, Webb and El Paso (Vargas 2012). The program’s objective is to assist residents in housing improvements, new construction, infrastructure access, and financial access for mortgages (McKenzie 2002; SECO 2011; TDHCA 2012; Vargas 2012). These centers are run by nonprofit organizations, local community action agencies, or local housing authorities.

To perform sustainable interventions on the houses in colonias, a number of federal and local programs provide financial assistance to colonias residents such as USDA Direct Housing Loans, Home Repair Loan and Grant Program, Mutual Self-Help Housing Program, Housing Preservation Grant, Weatherization Assistance Program, Property Assessed Clean Energy

(PACE), and Property Tax Incentives. Moreover, Giusti and Estevez (2011) propose micro-lending for housing improvements and suggest that this also has a potential positive impact on the local economy through creating employment opportunities in colonias in U.S. To apply micro financing for dwellers, it is good to know both the equity owned by residents and the cost of their future improvements before implementation (Choguill 2007). However, according to a recent study performed in Rancho Vista and Redwood colonias, the knowledge of residents about sustainability and sustainable housing practices is found to be very limited (Ward, Sullivan, et al. 2010). Therefore, residents need consultation of professionals / experts on sustainable design and construction techniques, and need information on building performance and energy consumption.

2.3 Methods for Low-Cost Sustainable House Design

By delivering knowledge of low-cost sustainable design practices and strategies, residents can determine improved choices with respect to sustainability while performing self-help construction. If the quality of housing is improved, the quality of life is increased and then it may cause new job opportunities related to construction leading to socio-economic stabilization in the society (Wekesa, Steyn, and Otieno 2011). If the quality of housing is improved, energy use will decrease (UN-Habitat 2008) along with residents' electricity bills (Gharaibeh et al. 2009; Machado 2006), and then their impact on the environment will also decrease as well (UN-Habitat 2008). In order to improve housing quality, there is a need to assist residents on how to improve their houses with low-cost and higher building performance construction techniques and materials (Choguill 2007; Tolba 1987). If assistance is provided by community centers in the settlements, it will empower the community. If residents participate in both design and construction process, it may reduce the cost of construction (Wekesa, Steyn, and Otieno 2011). This chain of reasoning suggests an altruistic motive for finding new and better ways to deliver knowledge of sustainable residential construction in the colonias, improving not only the lives of residents but also the general social welfare.

2.3.1 Low-Cost Sustainable Strategies

Studies on low-cost sustainable strategies for existing low-income houses branch out to two directions: (1) rehabilitation of existing houses and design, and (2) construction of new houses. Their findings exhibit that there are low-cost sustainable strategies to reduce energy use for low-income housing. Santamouris (2007) finds a strong relationship between income and thermal performance of the houses by combining socio-economic data of surveyed Greek residents and construction quality of their houses. Since low-income residents live in houses that scarcely meet the regional or local building codes, improving their construction quality plays a crucial role beside the additional sustainable building technologies and can reduce energy consumption due to their use (Alaghbari et al. 2011; Pulselli, Simoncini, and Marchettini 2009; Santamouris 2007).

Other studies stress the importance of early design stage decisions. Building orientation, building massing, building envelope and weatherization, passive heating and cooling strategies, building systems including HVAC, lighting and appliances, renewable energy, water conservation, and resource efficient materials (Global Green USA 2007) are the components that should be addressed for designing low-cost sustainable housing. Form, building body and building envelope are the three main elements that Thomas and Fordham (2006) suggest considering while designing a structure. Solar gain, materials and construction, and finishes, insulation, glazing, lighting, mechanical systems (engineering thermal comfort), ventilation (cross ventilation, stack effect ventilation) are the important determinants for energy use (Thomas and LLP 2006). According to UN-Habitat (2011), there are several proven passive, low-cost and low-energy strategies and techniques such as “passive solar heating, thermal mass, natural ventilation, evaporative cooling, other passive cooling techniques, high performance building envelopes and energy efficient mechanical systems.” However, they all need to be adjusted according to climate and human comfort requirements.

Two studies find that by considering sustainability in very early stages of design process, energy consumption can be reduced without using any additional sustainable technologies (Alaghbari et al. 2011; Schlueter and Thesseling 2009). Similarly, other studies find that design has a key role in sustainability (Pitt et al. 2009) and also can reduce the cost (Yates 2003). Morrissey, Moore and Horne (2011) investigate the house plan and orientation as low-cost options in design process; they investigated this option by modeling 81 different detached dwelling designs and discovered that energy usage can be reduced without any additional cost during design phase. Moreover, Yates (2003) states that building material selection has a significant impact on energy conservation. Winkler and others (2002) study the impact of energy efficiency interventions in low-income affordable housing; they focused on the heating or thermal interventions on the window size and wall and roof insulation, ceiling, more efficient lighting and water heating systems.

In order to reduce the cost of housing, self-help involvement of residents in all steps is required to overcome unregulated design and construction in low-income and informal settlements (Choguill 2007). This practice leads to long term cost-effectiveness, which is another important sustainability criterion. Two studies suggest using local materials to reduce cost and gain energy efficiency; self-help installation is crucial to reduce the initial cost (Mohamed and Darus 2011; Zami and Lee 2010). In order to make high quality self-help construction possible, there is a need for advisory centers for helping and assisting residents on how to reduce their energy bills (Clarke et al. 2008).

To sum up, low-cost sustainable upgrading practices for informal settlements is a complex process. The literature related to sustainable construction and design practices often focuses on houses for middle-income and high-income residents, rehabilitation of existing houses for low-income settlements, and infrastructure systems of informal settlements. Although there are low-cost strategies to reduce energy use for low-income housing, the focus of research has not been towards the quantitative documentation of different low cost practices for reducing energy usage (Bradshaw et al. 2005; Häkkinen and Belloni 2011) or the impact of improving quality of construction on cost (Mohamed and Darus 2011). There is a need for a comprehensive database of sustainable and affordable housing materials and construction techniques including a measure of cost, and energy consumption (building performance) which may be used in any specific geographical locale for low-income residents (Bordignon 1998). Such a database is outside the scope of my research, although my contributions may advance a method for exploring the energy efficiency and construction cost of materials and methods.

2.3.2 Spatial Agency: Sustainable Architectural Service Delivery Model from Experts to Residents

The notion of 'agency' in architecture refers to a new approach that is different from traditional space production. In the literature, several scholars have discussed the notion of 'agency' in architecture by focusing on architectural theory; they question the role of architects and advocate that the best solutions to a spatial problem can be produced by a collaborative process which involves 'agents act with or on behalf of others' (Cairns 2009; Doucet and Cupers

2009; Lash and Picon 2009; Schneider and Till 2009; Stickells 2011; Vardy 2009).The term 'agency' has its roots in social and political theory and recently has been employed in diverse segments of architectural discourse; it means "lead to other possible futures" or "guide society towards better end" (Doucet and Cupers 2009). Anthony Giddens (1984) interprets 'agent' as "being able to intervene in the world or to refrain from such intervention, with the effect of influencing a specific process or state of affairs". Giddens sees 'structure' and 'agency' as a 'duality' in which their dialectic pairing enables social reproduction as a recursive, on-going process. 'Agency' in architecture encompasses a variety of concerns such as the role of architects in guiding social and political change, and the architectural object and its impact on individuals and society (Lash and Picon 2009).

Awan, Schneider and Till (2011) have named this notion 'Spatial Agency', which refers to architects providing consultation to non-professional and self-builders in design and construction. It encompasses the concept of 'advocacy architecture' is the idea that architects can provide service to disadvantaged populations by active use of information technology and tools, and public participation in the design process (AFH 2006; El-Kadi 1999). Advocacy architecture incoprates the idea of resident empowerment, and self-help architecture that encourages residents' participation in the process of spatial design and construction (Davis 2006; Huchzermeyer 2004). In the same way, self-built environments (such as informal settlements) that emerge bottom-up, involving the actions of ordinary people, are seen as the result of "spatial agency"(Awan, Schneider, and Till 2011). This approach adopts a bottom-up theory that coincides with the structure of informal settlements.

In the context of spatial agency, 'agents' are the actors who provide support for others to empower self-managed approach, by being responsible for long term needs and demands of others who occupy; agents have specific roles: (1) operating as a collective reinforcement in the process of spatial production, (2) looking beyond the initial construction process after it is completed, and (3) providing support structures to empower others in self-managed and self-built process (Awan, Schneider, and Till 2011). Therefore, in this research, the term "agent" is used to refer to professionals engaged in these centers who "enable citizens to engage in their environment through giving specialist advice" (Sheffield School of Architecture 2012) and "bring professional services to people and communities who would otherwise not have access to them" (Awan, Schneider, and Till 2011).

2.3.3 Four Existing Studies on Sustainability and Housing Conditions in the Colonias

This study has been built on four existing studies.

(1) Reimers' (2009) study focuses on the diversity and the practice of the consolidation of colonias houses. He concentrates on the change in housing form patterns according to the household in South Texas. He conducted a field survey and semi-structured interviews to ten selected colonias on the change in house form and household characteristics over time. Results demonstrate that colonias share similar patterns of change over time. Therefore, it is important to understand the pattern of change in order to assure the success of interventions to improve housing quality.

(2) The study by Ward, Olmeda, Rojas and Sullivan (2010) investigated self-help housing conditions, and construction techniques in Central Texas colonias; Rancho Vista and Redwood in Guadalupe County, central Texas. They documented the existing housing conditions in these two informal subdivisions through a survey. The questionnaires developed by Reimers, and Ward, Olmeda, Rojas and Sullivan were used to develop the interview questions for this research.

(3) Ward and others (2010) developed a report on an evaluation of extending contemporary sustainable housing design and technology strategies to informal settlements: colonias.

(4) The work of Sullivan and Ward (2012) attempted to apply contemporary sustainable housing strategies to self-help informal housing in the U.S. colonias and in Latin America. They documented a number of sustainable housing applications utilized in U.S. and assessed their applicability in both U.S. and Latin America contexts. In the third and fourth studies, they have identified the optimal sustainable housing applications/ interventions to low-income houses by considering the cost and applicability by residents themselves through four strategies: "(1) "Microclimate design and technologies to support greater energy efficiency, (2) renewable energy technologies to support access to alternative energy, (3) water and wastewater technologies to promote water conservation and quality, and (4) waste systems to promote resource reuse and recycling" (Ward, Olmedo, et al. 2010; Ward, Sullivan, et al. 2010; Sullivan and Ward 2012). They assessed each intervention/addition according to ease of maintenance, cost savings, initial cost and human capital. However, these studies only focus on the rehabilitation of existing houses, mostly manufactured homes, without considering any improvements on the construction techniques and materials or design principles and they have not measured the change after applying these technologies.

The knowledge of residents about sustainability and sustainable housing practices is found to be very limited, and a careful examination of the sustainability of low-income homeownership is not well-established in the literature (Van Zandt and Rohe 2011; Ward, Olmedo, et al. 2010). Thus, my research differs from these previous studies by by utilizing advanced architectural practice methods and technology in order to collect data on housing forms, materials, construction techniques, energy consumption and cost analyses, and resident profile. With the increased knowledge on sustainable design practices, residents could be able to optimize their decisions in the world of sustainability when performing self-improvements in their homes.

2.3.4 Building Information Modeling Tool

Building Information Modeling (BIM) is a recently introduced technology in the Architecture, Engineering and Construction Industry (AEC); it is an object-based parametric modeling tool in which the objects are defined by parameters and rules may be set up by the designer to determine geometric and non-geometric features (Eastman et al. 2008). The BIM represents the building components with geometric descriptions and integrated information. A BIM representation is different from respresentations produced by other conventional design tools such as Computer Aided Design (CAD) that focus more heavily on drawing. The BIM is richer in non-graphic information and fundamental semantics of architecture and construction. This more complete representation enables BIM to support automated energy simulation, automated cost estimating, construction simulation, structural analysis and other models of building performance.

Although BIM has rarely been used for modeling structures in informal settlements, Geographic Information Systems (GIS) software are currently widely used for integrating spatial and non-spatial data and have been applied to studies of the colonias. GIS is a computer based-spatial information system developed and used to manage geospatial data and to solve spatial problems by using this data (Lo and Yeung 2007). Although CAD and computer-assisted manufacturing (CAM) systems are also considered to be spatial information systems, they are different from GIS as GIS uses geospatial data. GIS systesm have evolved from traditions of mapping and overlays upon 2D maps, while CAD systems have evolved from drafting and representation of 3D objects. Reference to geographic space (geographical coordinate system of Earth's surface) and representation at the geographic scale are the characteristics of geospatial data that makes it differ from other spatial data. In the context of modeling informal settlements, several studies in the literature utilize GIS to manage, monitor and predict residents' health, expansion of the colonias communities, and growth of the resources (Davidhizar and Bechtel 1999; Mier et al. 2008; Parcher and Humberson 2009; USDA-RD 2011).

GIS combines spatial data which is represented as points, lines and polygons and attribute data in conventional database tabular form including rows and columns (Gregory and Healey 2007). To that extent, GIS tool enables users to perform queries of what and where on the geographic maps. It is a platform to visualize the data; a GIS model can include data on geographic, environmental, demographic, structure, aerial photos, and land use maps. For instance; The Colonias Monitoring Program developed a GIS map that accommodates several data layers: "transportation routes, digital orthophoto quadrangles, digital raster graphics of Landsat imagery, colonias boundaries, hydrography, demographics, and geographic names" (HUD 2003). To enhance visualization and design process, several design software systems have been developed such as Autodesk's Project Galileo and Autodesk Civil, Bentley Systems's Bentley Map, Holistic City Software's CityCad and Placeways LLC's CommunityViz. These tools allow quick visualization of urban models (Gil et al. 2010). Although GIS is effective at studying phenomena at the geographic scale, the technology lacks parametric modeling and cannot easily accommodate data on design patterns, materials, construction, and individual buildings parameters and components.

BIM software has several significant capabilities for studying structures in informal settlements:

(1) *3-Dimensional Modeling of a Building.* BIM technology allows and supports creating 3-dimensional models of a building that reflects the real time changes (Lee, Sacks, and Eastman 2006; Eastman et al. 2008). From the 3D model, perspective visualizations as well as conventional plans and sections may be generated quickly to enable residents to understand a

design, constructors to list materials and quantities, and constructors to build the building accurately.

(2) *Documenting and Collecting Data.* BIM tool can document detailed information on the design, construction and operation of existing and proposed buildings. The National Building Information Modeling Simulation (NBIMS) committee configures BIM as folded into eight data sets: (1) designer data, (2) legal data, (3) geospatial data, (4) financial data, (5) specifier data, (6) environmentalist data, (7) sustainers data, and (8) owner/ occupier data (Bazjanac 2007; Eastman et al. 2008). In other words, BIM tools provide not only three dimensional visual models but also extensive information on individual buildings.

(3) *Developing specific libraries of components and system families.* Typical buildings can be modeled by BIM design tools using an embedded library of components. The tools also allow users to create their own library. This is crucial for modeling buildings in informal sttlements. The standard BIM components (doors, and windows) or system families (walls, ceilings, roof, and floors) are not capable of representing the real situation in informal settlements since these houses are built with materials and techniques that may not conform to the building standards. Thus, there is a need to develop new library that *supports modeling buildings in the colonias*. The library can include parameters such as dimensions, material types, thicknesses and cost.

(4) *Providing parametric modeling in BIM.* Parametric modeling can institute variation of geometrical components of objects through created models. (Hernandez and Roberto 2007; Woodbury 2010). Integrating parametric modeling into design process results in flexible solutions of forms and materials (Baerlecken et al. 2010; Steinfeld et al. 2010; Tang and Anderson 2010). Moreover, integrating algorithms in parametric modeling enables software to deal with more complex forms and leads to a variety in object geometry (Marcos 2010). Very importantly, parametric modeling allows the rapid adjustment and change of building representation to permit "what-if" studies.

(5) *Supporting performance analysis and simulation of a design for sustainability by using interoperable tools*. BIM supports simulations tools that can be used to analyze the cost, energy, and other performance of the proposed structures. Use of these simulation tools allows users to examine their design in early stages by changing the form, or materials, or applying

other strategies. To examine the risk of a proposed building, a number of simulation tools have been frequently used in U.S such as Energy Plus (www.energyplus.gov), DOE-2 (simulationresearch.lbl.gov) , eQuest (www.doe2.com/equest), Energy-10 (www.nrel.gov/buildings/energy10), HEED (www.aud.ucla.edu/heed), ECOTECT (www.ecotect.com), Green Building Studio (GBS), Vasari, TRNSYS (sel.me.wisc.edu/trnsys), IES-VE (www.iesve.com). However, these tools are mostly dependent on user inputs of building components and loads which presents a major challenge (Hand et al. 2008). To overcome this challenge, linking of 3D rich visual BIMs of buildings and the computational tools is the focus of most research efforts.

To sum up, BIM has the potential to make a positive impact on modeling informal houses to support visualization, design, and analysis. It is a complementary technology to GIS that allows study of the colonias at the scale of buildings and components rather than lots, roads, towns, and regions. The development of processes of applying BIM to the design of additions or new construction in the colonias may address the challenges to improving the sustainability of the individual houses and the communities.

2.3.5 Building Performance Analysis Tool: Autodesk Green Building Studio (GBS)

This research will rely upon a particular combination of BIM tools to model residences in the colonias and simulate their performance. Autodesk Revit enables users to perform energy analysis of a project in the earliest design phase by using Autodesk Green Building Studio (GBS) online service (Krygiel and Nies 2008).

By using BIM and interoperable tools for analyzing building performance (cost analysis and simulation tools), time and work are minimized for exchanging data between design tools and analysis tools to aid designers in achieving a more sustainable and high quality design (Bedrick and Rinella 2006). Autodesk GBS is a cloud-based tool that recieves data from the user, performs the analysis on a remote server, and reports results to the user. Autodesk Revit Energy Analysis Interface creates an Energy Analytical Model (EAM) and imports the model as a Green Building XML (gbXML) file to web-based open analysis Autodesk GBS service. The GBS service transfers building information as a Green Building XML (gbXML) file from Autodesk Revit to DOE-2. gbXML is a protocol to transfer building model data from BIM application to energy analysis applications (Bernstein and Pittman 2004). Autodesk Building

Performance Analysis (BPA) uses GBS's database to run analyses on the whole building based on several assumptions such as building construction, schedules and equipment (Stein 2013).

To sum up, in AEC industry, by combining graphical data and non-graphical data, BIM plays a crucial role in changing the traditional architecture and construction practices (Jung and Joo 2011). It can collect information of a project that includes design, construction, operation, and maintenance. Moreover, BIM guides designers towards more sustainable solutions in design by supporting performance analysis tools. According to McGraw-Hill Construction survey of about 300 BIM users, quantity take-off, scheduling, cost estimating and LEED/green analysis are the most frequently used performance analysis tools in BIM(McGraw-Hill Construction 2008). In terms of green design and construction activities, energy performance (67%), lighting performance (60%), HVAC design (52%), green building certification (48%), cost estimating (40%), building materials (42%), electrical design (41%), renewable energy (32%), carbon emission analysis (17%) and water use (12%) are the tools that A/E firms used in BIM (McGraw-Hill Construction 2010).

To that extent, BIM with integrated performance assessment tools can aid field agents to create affordable high performance buildings that meet building standards. With a BIM toolkit, the knowledge and ideas of experts can be modeled as a kit and field agents can assist a colonias resident to design a house or addition and understand the performance and the cost. Therefore, BIM may potentially have a positive impact on data collection of informal houses, and visualizing and analyzing the houses in 3-dimensions.

2.4 Summary

This study aims to develop a BIM-based method for experts to promote and identify low-cost energy efficient design strategies to residents for self-help housing construction in Texas colonias.

3 METHODOLOGY OF THE STUDY

This chapter explains the methodological approaches and considerations used to collect and analyze data for this research. Presented in this section are (1) theoretical framework for mixed-method research, (2) research methods - the qualitative and quantitative data collection and analysis methods for the research, and (3) research plan including the criteria for selection of study area and identifying a representative sample for both colonias residents and experts.

Figure 5 describes the tasks required to accomplish this study.

The research consists of an investigation of homes in the colonias, development of computer-aided modeling methods, and tests of the ability of the modeling methods to represent the homes and support design of additions. The investigation of homes includes a survey of homes in a study area near Laredo, TX, interviews of the residents, and discussion with experts about building patterns in the colonias. Computer-aided modeling methods are developed through acquisition of expertise in using Autodesk Revit and other BIM analysis tools and the refinement of methods through repetitive experience. The tests are conducted by modeling the existing houses with the newly developed tools and conducting an effort to remodel and improve the homes.

3.1 Theoretical Framework for Mixed-Method Research

This study aims to bring human factors and technology together. It combines survey research (qualitative), quasi-experimental research, and model-based research strategies.

This research employs a post-positivist framework which distinguishes reality as separated from the researchers' mind (Lincoln and Guba 1985). This ontological position requires objectivity. However, objectivity is not perfectly achieved since "[e]veryone is biased and all observations are affected (theory-laden)" (Trochim 2001). In the post positivist framework, objectivity can be best achieved through multiple measures and observations in methodology. Post-positivists believe that multiple measurements and observations can reduce errors in measurement and provide a better understanding of reality (Guba 1990). Researchers can mix aspects of qualitative and quantitative paradigm during design process (Creswell 1994). Qualitative research strategy refers to "an inquiry process of understanding a social or human problem, based on building a complex , holistic picture, formed with words, reporting detailed views of informants, and conducted in a natural setting"(Creswell 1994). It dwells on a constructivist or naturalistic approach (Lincoln and Guba 1985). Quantitative research strategy is, on the other hand, "an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analyzed with statistical procedures, in order to determine whether the predictive generalizations of theory hold true" (Creswell 1994). This strategy derives from a positivist, experimental, or empiricist paradigm (Lincoln and Guba 1985). To achieve the advantages of both paradigms of qualitative and quantitative research, I adopted mixed-method research similar to that proposed by Creswell and Clark (2011) as models of combined strategies to improve both internal and external validity.

Creswell and Clark (2011) identify the difference between mixed-method research as a methodology and as a method. They state that as a methodology, "it involves philosophical assumptions that guide the direction of collection and analysis of data and mixture of qualitative and quantitative approaches in many phases in the research process". However, as a method "it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of study"(Creswell and Clark 2011). I have used these definitions to identify my methodology and method.

The reason for selecting mixed-method research as the methodology of this research is to eliminate the weaknesses of each individual method through (1) triangulation, and (2) development by using methods sequentially. By using triangulation, it is expected to neutralize bias inherent from use of a particular data source, investigator, and method by combining and synthesizing results that derive from other data sources, investigators, and methods. Sequential development, on the other hand, would utilize results from the first method as information for the use of the second method (Creswell 1994; Groat and Wang 2002). Mixed-method research reduces the bias of the researcher, improves reliability and validity.

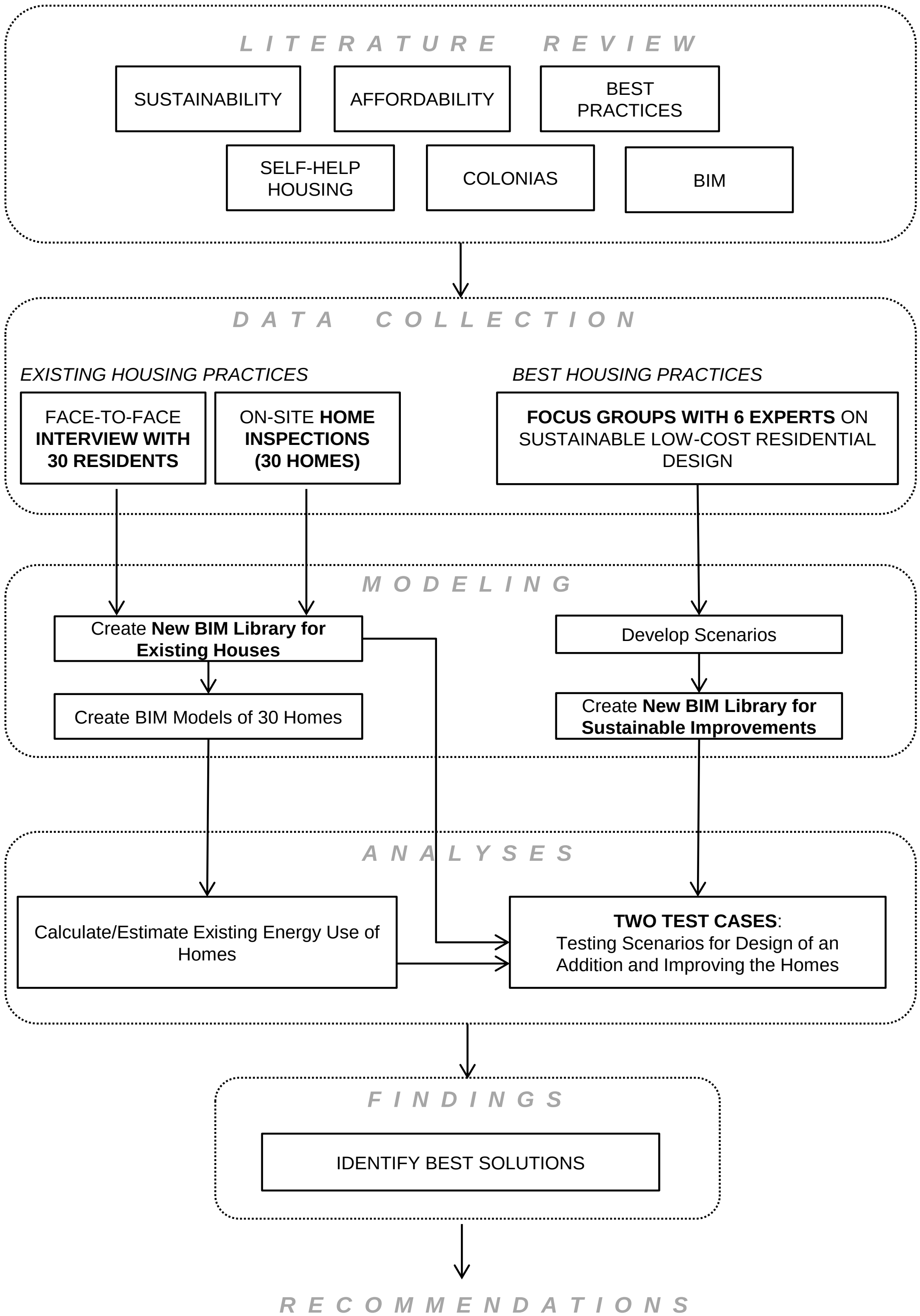


Figure 5: Conceptual model of developing BIM toolkit for low-cost sustainable practices in the colonias

3.2 Research Methods

A foundation of this research is 'knowledge engineering' which includes the following tasks: (1) "talk with human experts who perform the task, and extract from them the facts, representations, methods, and rules of thumb that they employ in doing the task", (2) "encode these in a running prototype system, and then extract more and more knowledge, as the program runs and makes mistakes which the expert can easily translate--in context--into additional pieces of knowledge that should have been in the system all along" and (3) test the system (Lenat and Feigenbaum 1991).

This study also adopts a mixed-method approach that Creswell and Clark (2011) define as a study collecting, analyzing and mixing multiple forms of either qualitative or quantitative data to achieve research goals. First, the survey of literature review built the logical framework and supported construction of a theoretical foundation for the research. Building upon this foundation, the second phase involved qualitative data collection methods with mixed-methods data analyses: (a) interviews with residents in colonias and field survey of their houses to document existing vernacular self-help building traditions of people living in colonias, and (b) focus groups with experts to identify ways to increase energy efficiency, improve quality of life, and assist in acquisition of equity for residents. The third phase relied upon quasi-experimental model-based research methods comprised of (a) building an apparatus (software process) and (b) conducting quasi-experiments with the apparatus through both quantitative and qualitative data analysis.

3.3 Study Area: Selection of Three Colonias in Laredo, Webb County, Texas

The study area of this investigation is Texas since it includes the largest number of colonias residents (Parcher and Humberson 2007). The case study included self-help houses that met the criteria of (a) accessibility and field work support, (b) data richness, (c) manageable size, and (d) varied ages and types of self-help housing. Sample population in this study consisted of the colonias residents in Laredo, Webb County, Texas who are performing self-help upgrading interventions to their informal houses. Webb County Self-Help Center in Laredo is one of the six centers established in 1995 by Office of Colonia Initiatives (Vargas 2012). These centers assist colonias residents in housing and community development, infrastructure improvements and educational services. Los Altos, Tanquecitos I & II, San Carlos I & II, Ranchitos 359 East and D-5 Acres are the five colonias that Webb County Self-Help Center targets (TDHCA 2008).

Several colonias in Laredo were visited in September 2012 and three colonias, along north of Highway 359 were identified as the focus of this study (Figure 6 and Figure 7). One of them is classified as “green” colonias whereas the other two are coded “red” by Texas Secretary of State (SOS 2012) (Figure 7). Therefore, in this study, they are reffered as Green, Red I and Red II with respect to the confidentility of the residents. Although Green Colonia is one of the smallest colonias in Laredo in terms of acreage, it has the largest population due to a higher density with 36 acres and 544 inhabitants located within the city limits of Laredo. On the other hand, Red I and Red II have smaller population and are located outside the municipal jurisdiction. They are bigger in terms of acreage (Figure 8 and Table 2). Another difference between the selected colonias is that Moreover, Green Colonia has a Community Center that may provide benefits to reach the residents whereas Red I and Red II do not. These three colonias represent the various characteristics of the colonias.

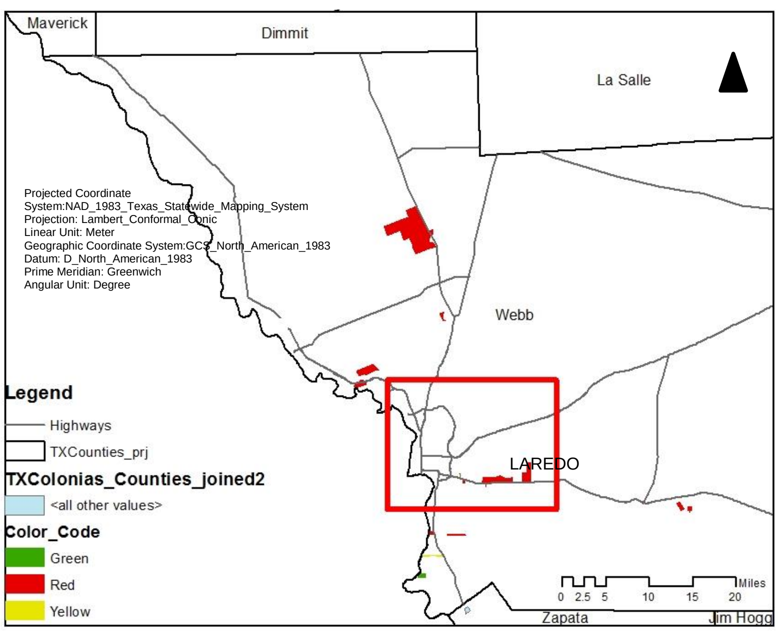


Figure 6: Map of colonias in Webb County: Color green represents green coded colonias, color red represents red coded colonias, and color yellow represents yellow coded colonias.

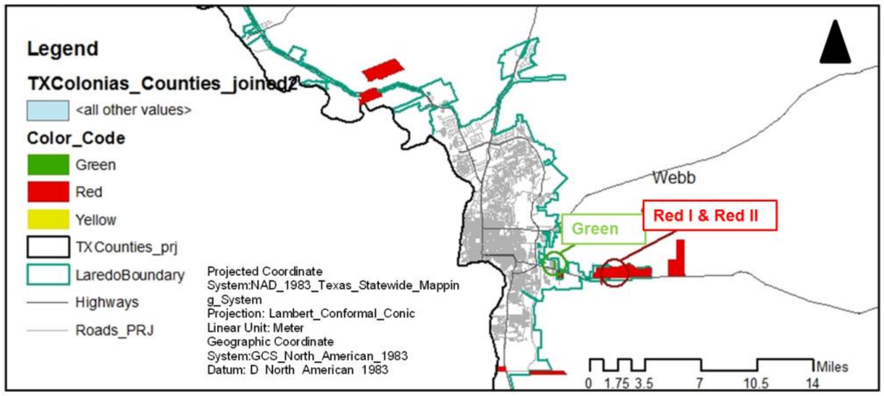


Figure 7: Map of colonias in Laredo, Webb County: Green Colonia and Red I and II.

Table 2: Three selected colonias characteristics (adapted from Abbott 2010)

SB827 Report Colonia Classification	Acres	Population (2000 census)	Promotoras	Total Number of Lots	Total Number of Occupied lots	public distribution of water	potable water on lots	private wells	Water hauled in	wastewater collection	trash Collection	Floadplain	Paved Roads	Electric Problems
Green	36.13	544	Yes	140	126	Yes	Yes	No	No	Yes	Yes	No	Yes	0
Red	53.11	474	Yes	96	81	No	No	No	Yes	No	Yes	No	Yes	0
Red	302.81	404	yes	95	59	no	no	no	yes	no	yes	Partial	yes	0
Red	82.37	345	Yes	98	66	no	no	no	yes	no	yes	Partial	Yes	0
Red	45.32	249	Yes	62	44	no	no	no	yes	no	yes	Partial	Yes	0
Red	442.08	85	Yes	26	8	no	no	no	yes	no	yes	no	yes	0
Red	586.98	13	Yes			no	no	no	yes	no	yes	no	yes	0
Red	368.71	603	Yes	291	129	no	no	partial	yes	no	yes	no	yes	0

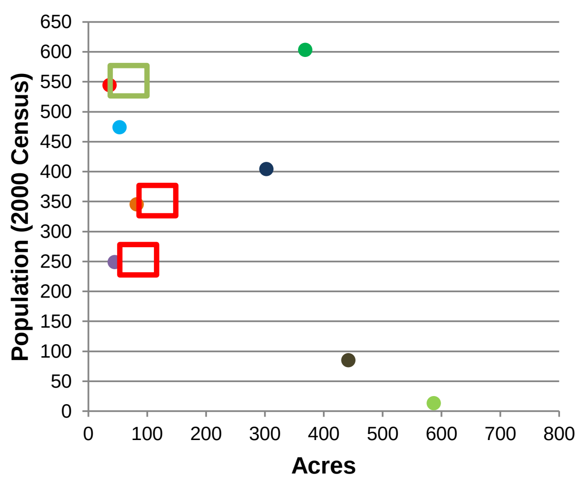


Figure 8: Density graph of colonias in Laredo, Webb county, Texas (adapted from Abbott 2010)

All of these colonias are served by “promotoras”, social workers who are hired from the community to assist residents in finding social aid of various types. The presence of promotoras, noted in the Table 2, improves access to colonias residents for conducting this research. Promotoras are managed by the Texas A&M Colonias Program, which was established by the state legislature in 1991. It has a central office which has moved from College Station to San Antonio, and three regional offices in Laredo, El Paso, and Weslaco together with 22 Community Resource Centers and 4 Service Centers (colonias.arch.tamu.edu). This program has a strong connection to the colonias residents which enables researchers to conduct interviews or field surveys.

3.3.1 Socio-Economic Profile

To collect socio-economic profile of selected three colonias, census 2000 data was referenced for Green Colonia CDP while Census 2010 data is used for Red I and II CDP. The data provided from census 2000 denotes that Green Colonia has 742 total population with almost exclusively Hispanic population (96.8%). Census 2010 data for Red I CDP show that with a total 316 population, the median age is 22.6, and the population is entirely Hispanic (100%). On the other hand, Census 2010 data for Red II demonstrates that the total population is 261 with a median age of 19.9. The population is almost exclusively Hispanic (98.5%).

Income level may indicate the resources that residents have to invest in their homes. American Community Survey 2011 (5 year estimate) demonstrates that Laredo has 55.4% employment rate within population 16 years and over. Median household income is $36,665. Red I has 51.3% employment rate. According to ACS 2011 data, most residents are in the $25,000-$34,999 income and benefit bracket.[2] For comparison, according to the same data source, Texas has median household income of $50,920 with a 60.2% of employment rate. Therefore, the selected colonias have a lower income and higher unemployment rate than the rest of Texas.

Census 2010 data for Red I CDP Census 2000 data for Green Colonia CDP demonstrates that Green Coloniacomprises 193 housing units in total with a 6.7 vacancy rate. 82.2% of the

[2] There is no data on Red II due to 0% response rate. Moreover, Green Colonia does not have data on income estimates from American Community Survey. This is why it is not mentioned here.

occupied houses are owner occupied. The average household size in Green Colonia is 4.12. In Red I, on the other hand, 25% of the homes are vacant and 78.7% of the occupied homes are occupied by the owner. Average household size is 4.21. Within 69 total housing units, in Red II, 85.5% are occupied and 64.4 % of them are owner-occupied. Average household size in Red II is 4.75.

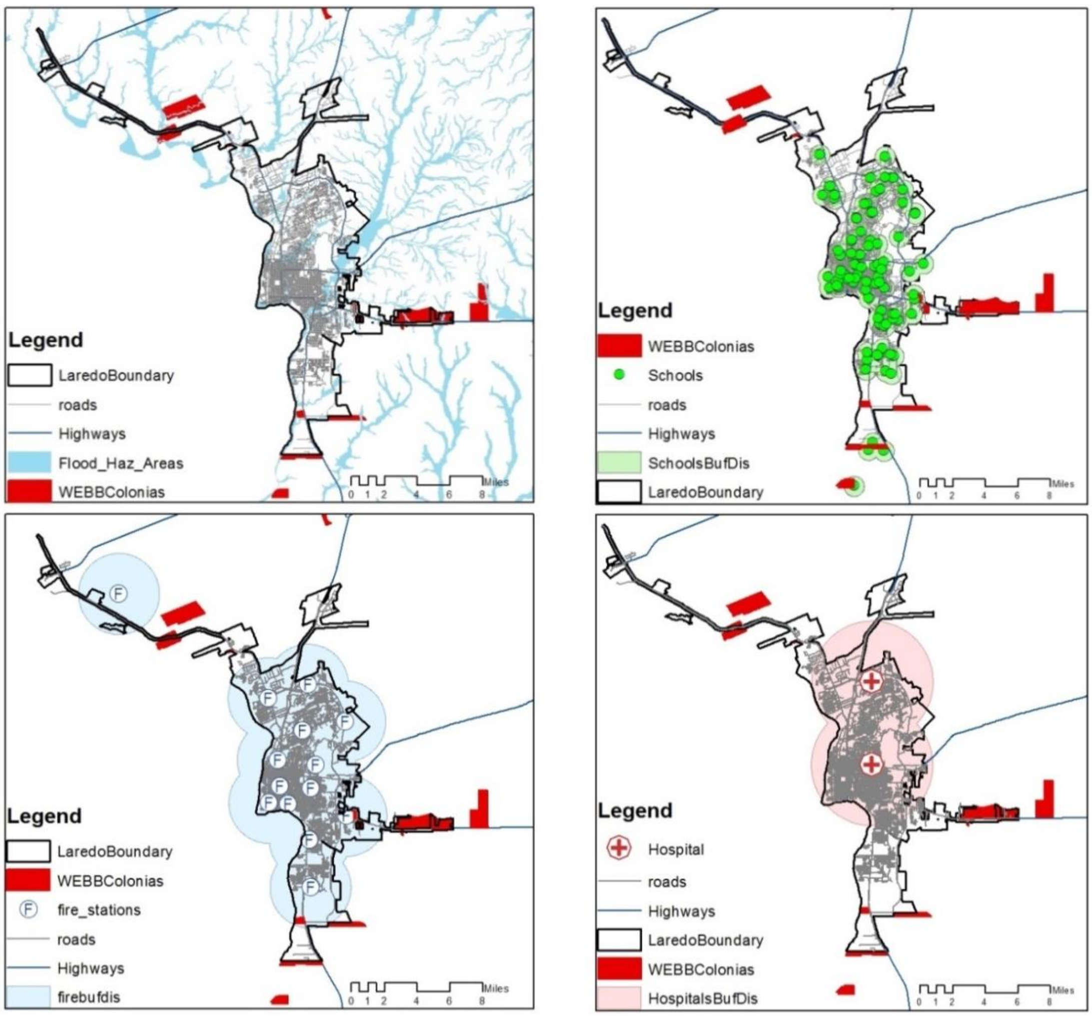


Figure 9: Location of Fire Departments (top left), Hospitals (top right), Flood Hazard Areas (bottom left) and Schools (bottom right) to colonias in Laredo, Webb County, Texas.

3.3.2 Physical Characteristics of the Houses

By help of Google Earth, aerial images, and Geographic Information Systems (GIS) technology, the area of the footprints of the houses on lots were calculated in square meters. Green Colonia accommodates more houses with larger footprints than Red I and II. There are several very small houses in Red II when compared to others.

Three colonias along north of Highway 359, in Laredo, Webb County, Texas were selected. Since self-built and self-managed houses are the main focus of this study, self-help houses were oversampled. Thirty houses have been identified and included as a representative sample of data: 15 from Green Colonia, 7 from Red I, and 8 from Red II.

3.4 Research Design

This research consisted of 5 main tasks: literature review, fieldwork, focus group discussion, BIM development, and testing.

3.4.1 Literature Review

The literature review focused upon secondary sources on sustainable housing, affordable housing, self-help informal settlements, colonias, best practices, and BIM. It has built the logical framework and has constituted a theoretical foundation for this research. This part contributed to every phase of this research such as: development of research questions and hypotheses, identifying the questions for focus groups and interviews, integrating modeling technology and determining a logical framework for my own.

Literature review was divided into four categories. The first line of inquiry focused on defining informal settlements with their physical and socio-economic features. Informal settlements have been discussed as a universal phenomenon and a global typology of formation of these settlements has been drawn from the literature.

The second category concerned defining colonias within the informal settlement universe. Colonias in U.S. were identified within a typology of informal settlements, profile of residents and were discussed as a means of socio-economic and physical features. The structure and challenges of housing was the main concern.

The third line of inquiry fused two concepts: affordable housing and sustainable housing to address self-help informal housing. Within the sustainable low-cost self-help housing context in the colonias, four studies were identified to constitute a basis for this current research study: (a) Reimers-Arias's (2009) study examining the colonias homes and their expansion patterns due to the residents' needs, (b) Ward, Olmedo, Rojas and Sullivan's study (2010) investigating housing conditions and construction techniques in Central Texas colonias, (c) Ward and others' (2010) report investigating applicability of the contemporary sustainable housing design and technology strategies to colonias, and (c) Sullivan and Ward's study (2012) on sustainable housing applications and policies for rehabilitation of low-income homes. This research differs from these previous studies by making use of technology and methods from advanced architectural practice to assist in understanding the performance of alternative housing forms, materials, and construction techniques, and their relationship to resident profile.

The fourth topic in literature review examined integrating Building Information Modeling technology to address the challenges of housing documented in colonias. BIM is a recent technology in Architecture, Engineering and Construction Industry (AEC). BIM application has several significant capabilities for studying structures in informal settlements; BIM technology allows and supports (1) *3-dimensional modeling of a building*, that reflects the real time changes (Lee, Sacks, and Eastman 2006; Eastman et al. 2008), (2) *documenting and collecting large amounts of data* on both existing and proposed structures including (a) designer data, (b) legal data, (c) geospatial data, (d) financial data, (e) specifier data, (e) environmentalist data, (f) sustainers data, and (g) owner / occupier data (Bazjanac 2007; Eastman et al. 2008), (3) *embedded library of components* which also allows users to create their own library, (4) *parametric modeling* which allows the rapid adjustment and change of building representation to permit "what-if" studies (Hernandez and Roberto 2007; Woodbury 2010), and (5) *simulation tools* that can be used to analyze the cost, energy, and other performance of the proposed structures.

3.4.2 Fieldwork in Laredo, Texas

Fieldwork was composed of interviews with a selected sample of residents in Laredo, Texas and collection of on-site data describing their homes. Preliminary visit to the Texas A&M Colonias Center in Laredo was made in September 2012 for two purposes: (a) to clarify upon which colonias to focus, and (b) to establish contact with the Colonias Program employees to facilitate fieldwork.

Development of the Instruments

The interview questions and home inspection survey were derived from similar studies that have been performed in colonias and informal settlements (Keall et al. 2010; Meng and Hall 2006; Reimers-Arias 2009; Ward, Olmedo, et al. 2010). The aim of Keall and others' paper (2010) is to link "the housing conditions to their effects on health, safety, and sustainability in England and New Zealand". To that end, they proposed a housing quality assessment tool which allows them to measure the effect of housing condition on health, safety and sustainability by visual inspection. Meng and Hall (2006), on the other hand, developed a housing quality model and index (HQI) for developing countries to evaluate and measure the current quality conditions of housing by focusing on both individual units and the city block level. HQI comprises eight categories: (1) Physical sustainability, (2) overcrowding, (3) housing services, (4) extra amenity, (5) tenure, (6) safety, (7) accessibility, and (8) housing price.

This study was built on three existing studies. Reimers-Arias (2009) focuses on the colonias along Highway 359 in Webb County. He concluded that the most commonly observed housing pattern is building a small permanent dwelling unit and then extending it by additions.However, the results of Ward and others' (2010) study shows different results in terms of housing diversity. They focus on Redwood and Rancho Vista informal homestead subdivisions in San Marcos which are not considered as border colonias. They concluded that the common house type is manufactured homes.

Ward and others (2010) documented the housing problems that residents reported about their houses are related to unstable and improper construction of houses, inadequate infrastructure services, and inadequate cooling and heating systems. They concluded that knowledge about sustainable housing techniques and design is very limited in these communities. Poor construction methods and the lack of access to infrastructure systems cause the colonias residents to pay higher energy costs per unit area (Gharaibeh et al. 2009). Based on the study performed in El Paso county colonias in Texas (climate division 5), the average electricity bill in colonias (82.5 $/mo) is 40% more than the El Paso average (59.7 $/mo) (Machado 2006).

I developed a questionnaire that builds upon the previous studies to collect data in five domains: (1) House Background Domain, (2) House Form Change Domain, (3) Infrastructure and Service Domain, (4) Community Domain, and (4) Household Domain. Moreover, a home inspection sheet was designed to gather information in five domains: (1) Construction Type and Materials, (2) Number of Rooms, (3) Exterior Features, (4) Garden, and (5) Plan, Elevation and Sketch of the House with Measurements.

Institutional Review Board approval for use of human subjects in research was obtained. The survey was conducted with 30 households and their houses. The survey instruments are attached in Appendix.

On-Site Data Collection: Home Inspections and Face-to Face Interviews

On-site data collection comprised field measurements and surveys of a sample of homes in colonias. The field measurements included15 homes in Green Colonia on April 11-12, 2013, and 15 homes in Red I and II on April 18-19, 2013 providing a typical range of self-help houses. The houses were documented for size and volume, orientation, ratio of fenestration on facade, construction materials and methods, and shading. Documentation of each house took 30 minutes.

Surveys were conducted in two periods; 15 interviews and home inspections were implemented in the Green Colonia on April 11-12, 2013 and 15 were implemented in the Red I and II colonias on April 18-19, 2013.

Bachelor of Environmental Design students Nasario Arrequin and Dulce Castillo, and Ph.D student Bara Safarova assisted me on site with home inspections and interviews. Mr. Arrequin and Ms. Castillo speak Spanish fluently. Texas A&M Colonias Program Associate Regional Director Jose Gutierrez and his staff (Rosa Freyre and Juan Galvan) facilitated access to residents.

In order to inform the residents and encourage them to participate, flyers were posted at the Center and mailed to residents in the sample one week prior to the visit. However, after a meeting with Texas A&M Colonias Program employees in Laredo, inviting residents to the center was found both confusing and inconvenient for the residents. Therefore, in-person household interview and home inspection on site together were chosen as a better technique. IRB was informed about this situation and new process was approved.

Interviews were conducted in Spanish by Mr. Arrequin under my supervision after a training process. I completed the home inspection sheet while the students assisted in measuring each house and drawing a sketch of it. Interviews took 15 minutes whereas home inspections required about 20 minutes.

All interviews were completed in Spanish; 70% of the participants were females and 100% Hispanic. Most of the participants were homeowners; from 30 households, only one respondent in this study was renter. The data presented in this report was documented as a result of a triangulation of interviews and home inspection data.

Data Analysis

The data collected from the interviews and on-site home inspection were analyzed to produce a report that documents the existing architecture and construction patterns in Texas Colonias through 30 homes from Laredo, Texas. I managed data entry, coding and decoding of the data.

Geographic Information Systems (GIS) technology was utilized to visualize the survey data in community scale. By using Autodesk Revit, polylines were created for each house. These were then exported to GIS within .dwg files through Aerial Imagery. Each of the .dwg files for the selected three colonias were added to ArcMap along with other data such as Red I and Red II shapefiles from Tax Assessors Office Webb County, Colonias shapefiles, and Roads shapefile from City of Laredo website. One of the major challenges that I came across was to convert the polyline from .dwg files into polygons. Each house should be represented as one polygon in order to link a created database to it. To achieve this, I proceeded with the following steps: (1) I exported polylines from .dwg into a shapefile, (2) I used Feature to Polygon function to convert these polylines into polygons, (3) by referring to aerial photos on ArcMap, I carried these polygons to their original location through Georeferencing, and (4) I defined projections. In order to identify the housing typology, I created a Microsoft Excel spreadsheet with addresses of each house and then linked this spreadsheet to the polygon. I used Red I and II shapefiles of parcels from Tax Assessors Office of Webb County because, for these two colonias, houses do not have formal mailing addresses. Moreover, the roads shapefile does not include the roads inside the boundaries of Red I and Red II colonias since they are not paved, and there is no sidewalk. Therefore, I referred to the ones provided by Tax Assessors Office for Red I and II. In order to protect the anonymity of the participants, these GIS maps were not included in this dissertation.

3.4.3 Focus Groups with Experts

The use of focus group with experts in this research was to create and document strategies and solutions on low-cost sustainable design in the colonias.

Development of Questionnaire for Experts

Questionnaire for focus groups were developed according to three domains derived from the literature: (1) Climatic Determinant Domain, (2) Building Design/Passive Design Domain, and (3) Mechanical Systems-Sustainable Technologies and Techniques Domain (Ward, Sullivan, et al. 2010; Choguill 2007; Global Green USA 2007; Waters 2003; Thomas and LLP 2006) (Appendix)**.**

Questions have been vetted through review by faculty members in the Department of Architecture at Texas A&M University. Institutional Review Board approval for human subjects in research was acquired before performing data collection.

Selection of Experts

The focus group was conducted with six participants. With the aim of exploring sustainable low-cost residential design, construction, and technology for colonias, the criteria for study participant selection were having expertise in this area as being a designer, architect or construction scientist in both practice and academic environment. As regional climate and industrial patterns are known to be strong determinants of construction practice, the participants in the focus group were from either Texas or Louisiana.

The selected participants were (1) a homebuilder who uses recycled materials and alternative methods to construct homes for the low end of the market (2) a construction manager and HERS REM rater from a state-supported organization for low-income families especially focused on the colonias (3) a sustainable building specialist and HERS REM rater from an international organization focused on providing affordable housing (4) a regional government-managed non-profit that constructs low cost, affordable houses, (5) the founder and the president of a profit based organization for building alternative energy and low energy buildings for low-income families who are suffered from hurricanes, and (6) an energy efficiency system engineer from a profit based organization for energy efficiency systems and projects for commercial companies (Table 3). The age of participants ranged from 30-60.

Table 3: Focus group participant profile

	Occupation	Company/ Organization		Target population
Participant-1	Designer, Builder & Owner	Non-profit	free salvage and recycle materials	Single mothers, low-income families, artists
Participant-2	Program Coordinator& HERS REM rater	State-supported	construction management	low-income families
Participant-3	Sustainable Building Specialist & HERS REM rater	State-supported	sustainable design and construction	low-income families
Participant-4	Executive Vice President	Non-profit	affordable housing development for single family homeownership	low-income families
Participant-5	execute director founder	Profit-based	alternative energy, low energy building after Katrina	Hazard recovery, Low-income families
Participant-6	energy efficiency systems engineer	Profit-based	energy efficiency systems and projects for commercial companies	

Data Collection Process: Focus Group

After receiving IRB approval, the event was conducted in College of Architecture at Texas A&M University on December 3rd, 2012. The focus group took place over a three and half hour period. The format was a round-table discussion. As the moderator, I posed semi-structured open-ended questions to the group. The questions were directly related to their expertise in sustainable low-cost housing design and construction. The discussion was recorded with two digital audio recorders and two video recorders.

Analysis

The data collected from the focus group was analyzed by following three steps:

(1) Transcription;
(2) Coding;
(3) Thematic analysis.

I have transcribed all recorded material with the speakers' names. Inaudible words were highlighted in the transcript with the time of the recorded audio and the video. The transcript including these marks was sent to the participants to review and edit their parts. After receiving changes and confirmation from each participant, the transcript comprised 29,310 words.

The transcript was assessed and analyzed qualitatively by developing themes. Content analysis was used to derive a list of consensus on best practices of building construction methods and strategies for the colonias. I managed data entry, coding and decoding of the data.

3.4.4 Development of Colonias BIM Toolkit (CBT) and Building Performance Analysis of Selected Homes

This study has used a model-based research strategy to explore the performance of homes in the colonias. Model-based research allows researchers to perform experiments on the model which are not affordable and feasible to conduct on the real subjects themselves. My investigation has developed computer-aided modeling methods using Autodesk Revit and other BIM analysis tools and refined the methods through repetitive experience.

The aim of this section was to develop and test the method for developing a BIM based toolkit for informal houses that represents the homes and supports remodeling and estimating current energy use of the selected houses and the whole community. It is limited to 30 selected colonias structures in Laredo, Texas.

This step was built upon the previous data collection process, which consisted of face-to-face interviews with 30 residents and on-site home inspection of their houses. The data served to identify existing self-help housing architecture and construction patterns.

The model-based research was comprised of three-steps:

(1) Identifying scenarios including (a) R-value of the building components, (b) air infiltration value (ACH), (c) HVAC systems and (d) usage schedule,

(2) Developing a new library of system family and building components to represent the construction methods, and techniques in the selected houses in Autodesk Revit[3] and testing the BIM-toolkit with a new library by modeling the existing houses,
(3) Calculating building performance of sample homes created under the scenario of designing additions to the homes.

Identifying Scenarios for Unknown Parameters

To explore data about the homes that was not available, alternative scenarios for material and home parameters were developed and simulated with the model:

- For construction materials and R-values, a set of rules and assumptions were established. These assumptions and rules was based on several resources: (1) on-site observations and face-to-face interviews with residents, (2) HUD code regarding the age of the structure, (3) a minimum level of insulation suggested by IECC 2009 for Webb County, Texas for self-help homes, and (4) current practice of manufactured homes suggested by Champion Homes(Champion Builders, Inc. 2014).
- Building infiltration values (ACH) for selected homes were retrieved from a comprehensive database for U.S. residential structures entitled Residential Diagnostic Database (Sherman and McWilliams 2007). The database was developed by Lawrence Berkeley National Laboratory (LBNL) (2011). This database provides a statistical model predicting air infiltration value according to 7 parameters: Floor area (square foot), ceiling height (feet), year built, region, climate zone according to IECC, foundation type and duct system location.
- For HVAC system options, I have used available alternatives for residential structures in provided by Autodesk Revit and Autodesk Green Building Studio, which are: (1) No heating or cooling systems, (2) Residential 17 SEER/9.6 HSPF Split Heat Pump, (3) Residential 17 SEER/0.85 AFUE Split/Packaged, (4) Residential 14 SEER/0.9 AFUE Split/Packaged Gas, and (5) Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump.

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[3] Autodesk Revit has an embedded library of components and systems families, and a library of materials. However, as these houses are built improperly without building codes, they require a different library.

Creating a Library for Existing Practices

Autodesk Revit 2014 was utilized as a Building Information Modeling (BIM) tool. First, I have developed a project template for creating a building model in Revit which includes (1) project parameters to express data gathered from on-site analysis and resident interviews for all houses, (2) project information on energy settings, location of the project, and materials for each of the houses that can be shared with all houses, (3) library of system families and components including information on cost and thermal characteristics, and (5) schedules for each house listing the parameter values for all relevant objects. This valuable set of information may be utilized in the future to calculate cost components.

This step involved creating materials that are not available in Autodesk Revit's embedded library. A library of building components and system families were created by both referring to existing Autodesk material libraries and developing new materials. For new materials, thermal properties of them were extracted from DOE 2 manual (Simulation Research Group 1991). By using these new materials and existing ones, I developed a new library of components and system families into a Colonias BIM Toolkit (CBT).

Testing the Colonias BIM-Toolkit (CBT) by Creating BIM Models of Sample Houses

I have tested the CBT by modeling 30 selected houses from three colonias in Laredo, Texas utilizing Autodesk Revit 2014. The data collected from inspections of existing houses and interviews of residents were used to model each home in the sample. Since IRB approval was for only inspection from outside, I was not able to collect data on interior spatial configuration of the residential structures. To that extent, modeling includes only exterior components. However, as these structures were built incrementally, each construction phase was modeled as a separate space. Creating spaces for each building stage enabled me to assign different parameters and age related analysis of these components.

The outcome was BIM models of 30 selected homes which were used to calculate / estimate energy use of each house in the following step.

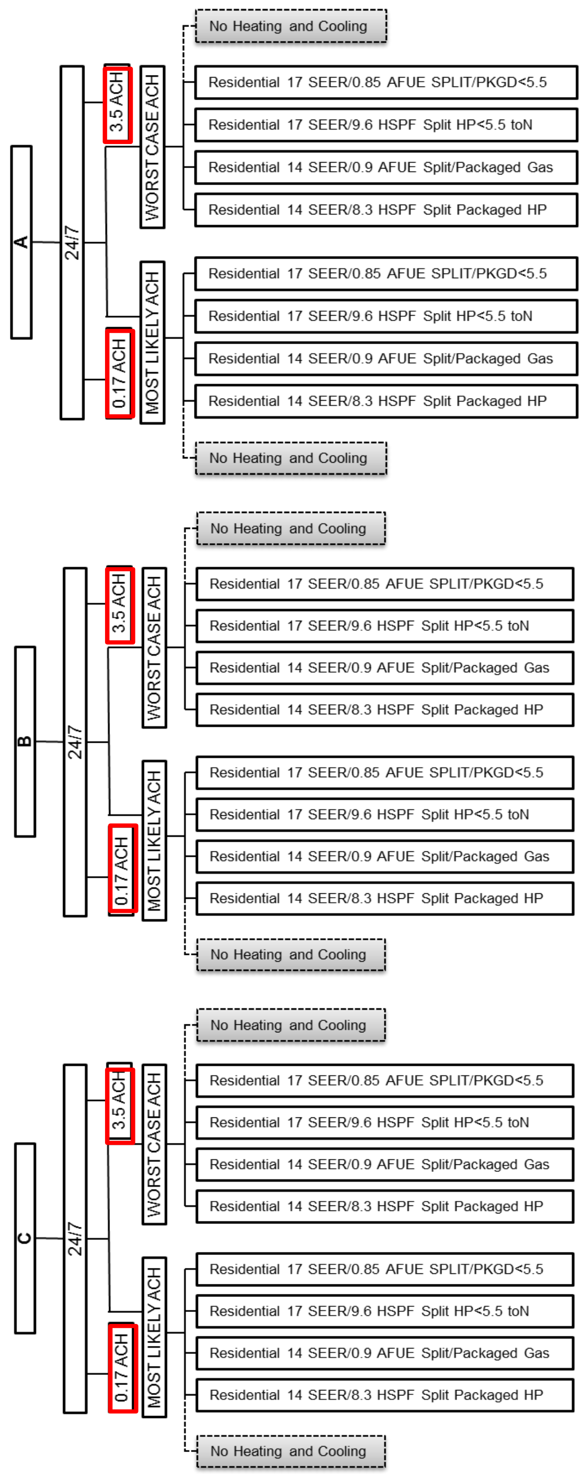


Figure 10: Alternative scenario parameters for sample homes: construction quality (A, B, C), schedule (24/7), infiltration values (0.17 and 3.5 ACH as GBS default infiltration values, and most likely and worst calculated from LBNL database), and HVAC systems.

Calculating Building Performance of Sample Homes

Autodesk Revit 2014 was utilized as a Building Information Modeling (BIM) tool and Autodesk Green Building Studio (GBS) was used for building performance simulations. BIM models of the sample were exported from Autodesk Revit to Autodesk GBS as a gbXML file.

20 scenarios were run for each house for a total of 600 simulations (Figure 10). Infiltration values for structures were assigned by editing the exported gbXML file from Autodesk Revit. Other parameters were adjusted in the Autodesk GBS user interface.

The outcome was energy use intensity (EUI) for each house and estimated EUI for whole communities of the selected three colonias. Relative performance was utilized between scenarios to identify how to improve the design.

3.4.5 Testing the Toolkit (CBT) for Design

A similar method was used to test the CBT as a tool in support of design of additions, utlizing Autodesk Revit 2014 and Autodesk GBS. The purpose of this section was to demonstrate that the CBT could be used for designing and modeling additions to informal houses in the colonias by considering building performance and affordable solutions for the residents. The solutions considered during design were limited to the suggestions derived from the focus group and the literature. Two houses from the sample of 30 homes were selected as case studies: House 15 and House 30. House 15 is comprised of a manufactured home built in 1974 and wood frame self-built addition built in 1994 (Figure 11). House 30 is a concrete structure which was built in 1992 in two phases (Figure 12).

The design problem in both cases was to design one bedroom and one bathroom 231 square foot addition with two windows. The size of the addition was identified by considering International Residential Code (IRC), Americans with Disabilities Act requirements for Accessible Design (ADA), and the sample plans designed by Habitat for Humanity affiliates.

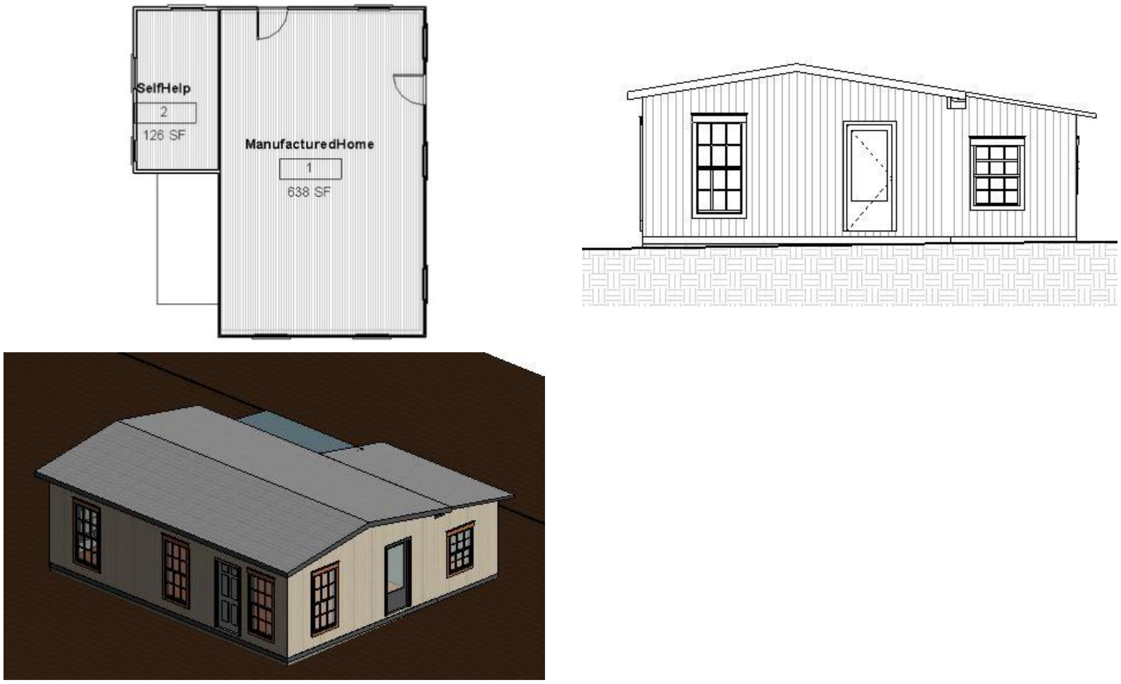


Figure 11: House 15 comprises a manufactured home with a pier and beam, wood frame, self-built addition: Plan, North elevation, and 3D BIM model.

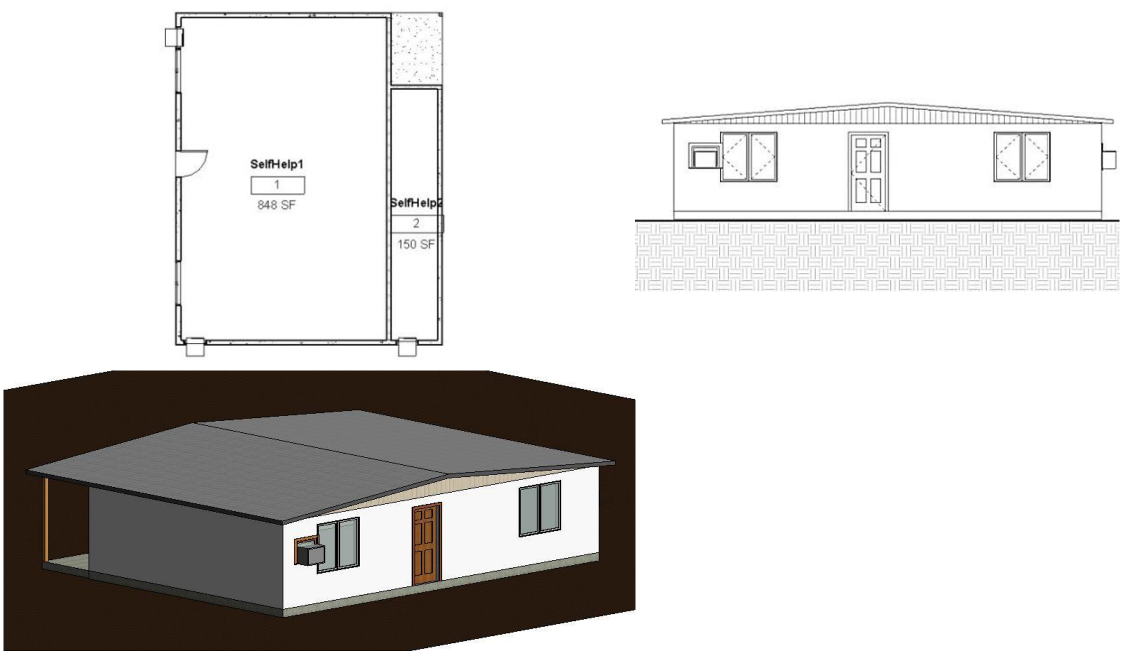


Figure 12: House 30 a concrete self-built structure: Plan, West elevation, and 3D BIM model.

The design process involved two preparatory steps:

(1) Setting the rules for the additional structure to colonias houses,
(2) Developing a new library of system family and building components to represent the suggested construction methods and techniques for the addition and testing these suggestions on the addition to two selected homes in the colonias in order to identify the best solutions for colonias homes.

Setting the Rules for the Additional Structure to Colonia Houses

Scenarios were developed according to the (1) form and location of the addition, (2) shading and fenestration strategies, (3) building envelope and materials, and (4) mechanical systems including HVAC systems, other cooling systems, behavioral set points, and domestic hot water strategies.

Creating a Library for Best Practices

I have followed the same steps to develop a toolkit for low-cost energy efficient strategies that I established for modeling existing colonias homes in the previous section.First, I have created a project template from scratch. This step was followed by creating materials that are not available in Autodesk Revit's embedded library. A library of building components and system families were created by both referring to existing Autodesk material libraries and developing new materials by referring to DOE 2 manual (Simulation Research Group 1991).

3.5 Summary

This section describes the methodological warrant, research methods and research plan of this study. It adopts mixed research strategies including survey, quasi-experimental and model-based research strategies to propose a new way for assisting residents of colonias to achieve sustainability in their self-help housing practices.

Three colonias from the city of Laredo, Texas were selected as the study area: Green, Red I and Red II colonias. They are coded according to USGS's classification of colonias.. The reason behind the selection of these colonias was to reflect the variety in characteristics of colonias in Laredo, Texas. Accessibility to residents and field work support were other major criteria of the selection.

This research employs five main tasks which build upon the previous phase. First, I performed literature review on the concepts of sustainability, affordability, best practices, self-help housing, colonias and BIM to build a logical framework and identify the theoretical foundation of this research. Second, a focus group was established with participation of six experts on sustainability and affordability in residential architecture to collect data on best housing practices for colonias' residents in self-help housing. Third, in order to collect data on existing housing practices in the colonias, I inspected 30 homes and conducted face-to-face interviews with their residents. Fourth, data collection processes were followed by development of Colonias BIM Toolkit (CBT) in Autodesk Revit 2014 to model the selected homes and perform building performance analysis. Last, I tested the CBT by designing an addition to two selected colonias self-help homes and compare the impacts of the addition.

4 EVALUATION OF EXISTING ARCHITECTURE AND CONSTRUCTION PATTERNS IN TEXAS COLONIAS

This section identifies a detailed profile of existing housing design and construction patterns in three colonias near the city of Laredo, Texas Selected colonias have been given names with respect to the classification of USGS: Green Colonia, Red I and Red II colonias.[4] Thirty interviews and on-site home inspection surveys were conducted. The interview questions (Ward, Olmedo, et al. 2010; Reimers-Arias 2009) and home inspection survey (Keall et al. 2010; Meng and Hall 2006) were derived from other studies focusing on colonias and other informal settlements around the world.

All of the participants interviewed are Hispanic, and all interviews were completed in Spanish. The majority (70%) of the participants were females. Home inspections include measurements of the housing massing and fenestration components and inspection of construction materials.

This study has been built on four existing studies on the colonias that provided the context and point of departure of this research (Reimers-Arias 2009; Ward, Olmedo, et al. 2010; Ward, Sullivan, et al. 2010; Sullivan and Ward 2012). The results are presented in five categories: (1) house acquisition and ownership, (2) house massing and construction, (3) infrastructure and services, (4) community, and (5) resident demographics. Aerial imagery was used as the third data source to build visualization of data collected on-site by utilizing Geographic Information Systems (GIS) technology.

These lead to a system for classifying houses in the colonias that is expressed as a toolkit for modeling the houses using BIM.

[4] The real names of the colonias are not used in this study with respect to the confidentiality of the residents. I refer them as Green, Red I and Red II.

4.1 House Acquisition and Ownership

To better understand the history and narrative of each home, several facts were collected: (a) year of resident arrival to this lot in this colonias, (b) land seller, (c) land finance, (d) initial land cost, (e) estimated investment on the house, and (f) estimated current house value.

Residents arrived in the colonias from 1970 to 2012. Most households (87%) report living on their lot for 15 years or more. Participants reported the initial investment on land and household investment on home (Table 4). According to these estimated numbers, there appears to be a slight difference between Green Colonia and Red colonias in terms of current estimated equity. However, the initial land cost seems to have been slightly higher in Green Colonia than Red I and Red II.

Table 4: Initial land cost and investment on the house reported by residents across three colonias

COLONIA	INITIAL INVESTMENT*		HOUSEHOLD INVESTMENT*	
Green Colonia		13		10
	Minimum	$2,500	Minimum	$10,000
	Median	$12,000	Median	$29,500
	Maximum	$35,000	Maximum	$100,000
Red II		5		6
	Minimum	$6,000	Minimum	$15,000
	Median	$7,000	Median	$27,500
	Maximum	$40,000	Maximum	$40,000
Red I		5		7
	Minimum	$7,500	Minimum	$1,600
	Median	$13,000	Median	$25,000
	Maximum	$16,000	Maximum	$40,000

* 7 resident left this question blank.

Table 5: Summary of data on land seller and land finance

COLONIA	LAND SELLER		LAND FINANCE*	
Green Colonia		15		14
	A company or land seller	2	Mortgage with Bank	1
	Inherited from a family member	1	Payments to seller over several years	12
	Previous Homeowner	12	Savings /cash	1
	Other (Rent)	0	Other	0
Red II		8		8
	A company or land seller	0	Mortgage with Bank	0
	Inherited from a family member	0	Payments to seller over several years	7
	Previous Homeowner	7	Savings /cash	1
	Other (Rent)	1	Other	0
Red I		7		7
	A company or land seller	0	Mortgage with Bank	0
	Inherited from a family member	1	Payments to seller over several years	6
	Previous Homeowner	6	Savings /cash	0
	Other (Rent)	0	Other (hereditary)	1

* One resident left this question blank.

According to Table 5, nearly all respondents are the homeowners (97%) while only one reported to be a renter. 6% of the participants purchased their land from a company or land seller while 83% purchased from the previous homeowner. Only 6% report having the land inherited from a family member. As expected in colonias, mortgage with a bank has played a minor role in land finance (3%). Over 83% of the participants report purchasing their land through payments to the seller over several years whereas 7% report using savings or cash.

4.2 House Massing and Construction

The survey collected data about the form and construction of the houses (1) to identify the approach to construction found in the colonias, and (2) to examine the physical characteristics of the houses.

4.2.1 House Construction Approach and Additions

The field survey revealed several types of home and the common pattern of incremental construction. The homes were classified by the construction approach of the initial structure, and include self-help homes that were constructed by owners, friends and families; contractor-built homes constructed by a commercial contractor; mobile homes; and caravans. Most of the homes consist of multiple additions, often of a different approach. Table 6 shows several examples from three selected colonias.

It is common to find a mixture of these generic types of structures on one lot. As mentioned before, the self –built type of structure was deliberately oversampled in this study. The sample includes self-built type of structure (70%), houses that include parts that are self-built and parts that are manufactured homes (20%), and houses that are self-built with adjacent or attached campers, buses, or RV’s (10%). Two residents reported living in a bus when they first came to the lot and during the construction process of their initial housing structure. More details are provided in Table 7.

Table 6: Examples from three colonias in Laredo, Texas

		
A self-built home which has been under construction since 1980. It has a cultural character in terms of design and materials used.	A self-built home	Self Help Program helped them to build their current 900 SF self-built house in 1996.Future plans on building second floor.
		
A camper (RV) integrated into the self-built part plastered with stucco.	A two storey house which has been completed in one year. Structure has concrete block walls with gypsum plaster on the first floor but wood walls on the second floor.	House 24 is a self-built structure with an RV on the site. It was remodeled by Webb County Economic Development Program.
		
A double-wide manufactured home and a custom built structure.	A wooden custom built home elevated on metal columns about 7 feet tall and 1,200 square feet concrete block structure covered with brick.	House with a school bus which was used as a temporary home while building the self-help structure.

Table 7: House types in three colonias

COLONIA	HOUSE TYPES	
Green Colonia		15
	Custom home – self built on site	53.33%
	Custom home – self built on site, Camper (RV)	6.67%
	Manufactured Home – self built on site	40.00%
Red II		8
	Custom home – self built on site	87.50%
	Custom home – self built on site, Camper (RV)	12.50%
Red I		7
	Custom home – self built on site	85.71%
	Custom home – self built on site, Camper (RV)	14.29%

4.2.2 Additions

The surveys indicate that homes were built in one to four stages. Three out of five participants have extended or made additions to their primary unit, mainly for additional living and bedroom space. Responses indicate that 43.3% of the houses were built in one stage, 40% were constructed in two stages, 13.3% in three stages and only 3.3% in four stages.

In the selected housing units, building a small permanent dwelling unit which is then extended by additions is the most commonly observed housing pattern. Within the sample, 30% of manufactured housing units or RVs are enlarged with attached or detached self-built structures. Manufactured homes are almost exclusively elevated from the ground by using wood piers or concrete blocks. On the other hand, the majority of the self-built houses are built on concrete block foundation. A small number of self-help houses that are built as detached additions to the primary units are elevated from the ground using steel columns .

Another example is a hybrid of self-built and manufactured structure. Manufactured structure is the primary unit and later on, residents built a self-help part including a roof for the manufactured home.There is a home which is still underconstruction. Several residents mentioned during interviews that they planned to expand their current homes in future. Other residents reported that they came on to the lot with a temporary RVs or buses, and they lived in these structures until they completed the construction of their self-built house.

4.2.3 Massing and Orientation

The basic form of the house is determined by its massing and orientation. Massing can be assessed both by the closeness to an archetypal form and the complexity as measured by the number of corners. Orientation can be understood as a relation to the compass points or to the street.

Table 8: Housing typology of the sample houses

		Green Colonia	Red II	Red I
Complexity of the House Forms (No. of Corners)				
	4	41.54%	58.49%	52.00%
	6	27.69%	16.98%	32.00%
	7	1.54%	0.00%	0.00%
	8	12.31%	13.21%	10.00%
	10	9.23%	1.89%	4.00%
	12	3.08%	7.55%	0.00%
	14	4.62%	0.00%	2.00%
	16	0.00%	1.89%	0.00%
Shape of the House				
	Rectangle	71.43%	92.86%	86.79%
	L-Shape	27.27%	7.14%	13.21%
	Trapezoid	1.30%	0.00%	0.00%
Construction Type of the Houses				
	Concrete	42.03%	44.44%	35.29%
	Wood	53.62%	55.56%	64.71%
	Other	4.35%	0.00%	0.00%
Roof Types				
	Gabled	73.33%	60.32%	53.57%
	Hipped	14.67%	25.40%	26.79%
	Flat	12.00%	14.29%	19.64%
Spatial Configuration of the Porches				
	Side	11.76%	26.83%	15.56%
	Front	60.29%	53.66%	53.33%
	Back	27.94%	19.51%	31.11%
Orientation				
	East	20.00%	29.00%	25.00%
	North	13.00%	0.00%	13.00%
	South	13.00%	43.00%	13.00%
	Southwest	7.00%	0.00%	0.00%
	West	47.00%	29.00%	13.00%
	Northwest	0.00%	0.00%	38.00%

Table 8 illustrates the variety in housing typology of the selected 30 houses by providing a general idea of the form complexity, massing of the home, construction types, and orientation of the houses. Number of corners of the houses is counted to measure the form complexity. Green Colonia has the most variety of form complexity, ranging between 4 and 14, whereas Red II has the lowest variety, ranging between 4 and 6 corners per houses. By considering the three settlements together, houses with 4 and 6 corners are the commonly observed ones. Basic housing forms are rectangle, L-shape, and right angled trapezoid; these forms vary in terms of size and height. Square L-shaped structures (6 corners) and right angle trapezoid (4 corners) are almost always self-built structures whereas rectangle shaped ones (4 corners) are either self-built structures or manufactured homes. On the other hand, 2 of the houses are two storey structures which are rectangle in shape. Only rectangle shaped houses have 2-storey houses. Moreover, 2 houses have rectangular one storey shape structures elevated 8 feet from the ground on steel columns. Gabled roofs are the most observed in all three colonias (73.33% in Green Colonia, 53.57% in Red I and 60.32 in Red II).

Orientation of the houses varies depending on the colonias they are located in. As the Green Colonia is established within the city limits of Laredo, it closely resembles formal settlements. Therefore, houses often have their front door facing the road (74% of the houses in Green Colonia) which is located along a north-south axis. However, since Red I and Red II are developed outside the jurisdictions of Laredo, houses in these colonias sit on larger lots. Although the residents have more freedom to orient their houses whichever direction they want, 71% of the houses in Red I and all of the houses in tRed II are built by having their front door looking to the street. A significant number of houses have covered porches or roof extensions on their front facade (60.29% in Green Colonia, 53.33% in Red I and 53.66 in Red II).

4.2.4 Size

Most of the participants (56.66%) have not reported the area of their houses. However, the measurements collected from on-site home inspection survey were used to model each house in Building Information Modeling (BIM) and area of houses was generated by using BIM. The smallest house of the sample is 350.81 square feet, whereas the largest one is 2895.64 square foot Table 9.

Table 9: Area of houses (SF) generated by BIM using on-site measurements

SF Range	Green	Red II	Red I
499 or less	0	0	1
500-999	4	1	1
1000-1500	6	2	3
1500-1999	3	3	1
2000-2500	2	1	1
2500 or more	0	1	0
TOTAL	15	8	7

Within the sample of homes, the number of bedrooms fluctuates between one and seven. While residents in Green Colonia report one to seven bedrooms, residents in Red I and Red II declare one to five bedrooms. Residents report that half bathrooms are not common in colonias, with only 13% reporting a half-bath. 46% of houses have one full bathroom, 46% have two full bathrooms, and only one house has three full bathrooms. Responses indicate that most houses (70%) have one living room, whereas 10% of the houses have two and 20% have none. Dining room, on the other hand, does not seem to be very common in colonias.

4.2.5 Construction Materials and Methods

To document the construction type and materials, a visual external inspection focused upon foundation, floor, walls, roofs, doors and window types and materials. Residents were also asked to describe their homes in terms of construction techniques and materials (Figure 13):

- **Foundation.** Findings show that there appears to be two foundation types: concrete slab, and piers and beam. Most of the houses (50%) are built on a concrete slab whereas only 13% are constructed on wood piers with a concrete foundation or cinder blocks. A mixture of the foundation types is also commonly observed in 37% of the homes.
- **Floor.** Ceramic tile (64%), wood (27%), concrete (16%), vinyl (7%) and linoleum (7%) are the mostly reported floor finishes.
- **Wall.** Observations of exterior wall materials revealed that concrete blocks (37%) with stucco cover, and wood frame system with wood siding (43%) are the main two types. However, a mixture of these two major types (20%) with metal siding, brick or stone walls also reported by residents and observed during the site survey.
- **Roof.** Gable, hip, and flat are the three main roof shapes in selected houses. The majority of the houses have a gable roof (64%), and hip roofs are also common (23%). Asphalt shingles (90%) are the commonly used roofing material, but some roofs use tar (3%), metal (3%), or concrete and tile (4%).
- **Doors and Windows.** Aluminum and wood were the observed types of doors and windows. Majority of houses have wood doors (80%). On the other hand, aluminum windows (97%) or a combination with wood windows (3%) is commonly used in the selected houses.

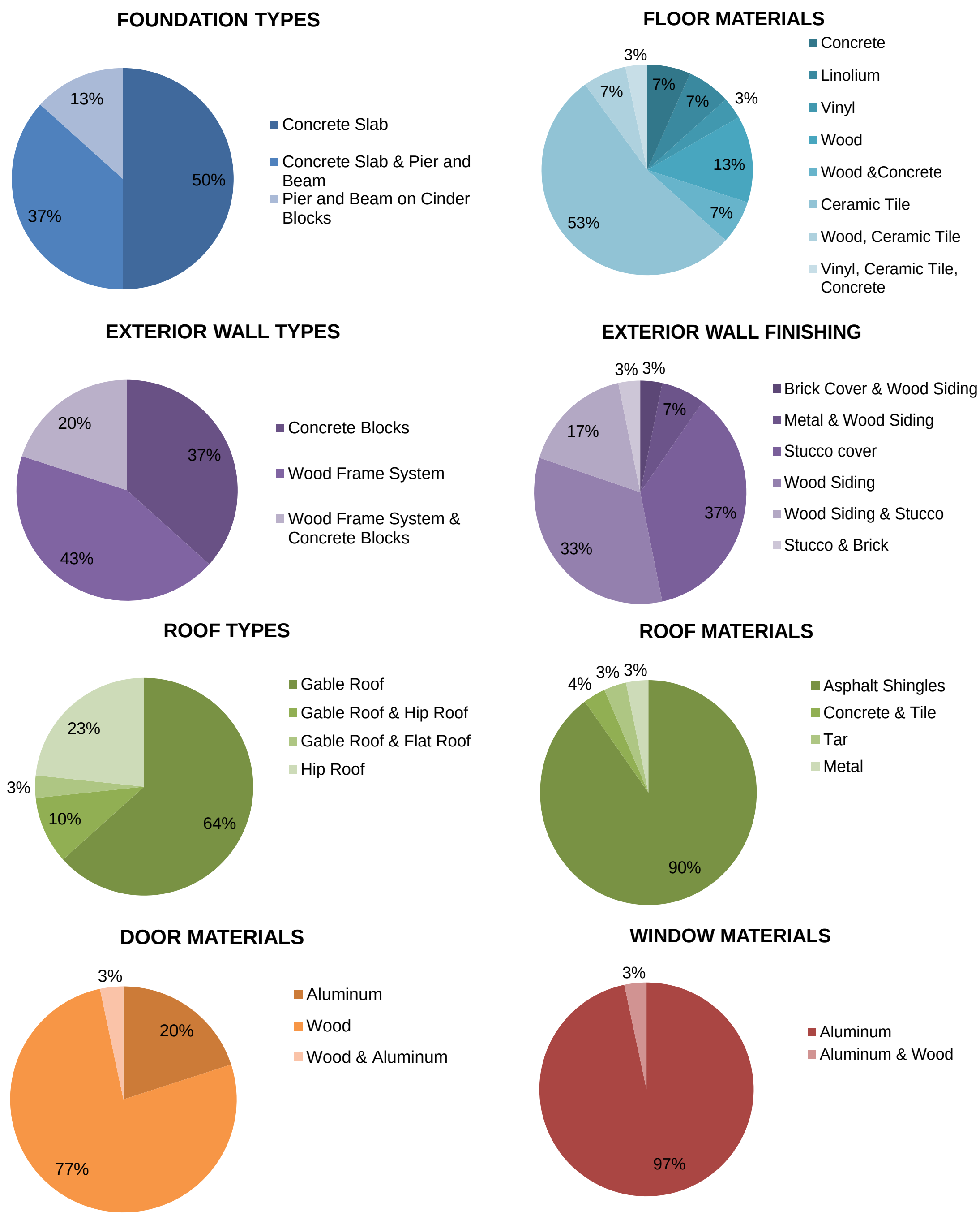


Figure 13: Construction type and materials used in selected houses

Table 10: Construction types and materials of the surveyed houses

FOUNDATION TYPES	%	FLOOR MATERIALS	%	EXTERIOR WALL TYPES	%
Green Colonia(15)					
Concrete Slab	26.67	Concrete	6.67	Concrete Blocks	26.67
Concrete Slab & Pier and Beam	60.00	Linolium	6.67	Wood Frame System	53.33
Pier and Beam	13.33	Vinyl	6.67	Both	20.00
		Wood	26.67		
		Wood, Concrete	6.67		
		Ceramic Tile	33.33		
		Wood, Ceramic Tile	13.33		
Red II (8)					
Concrete Slab	75.00	Linolium	12.50	Concrete Blocks	62.50
Concrete Slab & Pier and Beam	12.50	Ceramic Tile	87.50	Wood Frame System	12.50
Pier and Beam	12.50			Both	25.00
Red I (7)					
Concrete Slab	71.43	Concrete	14.29	Concrete Blocks	28.57
Concrete Slab & Pier and Beam	14.29	Wood, Concrete	14.29	Wood Frame System	57.14
Pier and Beam	14.29	Ceramic Tile	57.14	Both	14.29
		Vinyl, Ceramic Tile, Concrete	14.29		

EXTERIOR WALL FINISHING	%	ROOF TYPES	%	ROOF MATERIALS	%
Green Colonia (15)					
Brick Cover, Wood Siding	6.67	Gable Roof	73.33	Asphalt Shingles	86.67
Metal, Wood Siding	6.67	Gable Roof & Hip Roof	6.67	Concrete & Tile	6.67
Stucco cover	33.33	Gable Roof & Flat Roof	6.67	Tar	6.67
Wood Siding	40.00	Hip Roof	13.33		
Wood Siding, Stucco	13.33				
Red II (8)					
Stucco cover	50.00	Gable Roof	50.00	Asphalt Shingle	100
Stucco, Brick	12.50	Gable Roof & Hip Roof	12.50		
Wood Siding	12.50	Hip Roof	37.50		
Wood Siding, Stucco	25.00				
Red I (7)					
Metal, Wood Siding	14.29	Gable Roof	57.14	Asphalt Shingle	85.71
Stucco cover	28.5	Gable Roof & Hip Roof	14.29	Metal	14.29
Wood Siding	42.86	Hip Roof	28.57		
Wood Siding, Stucco	14.29				

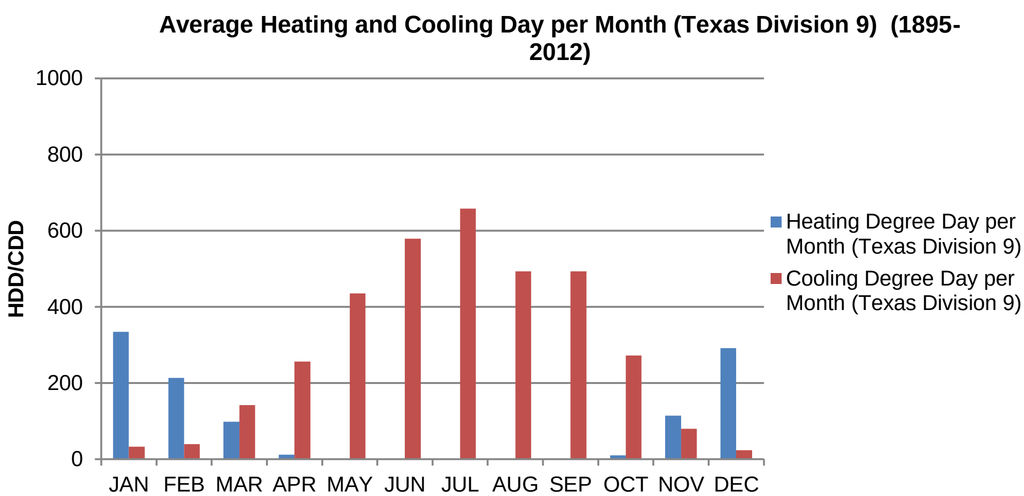
DOOR MATERIALS	%	WINDOW MATERIALS	%
Green Colonia(15)			
Aluminum	26.6	Aluminum	100
Wood	66.67		
Wood & Aluminum	6.67		
Red II (8)			
Aluminum	12.50	Aluminum	87.50
Wood	87.50	Aluminum, wood	12.50
Red I (7)			
Aluminum	14.29	Aluminum	100
Wood	85.71		

As shown in Table 10, foundation types, floor materials, roof types, door and window materials do not differ widely between three selected colonias. However, there are differences between the three colonias regarding the wall, roof and materials. In Green Colonia (53.33%)

and Red I (57.14%), most of the houses were built with wood frame wall system whereas concrete block walls are common in Red II (62.50%). On the other hand, selection of floor materials shows variety among all three colonias. Although asphalt shingles are the most preferred roof materials among the residents in three colonias, concrete and tar in Green Colonia, and metal roofs in Red I were also observed.

4.3 Infrastructure and Services

As a result of substandard construction, the typical energy costs per unit area for colonias residents, is higher than for typical residents in the rest of U.S. (Gharaibeh et al. 2009). The climate in Laredo, Texas (climate division 9) is hot and dry; cooling degree days (3509.6) are more than heating degree days (1076) (Figure 14). Hence, the major expense for Laredo residents is electricity for cooling.



Data Source: http://www.ncdc.noaa.gov
Figure 14: Climate data for Texas climate division 9 including Laredo, TX (adapted from US Department of Commerce 2014)

There appears to be a minor difference between three selected colonias , along north of Highway 359 in terms of availability of on-site services of electricity, water, sewer and garbage. While Red I and Red II recently have gained water and sewer connections, many houses in

Green Colonia received on-site services earlier, even though services were provided over a wide range of time from 1974 to 2012 (Figure 15).

According to the interviews, 73% of households in Green Colonia and 80% in Red I and Red II claim that they have had electricity since they first came to the colonias. However, the year of arrival of the household should be considered; in Green Colonia, residents in the sample have arrived from 1974 to 2007 and the average is 1986. On the other hand, households arrived in Red I and Red II between 1985 and 2012 with an average of 1996.

There appears to be a major difference in terms of water supply: only 6.7% of households in Red I and Red II and 40% of households in Green Colonia had water when they first came to the colonias.

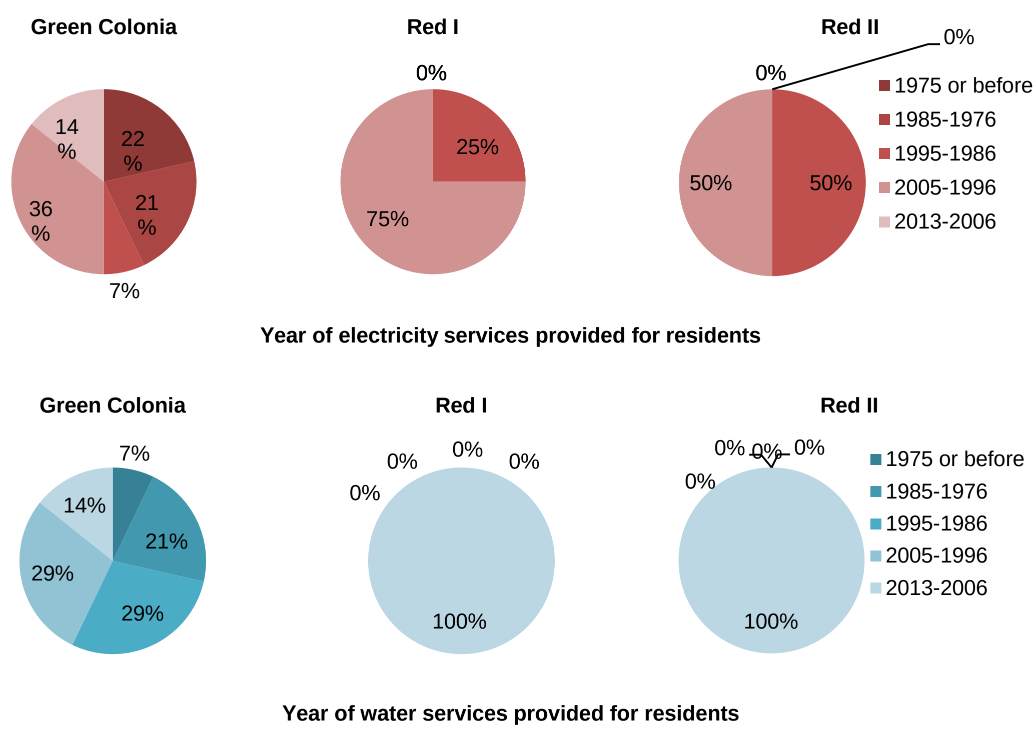


Figure 15: Years of on-site services, electricity (top) and water (bottom) provided for the participants

There are multiple options available for colonias residents for power sources, water heater systems, and air cooling systems. The type of options for power source include (a) electricity (metered supply), (b) main gas (metered supply), and (c) propane (large or small tank). Water heater systems, on the other hand, may be (a) electric water heater, and (b) gas water heater. In terms of air cooling systems, (a) central air conditioner (AC), (b) partial AC, (c) ceiling fans, and (d) stand-alone (floor) fans are the types that are used by colonias residents (Ward, Olmedo, et al. 2010).

Table 11: Power system of heating and system of air cooling systems used in three colonias among the sample of 30 houses

TYPE OF PRINCIPAL POWER SOURCE		TYPE OF WATER HEATER		TYPE OF AC SYSTEMS	
Green Colonia (15)					
Electricity (metered supply)	2	Electric Water Heater	3	Ceiling Fans	1
Electricity (metered supply), Main gas	11	Gas Water Heater	12	Ceiling & Stand Alone Fans	1
Electricity (metered supply), Propane large tank	1			Central AC	7
Electricity (metered supply), Propane large tank, Main gas	1			Central AC, Stand Alone Fans	1
				Partial AC	5
Red II (8)					
Electricity (metered Supply)	6	Electric Water Heater	7	Ceiling Fans	1
Electricity (metered Supply), Main gas	1	Gas Water Heater	1	Central AC	6
Electricity (metered Supply), Propane large tank	1			Partial AC	1
Red I (7)					
Electricity (metered Supply)	1	Electric Water Heater	5	Central AC	2
Electricity (metered Supply), Propane large tank	4	Gas Water Heater	1	Partial AC	4
Electricity (metered Supply), Propane small tank	2	No Water Heater	1	Partial AC, Stand Alone Fans	1

According to Table 11, all 30 houses have metered supply electricity. 70% of them supplement electricity with main gas or propane tanks. Only one house within the sample of 30 houses does not have a water heater. 40% of the respondents report electric water heaters and the rest use gas water heater. 90% interview participants have AC systems: 16 households report that they have central AC system whereas 11 participants report having partial AC systems at their houses. 10% of the participants report having only ceiling fans and standalone fans at their houses.

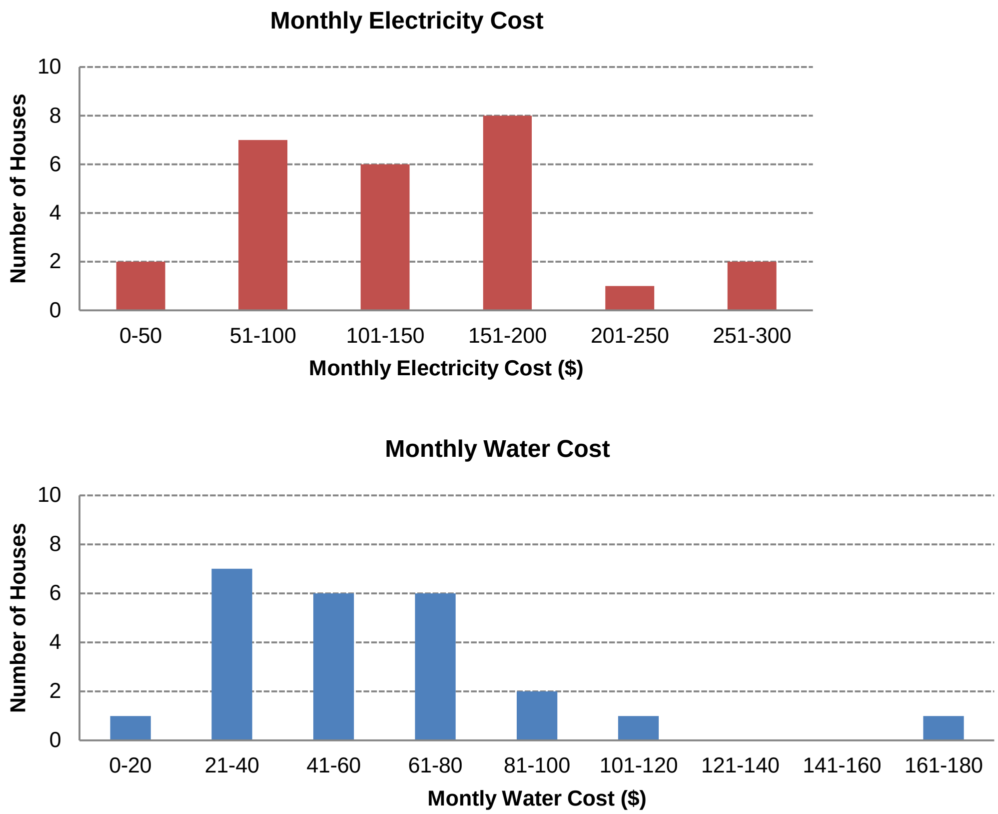


Figure 16: The distribution of monthly electricity cost (top) and monthly water cost (bottom) reported by residents

About 80% of the respondents answered the question about monthly water cost whereas about 87% answered questions about monthly electricity cost (Figure 16). The results demonstrate that monthly electricity payments of the participants fluctuate between $50 and $300 across homes. However, residents report for monthly water payments starting from $20 to $170 across homes. In terms of water cost, 79% of the respondents pay between $21 and $80. For most of the participants payments for electricity (81%) fall between $51 and $200.

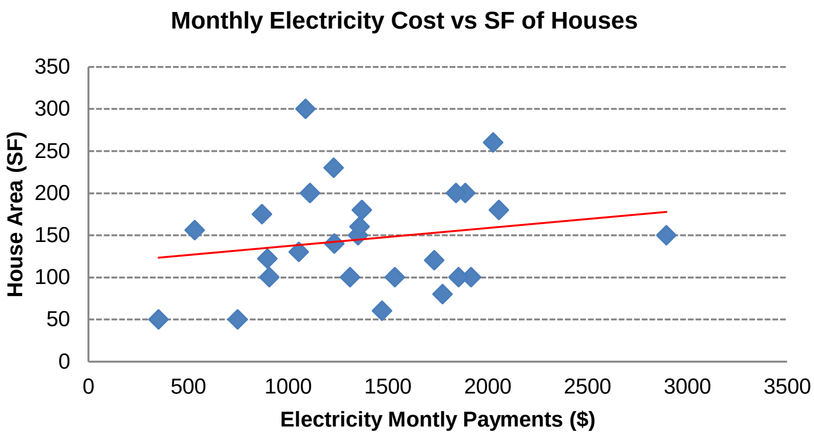


Figure 17: Monthly electricity cost reported by residents and area of houses generated by BIM models

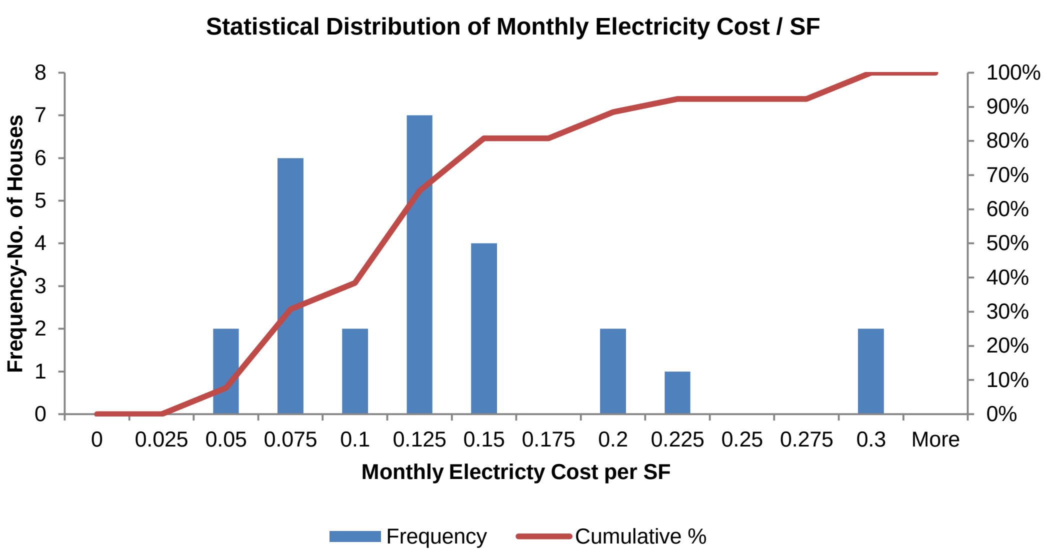


Figure 18: The statistical distribution of monthly electricity cost per square feet of houses

Figure 17 and Figure 18 demonstrate that there is no correlation between house area and monthly electricity cost reported by the residents. The reason for this may be the type of power system of heating and system of air cooling systems that residents use in their houses. Overall, 8% of the participants report the monthly electricity cost per square feet of their houses as between \$0.025 and \$0.05. 26% of the respondents pay between \$0.1 and \$0.125 per square feet.

4.4 Community Data

The survey results demonstrate differences in accessibility to grocery stores, gas stations, banks, and schools. Green Colonia, a community located within the City of Laredo jurisdiction is closer to these amenities than Red I and Red II, neighboring communities settled 6 miles away from Green Colonia and outside the city limits. Residents from the three colonias drive to access these amenities. Markets and community resources are described below.

- Grocery stores. In Green Colonia, there are two grocery stores that are assessed as close whereas, there is only one in Red I and Red II. HEB, 4 miles away, is the store preferred mostly by Green Colonia residents. On the other hand, Mely's/Walmart is the one for Red I and Red II which is 3 blocks away.
- Gasoline stations. There is a gas station at the corner of Green Colonia. However, Red I and Red II residents drive 4 miles for gas station.
- Banks. Green Colonia residents stated there are three banks close to their houses. The closest one is the Wells Fargo within a 4 miles distance. Red I and Red II residents have one close option which is 6 miles away.
- Schools. Because of its location, Green Colonia has better access to the schools, and residents have more choices than Red I and Red II. However, school bus service has been provided for all three colonias.

In the survey, residents did not mention any serious problems about these amenities.

4.5 Resident Demographics

Household domain includes questions about tenancy, age / gender / ethnicity, relationship, education background, occupation, present employment and years for each member.

All of the participants interviewed are Hispanic, and all interviews were completed in Spanish. The majority (70%) of the participants were females. However, this section has the lowest response rate compared to other sections of the questionnaire. Participants provide information about their spouse only but not their children. Age and relationship questions received responses; however, occupation was not disclosed most of the time. Only 16% of the participants responded to the question on occupation. *Promotoras* working at the Green Colonia Self Help Center (1 respondent), retired (1 respondent), construction worker (1 respondent), and painter (1 respondent) are the occupations mentioned during interviews.

4.6 Colonias Architectural Typology: Limitations and Generalizability

Results presented in this section have limited generalizability to other colonias or informal settlements.

This section provides a detailed investigation determining housing typology in order to propose that the results of this survey can be generalizable to three selected , along north of Highway 359 colonias. The data was analyzed by perceiving houses as a form and understanding the relationship between basic forms and their functions and construction characteristics. This analysis was based on Brown and Steadman's study (1991) in which they investigated houses not only as a form at top scale and functions at lower scale, but also considered the interior spatial configuration of the houses. A housing typology was generated from five steps: (1) identifying the basic forms considering the shape, size and height of the structure (complexity of the form), (2) classifying them according to structure types that include self-built houses, manufactured homes and RVs and campers, and (3) construction materials which consist of concrete structure or wood frame structure, (4) exploring different configurations of the porches to the structures, and (5) examining different configurations of these basic forms (Figure 19).

Table 12 demonstrates the architectural typology of the 30 selected homes. Rectangle shaped structures are either manufactured homes or self-built houses. L-shaped and right angled trapezoid structures, on the other hand, are almost always self-built. Self-built structures are built by wood frame or concrete, whereas the manufactured ones are constructed by wood frame with metal cladding.

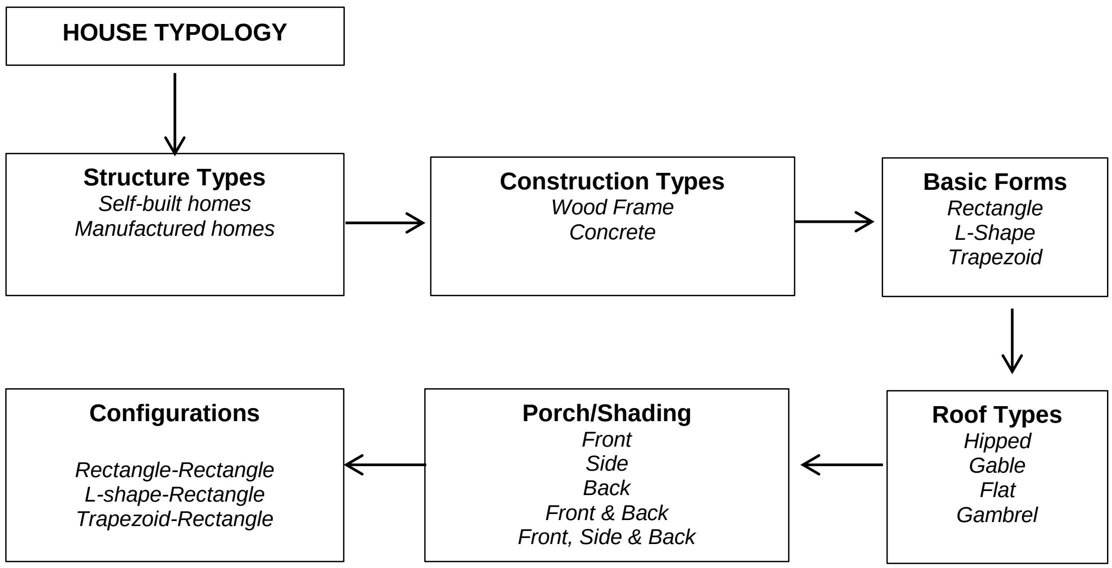


Figure 19: Framework for identifying housing typology of selected houses

The sample houses have four types of roofs: (1) hipped roof, (2) gabled roof, (3) flat roof, and (4) gambrel roof. Rectangle shaped self-built houses show a variety of roof shapes such as hipped, gabled and flat, whereas rectangle shaped manufactured houses only have gambrel roof. L-Shaped and right angled trapezoid shape houses are only built with a gabled roof.

In several houses, these three basic forms in different sizes are attached to each other to configure the houses with a larger number of corners. In addition, a rectangular porch is another feature that is used in 18 houses of the total sample of 30. It is often attached to the front facade of the house to shade the front door. However, in some cases, the back or the side door of the house has been shaded with a porch.

Table 12: Colonias architectural typology

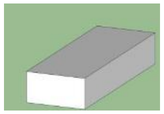
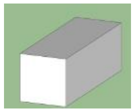
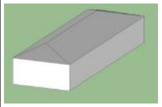
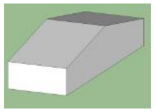
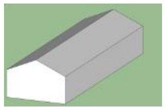
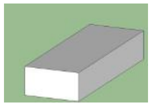
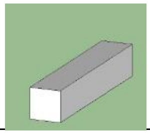
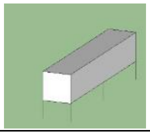
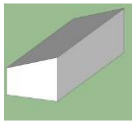
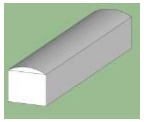
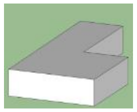
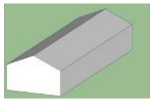
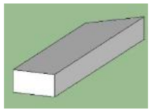
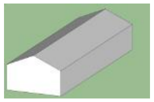
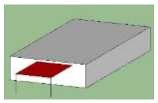
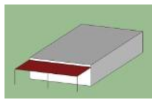
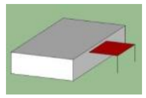
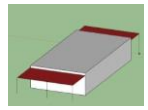
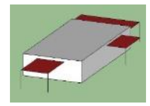
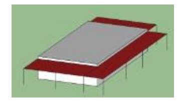
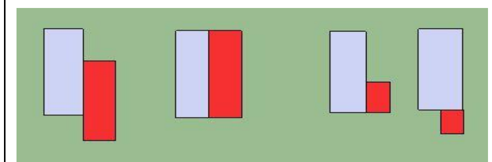
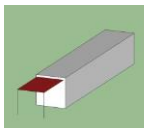
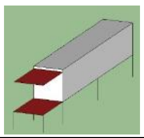
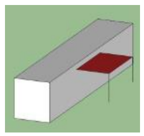
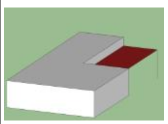
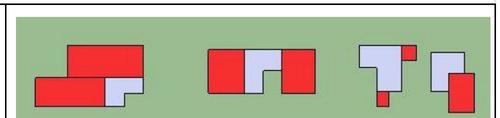
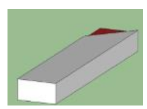
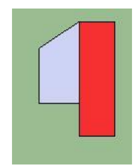
	HOUSE TYPES	CONSTRUCTION TYPES		BASIC FORMS			ROOF SHAPES			
		Wood Frame	Concrete	1 storey	2 storey	off ground	Hipped Roof	Gable Roof	Flat Roof	Gambrel Roof
RECTANGLE	Self-Built Home	√	√					 		X
	Manufactured Home (Single Wide)	√	X		X		X		X	
-SHAPE	Self-Built Home	√	√		X		X		X	X
TRAPEZOID	Self-Built Home	X	√		X		X		X	X

Table 12 Continued

PORCH/SHADING							CONFIGURATIONS
Front		Side	Back	Front & Back	Front, Side & Back		
			X				
			X	X	X	X	
	X	X	X	X	X	X	
X	X	X		X	X	X	

To that extent, the houses that are not selected for the sample of this study still fit in the typologies determined above. This makes the results of this study generalizable to other self-built houses in three selected colonias.

This research investigates only three colonias. Therefore, the results are only related to these colonias. Since climate is a major factor impacting the construction and design of self-help houses, results can be generalizable to other self-help housing in the colonias listed under the same climate division (Texas Climate Division 9). However, they cannot be generalized to the other colonias in the U.S.

My approach can be applicable to document current practices in other colonias and also other informal settlements comprised of self-help practices around the world.

4.7 Summary and Conclusions

Self-help border houses, manufactured homes, and recreational vehicles and campers are the major house types on the U.S.-Mexico border (Sullivan and Ward 2012; Ward, Olmedo, et al. 2010). Unsafe and substandard housing built by unregulated design and construction methods lead to poor building performance and increasing energy consumption which are the major challenges of colonias housing discussed in the literature. Although there are studies performed on changes in housing conditions over time (Reimers-Arias 2009; Ward, Olmedo, et al. 2010), there is a gap in the literature on documentation of the construction materials and techniques and design of the self-help houses in the colonias. The study in this section addresses this gap and its original contribution.

The study in this section clarifies and defines existing architectural patterns of self-help homes by highlighting the similarities and differences in self-help housing practices among these three colonias. Various measurements and data from 30 houses leads to generalization of the shared spatial characteristics. The field survey supports a conclusion that the homes in a colonias can be classified into types by (1) wood frame structures on either pier and beam or concrete slab, and (2) concrete block structures on concrete slab. Houses show particular patterns of form, massing and construction which can be assessed as a colonias architectural typology.

Moreover, almost all homes in the sample were built over time due to the changing needs of the family. Monthly electricity payments of the residents range between \$50 and \$130 across homes. The relationship between the location of the colonias, and history and narrative of homes, and the availability of the infrastructure, services, and resources is strong.

Findings of the surveys reveal (a) the history and narrative of homes, (b) the typology of homes, the quality of structures in the colonias, and the problems in these structures, and (c) the availability of the infrastructure, services, and resources. Documentation of current self-help practices can be beneficial to policy makers in order to highlight the problems in construction of homes, assess community and propose design upgrades that are applicable to these structures. Data can constitute a basis on other researches on the colonias. Although the results have limited generalizability to other colonias or informal settlements, the data collection instruments and process can be applied.

Data presented in this section serves to support the work done in the next sections to explore a process of applying Building Information Modeling (BIM) to model homes in the colonias and to predict the energy consumption of individual homes and the community. This information emphasizes the concerns about acceptability of the best strategies on sustainable low-cost residential design for these structures. Data collected in this section is used in Section 6 to develop Colonias BIM Toolkit to model these homes by utilizing BIM technology.

5 SUSTAINABLE LOW-COST SELF HELP HOUSING DESIGN AND CONSTRUCTION TECHNIQUES FOR TEXAS COLONIAS

This section explores and documents discussions by a focus group to identify sustainable low-cost residential design and construction techniques and strategies for colonias. The focus group consisted of six participants who have expertise in this area as either a designer, architect or building scientist in both practice and academic environment. It was convened in College of Architecture at Texas A&M University on December 3rd, 2012. The three and a half hours event was recorded and transcribed. The comments from the focus group participants were analyzed qualitatively by developing themes of current housing design, distinctive challenges in the colonias, climatic determinants and responses, building design and construction, and mechanical systems and sustainable technologies. The participants did not represent the organizations at which they work; they did not speak on behalf of these organizations.

The transcript of the focus group was analyzed and documented in three categories: (1) Climatic Determinant Domain, (2) Building Design/Passive Design Domain, and (3) Mechanical Systems-Sustainable Technologies and Techniques Domain.

5.1 Focus Group Participants

The focus group was conducted with six participants. Each participant has a different background and different perspective to sustainability and affordability. Three participants have experience related to a non-profit ground, two have experience from a profitable ground, and one from a state-supported one. As an example for a non- profit delivery model, one participant is a state affiliate of an international organization focused on providing affordable housing, advises all the affiliates who build homes in Texas. His aim is to make sure that design and construction of houses are as sustainable as it can be. Another participant, who works for a regional government-managed non-profit organization, designs and builds affordable houses for single family ownership from a non-profit ground for low-income residents. Moreover, a third participant is a homebuilder who uses recycled materials and alternative methods to construct homes for the low end of the market. One participant, who works at a state-supported organization for low-income families, has a lot of experience inspecting homes and approving loans and grants to improve the homes. His expertise is construction management and energy rating of these homes. He achieves energy efficient, affordable and sustainable houses by teaching construction management to the residents and measuring their homes as a HERS REM rater. Another participant, is well-experienced on affordable houses that are resistant to hurricane and from a profitable ground for hazard recovery. He employs alternative energy techniques and low energy building for low-income families. Lastly, one participant is an energy efficiency systems engineer and is highly knowledgeable in sustainable technologies and energy efficiency in houses. He focuses on energy efficiency systems and projects for commercial companies from a profitable ground, but also works on residential projects.

This variation in participants increases the level of validity of the outcomes of the focus group.

5.2 Current Housing Design

As an introduction, participants provided information on the current construction patterns and challenges in the colonias. One participant has provided the information on availability of on-site services in the colonias:

> 1989 legislature found some laws in place. Now all subdivision rules were development plan; you have to bring in infrastructure. So water, for last 20 years, water, waste water and electricity all have been driven through federal and state agencies to do these things. Most people in the colonias now have water, waste water and electricity in his land but still on the land that [is] undesirable. That is one reason why it is so cheap; a lot of colonias are on the floodplains.

He, furthermore, briefly explained the residential self-help construction patterns in the colonias, by the statement below:

> Especially in the colonias, but I have seen it other places throughout the state as well, they are low-income families and they build a little bit at the time as they have cash that comes in. So, foundation is poor. Was it designed correctly? No. And then walls are built in, cinder block walls that go half way up and there is rebars sticking everywhere, I have seen in different sizes. I have seen interesting things. Now they sit there for a year. Now all of a sudden, the walls start to come up. So, this is a real slow building process on their new house that is next to their manufactured housing unit on the same lot that is just falling further and further into disrepair. So, they are just slowly building when they got cash available; I am going to buy some concrete next month now I can start to do this.

> Now I can buy some sheet of plywood, as time goes on gypsum, right? Even in completed homes, there is no finish work that is really ever done either.

5.3 Construction Challenges in the Colonias

According to one participant, the biggest problem in self-help housing construction in the colonias is the wrong choice of materials and their improper installation. To illustrate, he mentioned two examples:

> As just a simple example, a bathroom the sheet rock that is all paper faced even behind tile. Walking there you smell it and I have seen.
>
> I will give one example where I was in a house in El Paso and I climbed up on a roof and I knew right away I am not walking on this roof and I saw that facial board was installed above roof deck in the shingle so every time it rains and I see holes. The rain, the water [goes] straight into the walls. So I go inside to the house. I go in the bathroom; 4 inch above the entire shower enclosure is exposed to the final basis wide open. I stepped up on, I can see mold and I walked outside to talk to the mom and kids come home right. 9-7-10 and 8 and I asked them up and I said are they okay. Oh yeah they have asthma allergies. When did that start, like they always have that? About 3 years ago. When did you move that house? 3 years ago. So the construction methods of the colonias residents in general are literally making the inhabitants sick and I have seen that on countless occasions. And of course most of these people don't have any kind of health insurance. So, like the way you build houses, we are all fully aware, that we can make ourselves sick by the way we built houses.

All respondents agreed that the reason for these challenges in self-help housing in colonias is due to residents' lack of knowledge in construction and sustainability which brings up the need for education and training. Two participants gave voice to that opinion by the statements below:

> It is about the education, we can do all of low-cost sustainable energy efficient design we want architecturally and then say okay, we are gonna try to train them how to do it but it is more training. For it is education most important thing. And we have troubles in educating our friends at the HPA because that is the least cost so they are least cost. We are least cost to make money on this side. They are least cost because they have no funds. So education least cost from your [one participant's] style and what you [another participant] see, is so important so the field agent idea is tremendous.
>
> I have been in most of colonias from El Paso to Brownsville and nothing about sustainable construction science or the physics behind that all is‒you don't see it.

> A lot of self-help is as you mentioned already. So, major problems and factors is that no one has any idea what that means.

Finally, respondents raised a question about the impact of cultural mind-set of residents on housing design and construction patterns. Culture has a major role in the selection of construction material, shape of the houses, and whether or not to use mechanical cooling systems installed in their houses. One participant informed us that self-help construction in colonias is an incremental building process, and most of the houses are still not finished. Another participant interpreted this ongoing process of construction as "a byproduct of the Mexican way of building as well because you don't get taxed until it is finished."

The following sections document the investigation of these challenges and suggestions on low-cost sustainable solutions by focus group participants.

5.4 Climatic Determinants, Orientation, and Passive Design

Two major points were made during the discussion about climate: (1) Climatic characteristics in colonias, in Laredo, and (2) strategies for orientation of homes and for sustainable cost-effective housing design.

5.4.1 Climatic Characteristics in the Colonias in Laredo

Climate is one of the most important factors that affect the housing design and construction patterns observed in the colonias. Most of the respondents have considered Laredo's climate as hot and dry which is different from the other colonias in the Lower Rio Grande Valley of Texas, which are hot and humid. Four respondents have agreed that Laredo has significantly high temperatures, however is not significantly humid:

> But it is their custom , they don't have central air heating systems.
>
> It is a hot humid climate and that affects everything…. I see a lot of houses in the colonias that they don't even have an HVAC system…. I don't see a lot of really deep understanding of building science and thermal dynamics about how to build sustainable in the different climate zones.
>
> So they all know that they are living in a place that is hot. But they don't have any relation in their mind and in their construction practices: what does that mean when I am building a home?
>
> So it is the sun in an overwhelmingly warm temperature climate.

But there is not a lot of rain; I mean it is still humid though.
But [rain] is not around Laredo.

The responses demonstrate that a significant number of residents in the colonias lack knowledge on how to build sustainable structures in their climate zone. One respondent asserted that “when you are in a hot humid climate, you have to design and build differently than you do up in Amarillo, very different.” Furthermore, he feels that incremental building process in colonias have created unfinished homes with inadequate consideration on energy efficiency.

5.4.2 Strategies for Orientation

Orientation of homes and walls in homes is an important consideration. In urban locations, orientation may be dictated by a primary need for orientation to the street. However, one participant pointed out that lot sizes in the colonias are often bigger than urban lot sizes. Therefore, when building homes in the colonias, the orientation of the structure relative to the street can be less of a concern.

Participants identified three features for placing a housing structure on the site to optimize solar gain: (1) orientation of the structure itself, (2) shading (overhangs, shutters, baffles, and trees), and (3) orientation and size of fenestration.

Three participants pointed out the orientation of the structure as one of the major features to be considered. South facade was asserted as the main challenge for the city of Laredo in terms of energy efficiency. To avoid solar gains, two respondents proposed several shading techniques for windows on the south orientation: louvred shutters, overhangs, baffles, and covered porches.

> So the **louvre shutters** or the **overhang**, you open them you can see out, tilt them in the afternoon wherever the sun is that you don’t want in…. So their **extended overhang** for solar avoidance is combined in the **porch** function which is a very valuable function. And let that be on the south side if possible.
>
> Orientation is the first thing right away and **large overhangs**…. That’s sort of a knee jerk reaction to design windows on the south but you can also put **baffles** there. So, you look south, but actually see east. And you have a **mirror** there so when you look outside you are actually looking that way. That keeps the sun off, but you also see all your landscaping either side. Mirror is free everywhere. That will be a way to sabotage that solar gain from the south.

> I think **overhang** is a fundamental item for where you know you are not going to have mechanical cooling, and it is everything you can do to keep the sun from coming in....Especially when you get in Laredo climate where you can put all the buildings you want on, you know, the south side but without an overhang for it, you are just really going to have a challenge.
>
> the lots are a lot bigger so that needed space for overhangs is not an issue.

However, another two participants argued that overhangs and functional shutters require extra material and, therefore, add to the cost.

As a counter argument, three respondents emphasized the gain from an energy efficiency perspective; solar gain in the winter can reduce heating costs. One of them claimed that there is a way to avoid adding extra cost in order to keep the sun out from the house:

> So see if you can build it in with or if you can orient the home as best as possible. If you can do structure design with **fewer windows on the south, east and west side**, if you can get away with the increased material cost to do **overhang** that keeps the sun from coming in during the summer months, particularly where you are just trying to survive. Those are all factors, I think, that come into play off the placement of the house and the major factors about the climate.
>
> But **larger, larger window aperture on the north for day lighting**, and since it is not a cold climate, that's not gonna hurt you because the northern, northeastern wind and less windows on the east, west and south.
>
> I automatically would say, **go lean on the windows**.

Furthermore, a fourth participant pointed out the importance of energy modeling besides adapting the strategies discussed above:

> One thing that I would recommend is for the spatial agents on the resources that they have, I would make sure that they **do energy modeling** because with a HERS Rating, all of your questions will be answered very quickly. And it is all about the building science. So all of these things go into good design but really without an energy model you are just guessing.

To sum up, first, orientation of the structure itself is important to consider in making the structure sustainable and affordable. It can be followed up by placing few windows on the south, east or west facades whereas on the north facade, for daylighting, larger apertures can be used. For passive sun avoidance, grow as many trees as possible. Moreover, although overhangs, functional shutters, covered porches, or baffles add to the cost, they are worthwhile to place in terms of energy efficiency and reduced operations costs.

5.5 Building Design and Construction

The goal of this part is to identify the best strategies for housing shape, housing fenestration and housing envelope.

5.5.1 Housing Shape

The shape of the structure has a non-negligible impact on the performance of the building. From an affordability point of view, all participants strongly expressed the importance of keeping the design simple. Six of the participants asserted that a rectangular structure with a smaller east and west walls is more efficient than other forms (Table 13). Moreover, none of the respondents considered having a courtyard as a good idea because it increases the wall surface.

In colonias, there are both single- and two-story houses available. Regarding the affordability concept, the cost of land was considered as a major determinant. However, it does not typically apply to colonias' residents. Most of the colonias are comprised of large lots. From that perspective, four of six respondents asserted that single storey homes are more affordable than double storey houses (Table 13).

In this context, two participants suggested that a rectangular gabled roof is a successful choice for low-income houses. Another participant said that rectangular gabled with about 33 degree angle on the gabled is a convenient base for PV panels on the south facing pitch. A fourth participant, on the other hand, proposed another idea about the roof shape which is to have larger roof pitch on the south in order to have clerestory windows on the north facade to collect more daylight (Table 13).

The interviewees' suggestions on the relationship between structure and the ground diverge based on differing construction skills, cost, and floor type and materials. Some respondents have strong opinions on elevating the building by using pier and beam construction technique while other participants believe having a slab connected to the ground is better.

Table 13: Discussion on house design features

House Design Features	No. of Resp.	Statements
Shape of the House	6	
		Keep the design simple
		That's a good point. A square structure is far more efficient than the L-structure which is far more efficient than the fancy architectural ins and outs that you wanna do to make it fancy and smaller versus bigger.
		We are settled for rectangle.
		Rectangle is actually better because you can have the east & west ends smaller and so that solar heat gain actually will be reduced.
		DOE Building American Research says smaller east and west walls because the sun comes up on the east goes down west during the hot season. So, the smaller walls there, the less windows there, the better. And a larger north wall in a hot climate works.
No. of Storey	4	
		We are talking about affordable housing, we are talking single storey house .
		Yes [single storey house].
		Single storey.
		In the colonias the cost of the land is not a major factor. Then a single storey home that meets the needs is going to work.
Roof Shape	2	
		Rectangular gable with about 33 degree angle on the gable is convenient base for PV panels on the south facing pitch.
		Anything makes the southern roof larger roof pitch and have windows on the northern side but I always call a solar roof then you have daylight. Instead of a roof looking like this (Λ), I would with this λ and you would bring this one up higher. This (longer side) is just your southern roof so it keeps the largest area, this one is the smallest then you have windows.
Structure, off ground/on ground*	6	
		elevating the building by using pier and beam construction technique
		a slab connected to ground
Size of the structure	4	
		Because I think anything above 12, they shouldn't be building for affordable housing.
		That's 20 by 30 or 30 by 40.
		I don't think the cost between 1200 and 1300 is measurable and if you can get a little bigger bedrooms for those kids.
		8-12 hundred, I see from Brownsville to El Paso, anywhere in between them.

*** These two options were discussed in detail under the section entitled "foundation".**

Two of six participants agreed about that statement. At that point, another participant brought up that in most of the colonias in Webb County, homes are built on floodplains. The local jurisdiction has little control over building standards: "The state legislature is another significant challenge because colonias are outside the municipalities. And the counties have virtually zero authority to do anything in the state…. They don't have zoning authority; they don’t have code authority.”All participants highlighted that, in the colonias, residents often have sewage at their backyards that make people sick.

5.5.2 Housing Fenestration/Aperture

This part presents the responses of participants on three aspects tha affect sustainable and cost effective housing: (1) strategies for placing windows and doors, (2) techniques and methods on controlling solar gain, and (3) techniques and methods on ventilation. The discussion started with distinguishing between two strategies for achieving thermal comfort in a house in the colonias: (1) non-air conditioned, self-built, low cost housing, and (2) air conditioned self-built low cost housing. Recognizing these differences was found important by all interviewees, as illustrated by the following statements:

> I think we have two trains of thought; two schools. One low-income, low-cost, self-built, non-air conditioned affordable living, and then the one that has enclosed envelope insulated and air conditioner. And in the two different schools of thought, ventilation is big here; passive solar avoidance and ventilation in a high mass are the biggest things for non-air conditioned low-income home. And then you have the best energy efficient low-cost mechanical systems for an air conditioned and highly insulated shell. Which makes it not so affordable; that is why I was going to throw it to you because you are building affordable insulated modern looking housing. You have to have air conditioner, or you are not going to sell .
>
> I see in the colonias more the window AC units but definitely see some central systems but then you look at that outdoor coil like they never maintained it. I see grass and bushes completely covering on the condenser.

Strategies for Placing Windows and Doors

Participants held a discussion about strategies for placing windows and doors by balancing heat gain and daylight. They proposed four strategies: (1) using the least amount of windows, (2) choosing the size of the windows depending on the orientation, (3) solar tubes as an alternative strategy and technique for daylighting, and (4) improving knowledge on how to install them properly (Table 14).

To sum up, education and training become important issues to consider.

Table 14: Discussion on strategies for placing windows and doors

Strategies for Placing Windows and Doors	No. of Resp.	Statements
using least amount of windows	2	
		I automatically would say, go lean on the windows
		but larger, larger window aperture on the north for day lighting, and since it is not a cold climate, that's not gonna hurt you because the northern, northeastern wind and less windows on the east, west and south.
choosing the size of the windows depending on the orientation	2	
		So the overwhelming factor for choosing is the least amount of windows because of heat input but enough to do a sufficient job of daylighting so that you don't have to use electricity. Lighting the building in daylighting is so much better way to light your building.
		Yes.
alternative strategies and techniques for daylighting	4	
Solar Tubes (daylighting)		Solar tubes are a good idea too because you don't take a hit on energy efficiency that the skylight has.
		Interesting enough you can take left over Flex Duct take the outside insulating layer, the reflective layer, turn it inside out and use it as a flexible solar tube. Great for bathrooms.
		or closets.
		Yeah just in anywhere…. We use mirror.
		or aluminum.
lack of knowledge on how to install them properly	2	
		And the windows installed correctly.
		Yeah, they have to be installed correctly.

Controlling Solar Gain

Orientation of the structure, shading (overhangs, shutters, baffles, and trees), and orientation and size of fenestration have been already mentioned under previous parts (Table 14). As a strategy for shading, participants brought forward the ideas of overhangs, shutters, baffles and covered porch.

Ventilation

Careful shading, air infiltration and insulation are ideas that emerged about controlling solar gain in housing structures. Two respondents emphasized the fact that homeowners and even contractors often do not understand the building science behind air-conditioning and energy efficiency:

> I like what you have said [redacted]. Some houses, there is no AC. Others that have it, I will go back to, I think what [redacted] said is incredibly important. Some ERVs and HVAC systems load calculations–good luck finding an HVAC contractor to do that right and the complications behind the load calculation; you are already speaking another language to homeowners. When I say load calculations [they say] "what are you talking about?"
>
> Field agent model teaching the building sciences works. With non-air-conditioned and air conditioned structures doing building load, heat load calculations on a design non-air-conditioned, passively cooled sustainable high survivability structure is just as important as doing it on that air-conditioned structure because you have no mechanical equipment. So let's say your air conditioning system has to work really well at least one speed, it doesn't exist. But it has to work because your house has to be a little cooler during the day then it was just a box, right? So you know, it is the infinite efficiency of the air conditioner doesn't exist, so you better have good ventilation. You better have the windows in the right place that help high mass, you better have occupants know how to manipulate your house when to open the window and when to do not. But the puzzle is completely different when there is air-conditioning structure. You don't open window when you turn on the ERV. When you take a shower you have to turn on the vent fan or the wallpaper comes off to the wall.

Ventilation as passive cooling strategies has been quite commonly mentioned by the participants in affordable housing design and construction. Following these strategies allow residents to build low-cost energy efficient houses (Table 15).

In short, cross ventilation, chimney stack effect, ventilation due to off ground structure and fans and ventilators are the passive cooling strategies that all residents can adapt to their houses if they do not have mechanical cooling systems. However, reducing air infiltration is important for the houses with mechanical cooling systems.

Table 15: Discussion on ventilation[5]

Ventilation	No. of Resp.	Statements
Cross Ventilation	1	
		cross ventilation on windows
Chimney Stack Effect	1	
		chimney stack effect
Elevated Floor Ventilation	2	
		If you pull that conducted air from underneath the house which is easily 3 or 4 degrees cooler than the outside air, and then that gives some ventilation.
		Yes!
Fans-Ventilators	4	
		It doesn't have to be an attic fan; it could be window box fan. If you buy one of those once a year, oh that one does not work then get another one 20 bucks.
		Passive attic ventilation is what they are talking about. If you have a closed attic, it has to be ventilated. An exhaust fan is blowing through the attic, blowing up to the attic.
		ridge vents
		We use continuous soffit vents and ridge vents where possible.… minimal cost increase
		We recommend ERVs[2] : Energy recovery ventilators. It is a good way of controlling ventilation that is coming into your house.

5.5.3 Housing Envelope: Construction Methods and Materials

The focus group discussion on the building envelope addressed eight topics: (1) framing and insulation, (2) foundation and Floor, (3) floor finishes, (4) roof and attic, (5) walls, (6) doors, (7) windows and (8) paint.

[5] One participant described ERV systems as:

> The way an ERV works, it is a two way system that, here in a hot humid climate, it will bring in the hot air, hot humid air if it is supply system, it will bring it into your return air plenum, and as it is going through the ERV, you are mingling the return air with it, and so what it does is it removes the humidity from incoming air and then it throws it outside. So you actually have dual ducts, and it kind of does a crisscross like this inside the box and then you program it so that it is on a certain amount of time depending on how big your house is and what kind of HVAC system you have. So some of our systems may run ten minutes every hour depending on the season but- so this is the way to go because again when you do your load calculations for your HVAC system, it is designed on that, and so there is not really a lot of maintenance; low-income families don't like maintenance. So an ERV is going to run by itself and it is going to make sure that the house is comfortable.

Framing and Insulation

Regarding the framing, the responses were mixed. One respondent supported the idea of looking for "free materials" and "performance" together; he suggested that framing of choice should be the materials that are free or very low-cost down in the colonias. Each respondent shared their experiences and choices on framing and insulation by the statements listed on Table 16.

Table 16: Discussion on framing types

Framing Types	No. of Resp.	Statements
Wood Framing (Advanced Framing)	6	
		From an energy efficiency perspective, 2 by 6, 24s and R19 batt inside all those frame base and you are saving money on lumber and there is numbers being crunched…. You are saving the money on lumber that in to the point that you can throw another R3 foam board on the outside so you got walls.
		We use advanced framing techniques[1] and that would be the 2 by 6 on 24 inches… we just use the code R13 walls or R19 - whatever the case may be. We have affiliates that actually encapsulate their entire building envelope. It is expensive. It will do the job definitely, but really what is more important than having that type of premium insulation is just making sure that your advance framing techniques are correct because not only have you saved 30% of your lumber frame package but now you get more area to have the insulation between the studs. That's really what it is all about, reducing solar heat gain.
		What about the 2 by 6 with the staggered the 2 by 4s? So you have the conduction thermal break.
		We have got R19 standards for the batt insulation and the foam board. [we use] 2 by 6 but 2 by 4 when we go with the foam board. 2 by 6, we can do without foam board.
		What about 2 by 4 with 6 inches and another 2 by 4?
		I think the name of the game is how do you get R24 or R28 in the least expensive manner and I think it varies depending upon what the cost of materials are.
Concrete Structures	2	
		And in this type of framing, is it gonna be 2 by 4s, 2 by 6s, adobe concrete block, I mean all types of construction are successful in what I call the new building which we were still waiting for because energy efficiency is in it. It is not part of it. It is like in the tube of it. It is in the concrete block, you can't do without it; may be before the mortgage crunch recently, but now, when you go back to 80s, energy efficient housing probably, but today you do not build a house without in some level.
		You know, you say that but I am the president of Local Home Builders Association. We don't have any members to do building energy star specifications. And the reasoning is they try to sell it to the homebuyer, homebuyers like it; they like the fact that their energy cost is going to be lower but they are not gonna pay upfront.

Participants endorsed advanced framing techniques with R13 or R19 walls for wood frame houses. However, a significant number of houses in colonias are built with concrete blocks. Adobe houses were also considered advantageous due to high thermal mass. Participants pointed out the cultural mind-set as an obstacle against the adobe structures (Table 16).

Foundation and Floor

Two types of foundation systems have been discussed by taking into consideration of cost, flood risk, energy, and cultural factors: (a) pier and beams, and (b) concrete slab.

Table 17: Foundation types discussed during focus group

Foundation Types	No. of resp.	Cost	Performance	Maintenance	Statements	√/X
Concrete Slab	4	High	High	Easy		
		√	X		Slab-on-grade is going to be lower cost than pier and beam but perform worse from an energy point of view.	
		X			I don't think it is lower cost. I think it is what the market demands on the slab-on-grade.	
					That's right!	
			√	√	You know we really don't do a lot of pier and beam in Texas. Yes, almost everything is concrete.	√
					I wanna slab house.	
			√		that is a pretty significant energy savings to do that.	
			√		Right, you would be surprised how much heat loss/gain comes off the slab.	
Pier and Beams	5	Low	Good	Easy		
		√			I think the pier-beams are whole lot cheaper than slab.	
		√		√	A pier and beam is something that one person can put it in his own foundation. I mean my 7 year old daughter could do that. Easy!	
				√	So easy. So when you are looking at affordable housing in the colonias where the person, where the family were building it week by week by week. It sounds like pier and beam foundation.	√
					Pier and beam is a slam dunk.	
					Pier and beam is the way to build a house in Southern United States.	
			√		And especially in flood zones where a lot of colonias exist	
			√		Yes!	

According to Table 17, most respondents asserted that pier and beam foundation is cheaper, easier to install, and safer in flood zones than concrete slabs. However, residents should have knowledge on how to build it. On the other hand, when considering the cultural preconceptions of many residents, concrete slab as more attractive than pier and beams due to identification of concrete slabs with wealth. Furthermore, three participants pointed out that the concrete slab can help cool the building through conduction of heat to the ground. However, it may not be as cheap as the pier and beam foundation. In short, if a lot is located in a flood zone, residents should use the pier and beam foundation; otherwise, both of the foundation types may be appropriate for colonias.

Responses on insulation materials for floor were mixed (Table 18). For instance, one participant prefers to use concrete in affordable housing projects. According to him, the decision on insulating the concrete slab depends on how far north the building is. He said that if the building is in climate zone 3, perimeter insulation around the exposed walls of the slab is required. However, for much of Texas, it is not required. As a result, insulating the concrete slab in Texas has been found unnecessary.

Participants recommended four suggested insulation materials for piers and beam floor:

- Data demonstrates that fiberglass insulation is the most affordable and has the lowest thermal performance (3 respondents). However, instead of batt and blown-in fiberglass insulation, three respondents asserted that spiderinsulation, spray applied fiberglass gives the same R-value as in open cell spray foam insulation, but with a lower cost.
- Only one interviewee supported use of blown-in, also known as loose-fill cellulose while others preferred use of it on decks only.
- In accordance with three respondents, recycled paper is cheap and has a good energy performance.
- Two respondents bring up the idea of recycled clothing as a low-cost, easy to maintain the option for insulation material.

- Spray foam insulation was found to be easy to use by two respondents. In terms of cost and performance, open and closed cell spray foam insulation was discussed[6]. To sum up, closed cell one is more expensive but having more structural integrity whereas open cell insulation is cheaper and durable against moisture.

Table 18: Suggested insulation materials for floor during focus group

Floor Insulation Types	No. of resp.	Cost	Performance	Maintenance	Statements	√ / X
Concrete Slab						
Insulation	3	High	High			
					It [whether or not insulating the slab]depends how far north you are. So it depends.	
		√	√		But if you are the right climate zone [far north] that is an expense that you will go to.	X
		√	√		All floors get cold because of the concrete.	
Pier and Beams						
Fiberglass	3	Low	Low	Easy		
		√		√	The winner is still fiberglass; cheap and easy.… So fiberglass is best for the cheapest.	
			√		I think they are the lowest performance because of installation challenge correctly.	√
					they need to be installed correctly.	
Spider Insulation as spray applied Fiberglass	3		High	Easy		
			√		I have talked the builders about why they are not doing more space foam insulation and one of the more reputable builders in the community, the way he thinks, he can get the same R value by using spider insulation. They spray in.	
				√	It glues itself.… And it is not gonna get settle over time therefore render it.	
				√	it glues itself; the piers to inner wall.	
			√		It is called spider because it looks like spiders on top of each other. It is Fiber glass. See, you get the insulation value of hollow fiberglass fiber but you don't get the insulation compression issues.	√
				√	and it is not gonna get sag over time therefore render it.	
					Fiberglass insulation was designed for a hot box test. That's what was manufactured for, not being put in people's houses. Never had those conversations with anybody smiling…. It is all we have. We couldn't tell what you install to your wall.	

[6] "**Open-cell foams are permeable to moisture and impermeable to air** R-value per inch: about 3.6, Cost: about $0.44 to $0.65 per board foot" and **"Closed-cell foams stop air and moisture** R-value per inch: about 6.5, Cost: about $0.70 to $1 per board foot"(Green Building Advisor 2013)

Table 18 Continued

Batts	1	High	Good	Easy		
		X	√	X	It will be probably blowing in versus using batts because you have greater chance of getting it right.	X
Blown-in	1			Easy		
				√	It will be probably blowing in versus using batts because you have greater chance of getting it right.… on a pier and beam we go in and put foam the floor.	√
Cellulose						
Blown-in	2			Easy		
					I love that loose fill cellulose. I think that is wonderful!	√
					We did foam on the roof deck but otherwise blow in cellulose insulation.	
Recycled paper	3	Low	Good			
					Recycle paper.	√
			√	√	Plus, yeah, insecticidal. Problem is it does settle a little bit. Okay, but we don't blow it in but we put it by hand. And I don't use dry walls. So that top plank inside walls is removable where you can add some more, put more batt in there if you need to. So I don't use dry walls so that is easy; it will be hard to hinge down the dry wall. I love that stuff.	
			√	√	Great idea! The top foot of your dry wall is hinged; ages sprinkle down insulation every five years to fill your walls up with little bit of insulation that settle down.	
Recycled clothing	3	Low	Good			
		√	√	√	And insulation isn't cheap but it can be cheap. You can get used cotton clothing, throw it in a bucket of boric acid, hang them on the line, throw up in your attic, and that competes within 2% of the R-value of the commercially available insulation. It is just that most people don't like the idea of somebody else's underwear in your attic but look what you get.	√
			√		long cotton fibers great insulation.	
Spray foam						
Closed Cell	2	High	Higher			
			√		well I know that close cell has so much structural integrity.	X
		√			it is more expensive.	
		√			it is more expensive.	
Open Cell	2	Lower	High			
		√			Open cell.	√
		√			Open cell, interesting.	
			√		Open cell has moisture migration but closed cell doesn't. It is decades, I think, before we really know what is going on with foamed attics, open cell floors? Personally, I will do closed cell on the floor because it is more like epoxy. It is there; it glues it together, creek and moisture is not gonna migrate one way to other.	

Table 18 Continued

Rock Wool	3	High			
		√		It is more expensive; it stopped because it is filled with the asbestos from the mine in Idaho and Montana.	
				They used to use it.	X
				but you can still get it.	
			X	I would have tested it before I put it into a house. If you go to a house with a rock wool in ceiling, it is a very good possibility that it is loaded the asbestos.	

Two insulation materials, on the other hand, were not evaluated as appropriate to be used in the colonias:

- Three participants brought up the rock wool as an insulation material. However, as it is filled with asbestos, it is not used anymore.
- Batts are not recommended by any respondents.

Floor Finishes

The discussion on foundation types and insulation materials was followed by sharing experiences of participants on floor finish materials. Respondents suggested three low-cost sustainable floor finish materials: (1) stained concrete for concrete slab, (2) wood, and (3) tile for pier and beam structure (Table 19). Labor was found to be the main factor that escalates the cost.

One respondent, who builds affordable houses with concrete slab, stated that, although concrete slab needs labor to be put down, the stained concrete is a finish that is cheaper than all the other materials, requires less maintenance than other materials and is easy to apply. This statement was approved by other three participants.

For pier and beam structures, however, two participants claimed that wood and tile are better choices than vinyl or carpet. According to one of them, one of the advantages of installing tile is the ease of finding the recycled or surplus tile from the outlets, with little extra cost. Moreover, these materials are easy to install; all participants agreed that the residents can install wood or tile by themselves. It can reduce the cost of labor.

Concrete slab does not create a need for insulation in Texas as it was mentioned in the foundation section. However, if residents prefer to build pier and slab foundation, participants suggest two insulation materials for subfloor: (1) fiberglass batt insulation material, and (2) open cell spray foam.

Table 19: Floor materials and floor insulation suggested by the respondents

Floor Materials	No. of Resp.	Cost	Maintenance	Performance	Statements	√ / X
Concrete Slab						
Stained Concrete	5	Cheap	Easy	Good		
		√	√		One thing we are finding very affordable regarding the floor finish is just to do stained concrete so that you don't have a finished floor, just slab.… If you pour a slab, an example is our Austin Affiliate; they actually do it themselves. They paid a company to come and do it once so now they do it themselves. So it is really effective.	
				√	Then it is cooler than carpet because the slab is connected to the ground. So in cooling dominated the climates, you want that cold or cool slab when it is in cold climates, you feel cold on a cold slab or terrazzo tile…. Something hold the winter heat the way the windows are oriented so the high mass concrete.	
				√	Now I am just a big fan of just stained concrete.…concrete has got a thermal mass, windows the south facing, proper over hangs, now that sun coming in hitting that floor holding that heat gives it back in when the day goes on.	√
		√	√		Well, you know, yes [it is cheaper than the conventional vinyl], because you don't have a finished floor. I mean, you gotta go get the labor or have the labor to put it down.	
		√	√		They don't spending any more labor time on finishing the slab.	
		√			the cost to put the floor down is less.	
					You still have to keep it coated.	
			√		I think they have to seal it like every 15 or 20 years depending on the use.	
		√			So lowest cost would be the stained slab.	
		√	√		for lowest cost you need to take slab. In his [one participant's] situation, with volunteers; I am go along with that you know that what we were paying for slab, we are paying for the labor coming and stain it. There is 2 or 3 operators than to the staining slabs.	
Pier and Beam						
Wood	2	Cheap	Easy			
		√			if you are building pier and beam, skip the Vinyl, skip the carpet.… Wood, tile.	√
		√			Wood.	
Tile	2					
		√	√		Wood, tile; tile is available by the metric ton anyway. Just knock on tile outlets front door and say can I have your broken tile. That's easy! It sticks to OSB, it sticks to pre-mixed ceramic tile pieces, it sticks to plywood, grout, seal, done!	√
		√			Used tiles.	

Table 19 Continued

Insulation (Sub-flooring)				
fiber glass batt insulation	3			
			We do a lot pier and beam, we would do fiber glass batt insulation in a sub-floor but we are down to the open cell spray foam.	√
			That’s what I have been doing.	
		√	Fiberglass is fine with no air conditioning. Anything under the floor is fine with no air conditioning unless you wanna ground connected which is even better but the migration of moisture to the floor. Now improved in a last couple decades.	
Open cell Spray Foam	2			
			We do a lot pier and beam, we would do fiber glass batt insulation in a sub-floor but we are down to the open cell spray foam.	√
			That’s what I have been doing.	

Roof and Attic

This section revolves around the roof as a building component with regard to its shape, materials, and insulation. On the subject of shape, gabled and hipped roof are the ones mostly preferred by the participants while they are building affordable and sustainable houses. Four respondents suggested gabled roof for its simplicity. Two of them elaborated how to make the gabled roof work as a solar roof (Table 20). Furthermore, two respondents asserted that a hipped roof with more pitches is more durable against wind resistance. No matter which type of roof is chosen, one of the two respondents emphasized the importance of adding overhangs, larger ones on the south, and installing a radiant barrier on the roof.

Table 20: Roof types suggested by participants

Roof Type	No. of Resp.	Cost	Maintenance	Performance	Statements	√/X
Gabled Roof	4					
					We like gabled roof personally.	
			√		for simplicity.	
			√		for simplicity, yes!	
				√	Anything makes the southern roof larger roof pitch and have windows on the northern side but I always call a solar roof then you have daylight. Instead of a roof looking like this (Λ), I would with this λ and you would bring this one up higher. This [longer side] is just your southern roof so it keeps the largest area, this one is the smallest then you have windows.	√
				√	if you do gabled and if you eventually put up PV panels and if the East-West axis is the longest of the axis, then that is going to be a great base for your PV panels because it is facing south. So rectangular gabled with about 33 degree angle on the gabled.	
Hipped Roof	2					
				√	but the hipped roof, with more pitches gives you better insurance premium. We founded that like 4 6 and 12 inches pitched roofs has more wind resistance.	√
			√	√	You know wind can't get in to lift it up.	
General Statements:					So you really need overhangs, larger overhangs on the south on the roof and radiant barrier must go on the roof for insulation material.	

The discussion on the materials used in roof unfolds three suggested materials: (1) Metal roofs, (2) shingles, and (3) license plate roofs (Table 21). Concerning the performance and maintenance, five respondents recommended metal roof because it reflects the sun and requires less maintenance. However, one participant asserted that although he prefers metal roof, it is not a cost effective option. However, according to another participant, metal roofs are cost effective in the long term considering maintenance. On the other hand, two other respondents brought up shingles as another option. In order to increase the thermal performance, a third participant emphasized that light colors of shingles should be chosen. Another participant, furthermore, came up with a new idea of license plate roofs in which recycled plates can be used. Hence, it is a cost effective option. Moreover, it shows a similar level of performance with the metal roof.

Table 21: Roof materials asserted during focus group

Roof Materials	No. of Resp.	Cost	Maintenance	Performance	Statements	√/ X
Metal	5	Moderate	Easy	Good		
			√		I always go with a metal roof. I have done one asphalt shingle roof. They are all metal because that lasts a long time.	√
				√	It reflects the sun.	
				√	Metal reflects the sun.	
				√	One advantage with metal is that the water that you might want to harvest is cleaner and can be more easily treated to be drinkable. So metal roof is the best all around.	
		X			We prefer metal, but it is not the most cost effective but we most prefer.	
		√	√		I challenge youl; in the long term, it is more cost effective because you will replace your shingles.	
License Plate Roofs	2					
				√	License plate roofs…. we replace the license plates. If you get the pitch up, we want water to run away; we don't want it to mosey. We want it to go away but down there, there is not that much rain so that's probably not much of an issue.	√
					License plate roofs.	
Shingles	2					
				√	if they are going to use any shingles, we always ask them to use the light colored shingles.	√
					we use composition shingles…. We use a 30 year architectural shingles.	

Regarding the insulation, one participant declared that in most of the self-built houses in the colonias, residents do not put any insulation in the attic; furthermore, there is no access to the attic. "In the bigger picture, when we are talking about colonias, self-help housing, when they are building their houses over 3, 4, 5 year period, they put up that ceiling gypsum and hopefully, it has the right thickness and then they are done; these are uninsulated ceilings."

Table 22: Attic insulation material suggested by the interviewees

Attic Insulation	No. of Resp.	Cost	Maintenance	Performance	Statements	√/X
cellulose	6					
		√		√	For affordability and for performance, cellulose in the attic.	√
					cellulose in the attic.	
				√	that is what we do but the platforms the air handers and stuff let's go put batts underneath that.	
				√	raise them up about 3 inches.	
				√	The method there is to put 3 to 4 inches of blond cellulose, if not 6 and then stretch fiery berry foil on top of that horizontal. Killer!	
Foil	1					
				√	The method there is to put 3 to 4 inches of blond cellulose, if not 6 and then stretch fiery berry foil on top of that horizontal. Killer!	√
				√	But to have that shiny surface and it works in winter and summer because the heat can't radiate out and it can't radiate in.	
Recycled clothing	3					
		√	√	√	And insulation isn't cheap but it can be cheap. You can get used cotton clothing, throw it in a bucket of boric acid, hang them on the line, throw up in your attic, and that competes within 2% of the R-value of the commercially available insulation. It is just that most people don't like the idea of somebody else's underwear in your attic but look what you get.	√
			√		long cotton fibers great insulation.	

The insulation in the attic is very important. Concerning the air infiltration to the house, all focus group participants suggested not opening up any holes on the ceiling for any lighting fixtures. It may reduce the energy efficiency of the house as revealed in the statements below:

> So a couple items here then. One we haven't talked about is ceiling of the rooms of the home. The fundamental is: do not cut into those ceilings for anything, for particularly recess light fixtures. It just kills your air infiltration that's a fundamental item that really knocks down the energy efficiency of homes; when you start having - when you start opening up holes in ceiling for light fixtures.
>
> Yes, you are exactly right; the ceiling is the number one plan for infiltration.
>
> It is a hot box, they are getting radiation long before the air temperature in the house is hot, they are getting radiation
>
> And that attic is getting up to 180.
>
> Certainly!
>
> So the insulation in the attic is very important.

Table 23: Sustainable technologies integrated with the roof discussed during the focus group

Sustainable Technologies	No. of Resp.	Cost	Maintenance	Performance	Statements	√/X
Water reclaim	6	High	High	Good		
					Definitely water catching. water reclaim.	
				√	I am just a fan of gutters; where we are putting them on and capturing the rain water… and every inch per square foot gives 0.6 gallons.	
					if there is rain in the area, let's grab it. That's what happens.	
				√	It is to flush your toilets and water your garden, to wash your dog's feet.	
				√	flush your toilet, just you can't drink it.	
				√	I still think it is something cost prohibited for affordable housing but it may be getting better where you live in an area where the housing is in that area that doesn't have zoning restrictions against the 5000 gallon tank. I don't know what the cost are in these days, I don't wanna come in down, but 5000 gallon tank on the property somewhere you [one participant] are capturing that rain water in the 5000 gallon tank, you use it every other purpose other than drinking.... If you can get a way not having the burry the tank structure, if you are in a place where you can put the tank structure on grid then I think the cost is getting to be a reasonable cost. I don't know if that fits the model of affordable housing cost but it is a consideration.... You use the tank for everything other than drinking including flushing the toilets.	√
				√	A 500 gallon cistern will manage a family of 4 for six weeks.	
Solar Water Heaters	3	High	High	Good		
		X		√	On affordable housing, you may wanna go with the solar water heater but it is for photovoltaic cells it is not for poor; not there yet.	
		X	X	√	Water heater, unfortunately, is there is a reasonable amount of maintenance required there first of all, and secondly, if there is any other alternative to heating of water particularly with these new heat pump water heaters. Solar water heating is getting to be not as favorable of an action as it used to be.	X
		X	X	√	If you are in a high mechanical design ground, so if you are looking at middle class, upper middle class houses not a lower middle class houses.	
General Statement					There are some health issues that go along with that though and so, they need to be designed correctly.	
Green Roof	4					
			X		But the problem is you have to get a rain you keep it alive.	
		X	X		Yeah, your roof needs to be strength.	
		X	X		Yeah, now you are talking about the professional engineers to certify the exterior walls are for affordable housing effort.	X
			X		that's a high maintenance subject.	
					I would think we [Habitat for Humanity] will never do that.	

On the subject of insulation materials in the attic, responses suggest that cellulose, aluminum foil and recycled clothing are the three options brought up during the discussion as being cost effective and providing energy savings (Table 22).

Lastly, the responses on the low-cost sustainable technologies applied to the roof of the houses are summarized in Table 23. Participants pointed out three strategies: (1) water catchment, (2) solar water heaters, and (3) green roof. According to five participants, water catchment is worthwhile for colonias residents despite the cost. Another focus group participant stated that "if you have a metal roof and sprinkle it on a cycling basis that could make a huge difference."

The opinions of three participants on the second suggested strategy, solar water heaters, are that regarding the cost and maintenance, it is not a convenient technology for affordable housing whereas there is a consensus on its ability for energy recovery. Lastly, four participants expressed their views about green roofs. None of them suggested it for colonias residents. The reasons behind their opinions are that (a) it will increase the cost of the roof design, (b) it will require professional engineers to design it, and (c) it will need water to keep the plants alive. Therefore, this idea was found to conflict with the affordable housing concept.

In brief, water catchment is the only strategy that relates to water systems that was recommended during the focus group session.

Wall Materials and Insulation

In this section, participants have shared their expertise on wall materials and insulation which can be applied by colonias residents. First discussed topic was the existing construction patterns in colonias. One of the focus group participants emphasized the challenges that he has come across as a lack of knowledge in construction. He said "I have seen self-help construction in El Paso, where we see a lot of stuccoes and it was not done right and within a couple of years, it starts to fall apart."

Participants arrived at the conclusion that the existing construction patterns and challenges in colonias are based on the cultural mind-set of the residents (Table 24). Three respondents thought the rejection of adobe houses is a result of preferring a wood and brick house which is more "American."

Table 24: Statements on cultural resistance to adobe houses

Statements on Cultural resistance to Adobe House
I have always been a big believer in the adobe houses but I have heard and I am on the edge of what I know, they could build adobe houses down there but that is not becoming American. And they want to have a real house like real Americans meaning brick. So all the building material in the world, they are walking on everyday but there is resistance to that an adobe house, a 2 foot wall; there is a good bit of energy efficiency there. But that needs more get to build because there is this cultural resistance to looking like a peasant or being poor. So we want brick.... that is a cultural mind-set; that is the problem
No, you are exactly right. Especially in El Paso, some of them are doing it but especially in Webb County where Laredo is, many years ago through A&M a machine was purchased to make adobe bricks and another program that oversees the colonias Self-help center program, that's it. I can go many details as all you want but a Tool lending library is also exist in all our self-help centers. So counties own all these tools and have classes residents come in and they learn how to do certain things install adobe, install a door and come borrow the tools that you need just like library checking out book. An entire building is made out of adobe brick and they even cut off the section inside, then you see the actual brick itself. They, a county and a couple non-profits down there, have tried to build adobe houses and exactly what you said. People flat out and resist and say "I don't want that". There is resources right there in Webb County to do it and that machine is sitting there idle right now.
What a lot of nonprofit in El Paso does that it is all through the bootstrap which he [one participant] knows very well because they are all Habitat's. That's all self-help housing, do constructions for centuries long, is that organization in El Paso is building adobe houses but you only know it when you look at the windows and doors that you can see the thickness of the walls in the inside you actually do the framing and gypsum do it for the wall covers, in the outside it is stucco so it looks like the rest of El Paso area. You would know because the wall is that thick but they make it look like it is not adobe.
So you have the culture where they don't wanna look and learn from their past because that is a poor past mentally and culturally in those they are not, they are rich in a lot of ways, right?

Considering the fact of the cultural mind-set of the residents, focus group participants suggested two types of wall materials: (1) concrete blocks, and (2) wood frame (Table 25). Concrete block structure with insulation on the exterior was found to be better in terms of cost and thermal performance by three respondents. However, most of the respondents build affordable houses in wood frame.

Wood structure, on the other hand, was discussed in detail under framing section. All participants brought up three exterior cladding options: Hardy plank, wood siding, and brick. Hardy plank was assessed as the most convenient one for colonias residents regarding the cost and performance.

Table 25: Wall materials and exterior cladding options discussed during focus group

Wall Materials	No. of Resp.	Cost	Mainte nance	Perfor mance	Statements	√/X
Wood	6					
					yes [we are going to get away from concrete structures], unless it is that homeowner who takes 5 years to build a house. I see those concrete walls.	√
					I have used dry stack wood and the other allowable dry stack granite; glue that together [for both interior and exterior]	
Hardy Plank (exterior cladding)						
		√		√	I use a lot of hardy…. it needs to be cost effective.	
				√	I use hardy plank all the time.	
		√		√	Yes [I found them cost effective, and maintenance free], that's really the number 1 exterior material we have.	√
				√	Well along with that hardy plank, a hardy board is building a rain screening in there as well.	
Wood Siding						
					And also don't overlook wood. I mean wood is a great siding. It is always okay for wood to get wet. It is never okay, that it can't dry out. So just get any wood and explore some organic design and you got free siding almost. Well people don't think that way, but if they will start to think that way when they save a lot of money.	√
					you put it up vertically, so it sheds the water faster.	
Brick						
					I like the sweep holes on brick. there is a drainage plan behind the exterior wall cladding.	
Concrete Block	3					
		√		√	There is nothing wrong with concrete block, I mean.	
		√		√	Nothing!	
		√		√	Not at all.	
		√		√	You put insulation on the outside.	
		√		√	If you are committed to conventional building and you are not gonna be building what, an adobe brick but you have a real brick like real Americans and you can pack all the, interior walls with thermal mass. Do the adobe from the inside and so when you see these dry wall contractors when they finished, there is this pile of stuff out in front of their building. Well, what they could do is finish all the exterior walls and then put all that rubble inside the interior walls working around the wires and so forth. I put rubble in my interior walls routinely-- brick, concrete, whatever you have--and you are adding some thermal mass inside the insulated envelope and that is gonna help and that is free. You just have to be smart enough to do that.	√

Table 26: Statements on wall insulation materials by participants

Wall Insulation	No. of Resp.	Cost	Mainte nance	Perfor mance	Statements	√/ X
Cellulose	6					
			√		We have talked about advanced framing. I like the blown in wet cellulose and it covers all, you can't screw up when it comes to insulation .	
		√			So affordable cellulose, you know, packed cellulose, packed cut fiber for down where she is, people building these houses.	
				√	One of the things we do on our interior walls are bedroom walls especially for the master bedrooms, we use sound insulation. We use sound insulation on all plumbing walls.	√
				√	they got homes exactly that way. In the plumbing walls but, master bedroom is insulated for sound, sound proofs.	
Batts	4					
					The walls we use the batts.	√
				√	From an energy efficiency perspective, 2 by 6, 24s and R19 batt inside all those frame base and you are saving money on lumber and there is numbers being crunched and … before. You are saving the money on lumber that in to the point that you can throw another R3 foam board on the outside so you got walls.	√
				√	R24 R28 exterior walls is what should be aimed at for these high energy efficiency low-income housing structures. And then how you do is gonna depend upon what the business model is, what is available, and what will it cost so.	X
		X		√	we just use the code R13 walls or R19 - whatever the case may be.… we have affiliates that actually encapsulate their entire building envelope.	√
		X			It is expensive.	
				√	That's really what it is all about, reducing solar heat gain.	
Recycled Paper	2					
		√	√	√	Problem is it does settle a little bit. Okay, but we don't blow it in but we put it by hand. And I don't use dry walls. So that top plank inside walls is removable where you can add some more, put more batt in there if you need to.... So I don't use dry walls so that is easy.	√
			√	√	Great idea! The top foot of your dry wall is hinged; ages sprinkle down insulation every five years to fill your walls up with little bit of insulation that settle down.	
Tight Houses	4					
					That's what flooding tape there for infiltration but it is already inside the wall section.	
					the last we did we put the Styrofoam sheeting from the outside, they came back and they made us put patches over all looking any punctures in the foil sheeting.… just got that full seal on the outside.	
					that's what we do automatically!	
					Well, just know that if you don't do a blower door test and you are building super tight houses like what you are describing, you may need to bring in mechanical ventilation.	

In terms of insulation materials for walls, cellulose, batts, and recycled paper are the ones suggested by participants (Table 26). They arrived at the conclusion that cellulose and recycled paper are cheaper, easier to maintain and have better performance than batts.

Doors

This section includes the door types and materials that participants have found to be successful for sustainable and cost effective housing (Table 27). Participants reached consensus on single metal doors as the best option for colonias residents. The responses on whether to have a glazing or not on the door were mixed. Two respondents suggested putting a small glazing (3 inch square) on the front and back doors. However, another two participants prefer not to put any because it has an impact on the cost.

Lastly, some of the participants have used storm doors in their affordable and sustainable housing designs. They arrived at the conclusion that if wind is a major factor, it will be better to use storm doors. However, its impact on the cost should not be ignored. As colonias do not have wind as a threat, storm doors were found to be unnecessary for these settlements.

Windows

In this section, participants have shared their expertise on window materials and type which can be applied to colonias. Vinyl double pane windows are the ones that have the consensus (Table 28). Triple pane windows were considered too expensive and unnecessary for the Texas climate.

Regarding the windows and doors, two participants emphasized the importance of installing them correctly by the statements below:

> And the windows installed correctly.
> Yeah, they have to be installed correctly.

To sum up, although window and door choices are crucial in terms of energy efficiency, "shading, air infiltration, and insulation" should be considered together to have a better result as stated by two respondents (Table 28).

Table 27: Discussion on door types and materials

Door Types	No. of Resp.	Statements
Exterior		
Metal Doors	6	
		I don't think we can get away from the **modern metal door**, right? [everybody agreed]
		You get **pre-hung, exterior energy star** qualified door retail for **100 bucks** at Lowe's.
		Metal clad insulated door, mine are always job site doors that are insulated.
Storm Doors	5	
		Storm door is a good thing. Yes.
		Yes.
		Yes.
		Yes.
		it is a good thing but it adds to the cost.
Glazing on the door	6	
		Double insulated right?
		Yes, **double insulated.**
		The best is **double or triple insulated**.
		we are talking about door itself. Why you **double the cost** when you put that little half mullion glass, right?
		Let's say **doors with no windows**! [everybody nodded yes]
		We typically put the **window on the front doors and in the back doors**.
		Yes, we put **windows on the front door and back doors** too. It is s**ingle glazed quarter inch plate**.… The rule is any glass in any door unless it is 3 inches square must be tempered or decorative … and the reasoning there is whatever decoration there is going to sabotage those machetes flying through the air breaks which is pretty close to truth.
Interior	3	
		Simple.
		Whatever you can make.
		a few exception that if there is **hot water heating inside the conditioned space**, then the door to that area needs to be **an exterior type door for insulating an airflow purposes.**

Table 28: Discussion on window types and materials

Window Types	No. of Resp.	Cost	Perfor mance	Statements	
Vinyl-Double Pane	4	Low	Good		
			√	We install double pane low-e vinyl frames.	
		√		let's get them ahead of time then we know. And we are talking about cheap and so that's what you need to do.	
			√	The best standard is what they say: the vinyl	
			√	Low-e	
			√	Plastic windows with low-e glass double pane.	
			√	So plastic window keeps the inside surface from being hot when the outside is always hot. So you have thermal break and then the glass has to be shaded which is low-e stops some of heat; let the sun shine in the glass that's why double pane windows are thermal break. that's pretty much the standard in building now. No more aluminum single pane.	√
Triple Pane	2	High	Good		
		X	X	what you don't wanna do is not go with these expensive triple glazed, high energy performance windows are (A) expensive, (B) may for a more of up north usage where they don't work right here. What you just said is the optimum for down here at this latitude.	X
		X		you don't need it here.	
General Statements				And a major component in making this kind of decision on windows is that it does no good to have a double insulated low-e window, if you haven't addressed the other major components of energy efficiency: infiltration, energy efficiency, thermal masses and so. That is an ensemble that must go together. Otherwise it is stupid just spend money on low-e windows, when air is flowing through your duplex outlet.	
				Shading, air infiltration, and insulation; the three fundamentals. If those are not in place, you spend all you want on windows and doors, but it is not gonna do much good.	

Paint

The last section under the housing envelope part is based on the discussion on paint types. First, the relationship between culture and the choice of coloring on the houses was examined by four participants:

> Cultural paint.
>
> Here is interesting culturally, when it comes to the colonias when you spent time driving around explore a lot of colonias, bright yellow house, bright blue house, green house with yellow, purple.
>
> They use a lot.
>
> A lot of color.

Table 29: Discussion on paint

Paint	No. of Resp.	Statements
Zero VOC	5	
		Zero VOC at 10 bucks a gallon.
No Paint	1	
		and my feeling is avoid paint all together but if you can't, use low voc. Every time you paint something, it adds decades of maintenance.
Colors (Exterior)		
White	2	
		you know on the exterior white.
		white!
		For an adobe building, you want white and less American.
Other Colors	2	
		Well, we don't typically use white except the trim. We try to go with whatever the large volume track builders use because they have market studies more in depth than ours.
		we have learned a long time ago, we picked the color palette and then they pick a color from our color palette.
		That's what a lot of people do.

It was followed by the suggestions on paint type for colonias residents. As summarized inTable 29, zero VOC is the type that was recommended by all respondents. One respondent asserted that if residents cannot afford zero VOC paint, it is better to avoid paint at all because of the maintenance.

5.5.4 Mechanical Systems-Sustainable Technologies & Techniques

The goal of this part is to identify the best mechanical systems, and sustainable technologies and techniques for houses in the colonias.

Heating and Cooling Systems

Under this section, participants have explored the low-cost sustainable heating cooling systems for colonias residents. They brought up four technologies: (1) energy recovery ventilators (ERV) or house dehumidifiers, (2) heat pumps, (3) central air systems and (4) multi-speed air conditions or mini splits (Table 30). For residents without any air cooling systems in their houses, three respondents suggested installing ERV and house dehumidifiers. These systems have low maintenance and high performance advantages. On the other hand, heat pump is another suggested system. Heat pump can be a small unit that can be mounted on the wall or window. According to one participant, two tons is enough for affordable housing standards.

For the residents who prefer to have an air cooling system installed in their houses, central air systems and multi-speed air conditions or mini splits[7] are the systems that were discussed during the focus group.

Table 30: Discussion on heating and cooling systems

Sustainable Technologies	No. of Resp.	Cost	Maintenance	Performance	Statements	√/X
ERV or house dehumidifier	3		NA	Good		
			√	√	We recommend ERVs, Energy recovery ventilators. It is a good way of controlling ventilation that is coming into your house.… So this is the way to go because again when you do your load calculations for your HVAC system, it is designed on that, and so there is not really a lot of maintenance; low-income families don't like maintenance. So an ERV is going to run by itself and it is going to make sure that the house is comfortable.	√
Heat Pump	2					
				√	The heat pump that I use, does a good air exchange. Because part of it is humid.	√
					no it is just a window unit but they just put it into the wall.	
					I don't know if it is made for window or not, I mount it on the wall and usually it is a half-ton, one ton, or ton and a half, and most recently I use the two tons.	
central air systems	4		High			
					So probably for central air conditioning properly sized.	√
					Size is important.	
					by modern heat properly on top of the list, properly sized.too much is not better.	

[7] One participant describes the mini split systems as below:

> The mini split is that window unit split into two pieces. Mini split, they all put split systems as for a residential air conditioner system. The reason for calling split systems is because again first American air conditioner was a window unit. So we split that unit up; we put the evaporator over here and heat part over here, the condenser that's what we have in all our houses. It is a split system. HVAC central split system. We called central system. The mini split is a mini split systems, your window unit, the part that is hanging inside stays, is mounted on the inside of the wall, the part that is hanging outside goes down to the ground. Then you got to ten foot two ten foot for free. So it is mini split. Quarter inch … and it has variable speed from 9000 btus to a ton and a half. And the really cool thing is that a ton and a half unit brings it 9000 Btus we will do 50% of its energy as a dehumidifier.

Table 30 Continued

Multi speed Air Conditioners/ Mini Splits	4	Mode rate	Low	High		
				√	Decades in the future for how they become that all air conditioners are multi speed, this is what Asia has decided. In china, you can't build a building without multi speed variable capacity air conditioners and there is modern building standards.... They are starting to make them now but that's not have any bearing on what they are doing down there. I think it is a window unit or mini split.	
					5 years from now, you will be doing that with a mini split. your installation cost will go down some and your operating cost will go down dramatically.	
				√	There are. You build a 12 to 15 hundred square foot structure that is on the order of, let's say, 5 to 8 kBtu per degree a day for all you need is a ton or may be ton and a half. It is all we need. Anything beyond that is too much for the home. It is a well-insulated energy efficient home, what is common now what is actually appearing now is these mini-split units that go down to one ton area and do the very efficient.	√
			√	√	That's what I do. I get high energy efficiency heat pump, you get one and then there is no duct to work in the house. Skip the duct work in the house because no homeowner is capable of cleaning their own ducts.	
			√		No duct leakage	
					Um, twice as expensive as the cheapest AC.	
		√	√		but, when your lowest cost option is a 3 ton central unit, now you can go down to that ton or ton and half to you need. So yes, on a per ton basis, it is more expensive option but their actual cash out flow is no different the way you spend on that 3 ton unit, you might wanna argue that gosh, I haven't bought a ton and a half capacity, why should I have to pay the same prices while I was paying three times but that will fix it self as times goes on that will fix itself at least you are getting the unit sized properly.... So instead of a duct work structure, you have got a refrigerant line structure. That's expensive to install.	
		√	√		And if you are starting from the beginning then you are footing in some type of pre-manufactured the exterior wall structure that's gonna have some kind of good efficiency, you're blowing in the insulation in the attic, you are putting in probably a 1-2 time mini split unit that does just fine for 800 to 1200 square feet then you have got your heating and cooling cost on average on 12 month growing average basis probably down to 20 to 40 dollars a month.	
					[It works for multiple rooms] It is called variable volume refrigerant, the compressor spins at variable speeds and if you have one room that needs air conditioning, the compressor runs just fast enough to pump in up free to that one evaporator coils	

Determining the proper size of the AC unit for a house is the most important thing that residents must consider. However, it is inevitable that residents should spend time and money on the maintenance of these systems. Opinions about the multi-speed air conditions or mini splits, on the other hand, were mixed. All participants agreed that it has a good performance and requires low maintenance. However, they have different opinions about the affordability of these systems for colonias residents. Some asserted that, in the long run, it would compensate the initial purchase cost whereas others stated that it will be an option for the future because it is not affordable yet.

To summarize, the consensus is ERV or house dehumidifier, or properly sized air conditioner systems for colonias residents.

Water Heaters

Three water heater types were discussed in detail regarding the cost, maintenance and performance criterion for colonias residents (Table 31). Heat pump for hot water heaters was found to be the most cost effective and the easiest to maintain. Second suggested option was manifold hot water design. Participants all agreed that solar water heaters are not appropriate to install for the houses in the colonias because they are expensive. They also emphasized that water heaters should be designed correctly; otherwise they may cause health problems for residents.

Table 31: Discussion on water heaters systems

Sustainable Technologies	No. of Resp.	Cost	Mainte nance	Perfor mance	Statements	√/ X
Solar Water Heaters	3	High	High	Good		
		X		√	On affordable housing, you may wanna go with the solar water heater but it is for photovoltaic cells it is not for poor; not there yet.	
		X	X	√	Water heater, unfortunately, is there is a reasonable amount of maintenance required there first of all, and secondly, if there is any other alternative to heating of water particularly with these new heat pump water heaters. Solar water heating is getting to be not as favorable of an action as it used to be.	X
		X	X	√	If you are in a high mechanical design ground, so if you are looking at middle class, upper middle class houses not a lower middle class houses.	

Table 31 Continued

heat pump for hot water heaters	4	Low	Low	Good		
		√		√	these are heat pump for hot water heaters that are actually working pretty well at a much lower cost per Btu than just straight electric element.	
					they look like standard water heaters I think that's what we are putting there.	
				√	They actually work pretty well.	
				√	They work great.	
		√			Well, they are 3 times cheaper than electric ones.	√
			√		now you have an alternative to solar that doesn't have a maintenance associated with it.	
			√	√	10- 15 [years of life expectancy]that is just tank that is again the tank that goes up first.	
		√		√	So low end solar hot water heating in that climate for a poor people is phenomenal. Actually in a county where you don't have plumbing codes, where they bought it, you could get very low cost, very simple solar hot water heaters.	
manifold hot water design		Moderate		Good		
		√			So your houses, you all moved the manifold hot water design you have Building America approved that was cost-effective spatial with plastic pipes.	
			√	√	Manifold hot water; it is, think of how you have an electrical fuse box in your house and all of the circuits are tied in and you can switch things off. Well hot water manifolds are the same. Well if the piping comes into a central location, via this manifold, you can actually go turn off any one of the lines you want and so it is just a way to maintain things a lot simpler and then we try to have the hot water heater somewhat centrally located so that water runs are not that far	
				√	So your hot water runs like this *[showing horizontal flow]* stops often and hits all the places so it is done- the water heater is here and it goes like this. So it is a manifold. It is more parallel in series.	√
			X		one of the things I fight my staff on it is putting in that manifold, they don't think those valves will last they will fail overtime how many times you turn it, keep you go up to the meter and turn off the water from the meter. And if you need to fix a leaky faucet you just turn off that faucet you don't turn off the water of the whole house, you will be still doing laundry and dishing while you actually shower.	
		X		√	Probably [manifold costs] a little bit more but I mean it is worth it.	
General Statement					There are some health issues that go along with that though and so, they need to be designed correctly.	

Table 32: Discussion on lighting systems

Lighting Systems	No. of Resp.	Cost	Perfor mance	Statements	√/ X
Recess Lighting	4	High	Low		
			X	we don't really use recess lighting because of the cost but… the ceiling is the number one plane for infiltration.	
			X	Recess lighting where you gotta cut a hole. Well, he [one participant] was actually illustrating it a better there is actually 2 problems: (a) the cost of recess light fixtures are expensive, (b) you are killing yourself from a structural energy efficiency point just by cutting in a hole in the ceiling.	X
			X	You see, it is terrible lighting efficiency; a light in a hole, that's gonna come out.	
			X	it is a chimney.	
Can Lights	2				
				can lights.	
			√	In my first couple of houses, we did two spec homes that aren't necessarily targeting for low-income sub division we are working in and we did some can lighting in there but we did the sealed cans and we still meet energy star.	√
CFLs	3	High	Good		
			√	CFLs	
		X	√	But they are expensive.	X
		X	√	yeah they were expensive.	
		X	√	So they won't be down there in the colonias.	
Cost Effective CFLs	3	High	Good		
		√	√	cost effective CFLs [Compact fluorescent light] are there.… But at this time CFL, compact fluorescent lighting or daylighting.	
			√	Yeah! You have to replace fixtures that are not working very well, making energy star qualified as well.	√
			√	you have to look at the right ones; the ones not you wanna look for are amalgam technology CFL bulbs.… But they don't buzz and they don't die early.	
Amalgam technology GFO	1				
				amalgam technology GFO [glass fibre optics].	
LED	2	Very High	Good		
				It would be smart strategy and down the pike we have done LED systems but that is not here yet.	X
		X		That is not affordable yet.	
Solar Tubes (daylighting)	4	Low	Good		
		√	√	Solar tubes are a good idea too because you don't take a hit on energy efficiency that the skylight has.	
		√	√	Interesting enough you can take left over fletch top take the outside insulating layer, the reflective layer, turn it inside out and use it as a flexible *solar tube. Great for bathrooms*	√
		√	√	or closets.	
		√	√	Yeah just in anywhere.… We use *mirror.*	
		√	√	or aluminum.	

Lighting Systems

Lighting systems are the second most important factor that has an impact on electricity cost for residents.

Table 32 summarizes the dialogue on the lighting systems that participants have found to be successful for the houses in the colonias. They recommended can lights and cost effective CFLs. Furthermore, using solar tubes to capture daylight was also highly recommended by the participants.

Appliances

The conversation on appliances shows that the consensus is on Energy Star appliances.

Plumbing

Common response for plumbing is selecting low flow fixtures such as toilets and shower heads and performing water catchment. One respondent proposed that residents may do "heat harvesting from dishwashers and showers too."

5.6 Limitations and Generalizability

The findings of this section have limitations regarding the generalizability of the results. Although each participant has a different background in terms of organization and companies and target client for their work, the low number of participants invited to focus group reduces the degree of external validity of the findings. However, the variation in their interpretation of the concept of sustainability and affordability enriches the results.

The target of the focus group discussion is colonias in Laredo, Texas. Therefore, the results are not generalizable to other colonias in different climates. However, a similar process can be performed to collect data for other informal settlements to identify guidelines and strategies for low-cost sustainable design practices.

5.7 Summary and Conclusions

Poor building performance and increasing energy consumption is one of the major challenges of colonias housing discussed in the literature (Machado 2006; Gharaibeh et al. 2009; Ward, Sullivan, et al. 2010; Sullivan and Ward 2012). Existing studies in the literature focus on homes of middle- and high-income residents. Studies on colonias homes are very limited in number and investigate rehabilitation of existing low-income houses, and infrastructure systems (Ward, Sullivan, et al. 2010; Sullivan and Ward 2012; Gharaibeh et al. 2009; Machado 2006; Donelson and Esparza 2010; Giusti and Estevez 2011; Donelson and Holguin 2010). Other proven, passive, sustainable cost effective strategies and techniques have to be adjusted according to the climate and the human comfort requirements of the target community (UN_Habitat 2011). The study in this section addresses this gap.

This section of the study has contributed low-cost energy efficient residential design and construction guidelines and rules for self-help colonias homes in Laredo, Texas. This study is original by proposing design and construction strategies appropriate for colonias residents in Laredo, Texas. It is aligned with the existing self-help practices of residents.

A focus group discussion with experts, who have exprience in affordable and sustainable residential design in Texas, leads to clarifying best solutions for colonias self-help home design and construction. A simple rectangular one story structure with gabled or hipped roof and reduced window aperture on South, East and West is a good solution in terms of energy efficiency and affordability. Advanced framing has been suggested as the best practice if it is a wood frame structure. Concrete block structure has also been proposed as it has a high thermal mass and is aligned with attitudes of residents about construction. There was a consensus that a careful design of mechanical systems has a major impact on energy consumption. The experts suggested reducing or eliminating HVAC use through careful passive design strategies, such as natural ventilation, careful orientation, and low-cost shading of windows. Other low-cost sustainable cooling systems such as ERVs, mini split air conditioning systems, and evaporative cooling systems by substituting conventional HVAC systems may also be appropriate. Several other sustainable strategies such as water reclamation and reuse, cost effective lighting and plumbing strategies were revealed during focus group as good strategies for colonias residents in Laredo. Findings of this section have been corroborated with the literature.

Documentation of strategies could enable (1) policy makers to set up regulations on improving colonias homes in Laredo, Texas, and (2) help centers to advise residents during their self-help construction practices and to provide expert consultation.

There was also a consensus in the focus group on highlighting the lack of knowledge of residents on sustainability and construction techniques which emphasizes the need for education and training of residents in order to increase their knowledge on these issues. The guidelines suggested by experts were used to develop Colonias BIM Toolkit (CBT) for best practices and serve to support the work done in the Section 7 to explore the use of CBT to design sustainable and affordable additions to existing homes. The CBT was tested by designing additions to two colonias homes.

6 DEVELOPMENT OF A COLONIAS BIM-TOOLKIT (CBT)

This section explores and documents a bottom-up process of applying Building Information Modeling (BIM) as an advanced tool to solve design problems for homes in the colonias and to predict the energy consumption of individual homes and the community. The purpose of this section is to demonstrate a method for developing a BIM based toolkit for informal houses that represent the homes and supports remodeling and estimates current energy use of the selected houses and the whole community. The scope of this study is limited to 30 houses from three colonias, along north of Highway 359, in Laredo, Texas (Green Colonia, Red I and Red II) which are selected as a representative sample of data. This BIM based toolkit was utilized to test whether houses in the colonias can be modelled rapidly and despite the lack of building data whether a process of calculating building performance of houses can be developed. This study is intended to prove the concept of using BIM to represent homes that are characteristic of informal settlements to guide the design of remodeling and new additions to the homes.

After considering the existing self-built housing design and construction patterns in the colonias documented in Section 3, I then identified options for reconstructing unknown data to calculate energy use of the sample homes: (1) R-value of the building components, (2) air infiltration value (ACH), (3) HVAC systems and (4) usage schedule. Second, I developed a new library of system family and building components to represent the construction methods and techniques in the selected houses in Autodesk Revit and tested the Colonias BIM Toolkit (CBT) with a new library by modeling the existing houses. Autodesk Revit has an embedded library of components and systems families, and a library of materials. However, as these houses are built improperly without building codes, they require a different library. Third, I calculated building performance of sample homes by using Autodesk Green Building Studio (GBS) and Autodesk Revit, undertaking a parametric variation of the factors to develop probable energy performance.

The process and results of these four steps are documented briefly in the following sections.

6.1 Design and Construction Patterns of Homes in the Colonias

To cover a typical range of homes, 30 houses in Green Colonia (15 homes), Red I (7 homes) and Red II (8 homes) were identified. The combination of face-to-face interviews with 30 residents and home inspections on-site helped to document the size/volume/aspect ratio, orientation, form complexity (number of corners), ratio of fenestration on facade, construction materials and methods, and shading. There are three major types of structures: (1) self-help structures, (2) manufactured homes with self-help parts, and (3) a combination of RVs or campers and self-help homes. The massing of the homes can be described by three basic forms: rectangle, L-shape and trapezoid. While L-shaped and right angle trapezoid structures are almost always self-built homes, rectangle ones can be manufactured homes, RVs or campers, or self-help structures. These basic forms show a variety in terms of size, construction materials, and roof types. Self-help structures were built as wood frame structures and concrete block structures. However, manufactured homes are wood frame structures. Four roof shapes were observed in the sample: (1) Hipped roof, (2) gabled roof, (3) flat roof, and (4) gambrel roof. A significant number of homes in the sample have shading elements such as a covered porch or extension of roof overhangs (18 homes).

There were several challenges in creating BIM models of the homes and calculating building performance due to lack of data. First of all, on-site data collection via inspections and interviews included data on footprint of the houses with measurements, and materials for each house. However, interior configuration of the houses was not inspected due to the sensitivity to the privacy of the residents. To that extent, I was able to model selected residential structures with exterior walls only. However, since I have collected information on each stage of the construction of the homes, I was able to develop a model for each stage separately allowing assignment of different parameters to different spaces of the homes. Additionally, there were three unknown factors which played an important role in modeling and building performance analysis: (1) the existence of the insulation material and its thickness which results in a lack of information on R-values of the building components, (2) air infiltration value and (3) type of HVAC systems. [8]

[8] Although, during face-to-face interviews with residents, the question about insulation was asked, none of the participants responded to this question. Moreover, during the on-site inspections, it was not possible to

Table 33: Alternative three scenarios for unknown factors

1. CONSTRUCTION METHODS/R-VALUES								
FLOOR								
	WOOD FRAME	INS	INS MAT	R-VALUE	CONCRETE SLAB*	INS	INS MAT	R-VALUE
SCENARIO A	Wood Joist 8"	X		R5	Concrete 4"	X		R2
SCENARIO B	Wood Joist 8"		batt ins 3 1/2"	R14				
SCENARIO C	Wood Joist 8"		batt ins 3 1/2" with insulated sheet	R18				
WALL								
	WOOD FRAME	INS	INS MAT	R-VALUE	CONCRETE BLOCKS	INS	INS MAT	R-VALUE
SCENARIO A	Wood Siding on Wood Stud 2 x 4	X		R2	8" Concrete Blocks with Stucco Finish	X		R1
SCENARIO B	Wood Siding on Wood Stud 2 x 4		batt ins 3 1/2"	R11	8" Concrete Blocks with Stucco Finish		rigid ins 1/2"	R5
SCENARIO C	Wood Siding on Wood Stud 2 x 4		batt ins 3 1/2" with insulated sheet	R14	8" Concrete Blocks with Stucco Finish		rigid ins 1"	R7
ROOF								
	WOOD FRAME	INS	INS MAT	R-VALUE	CONCRETE BLOCKS	INS	INS MAT	R-VALUE
SCENARIO A	Gypsum Board Ceiling	X		R2	Concrete 4"	X		R1
SCENARIO B	Gypsum Board Ceiling		batt ins 3 1/2"	R12				
SCENARIO C	Gypsum Board Ceiling		batt ins 3 1/2" with insulated sheet	R16				

*** As the thickness of concrete slab thickness of the structures are measured on site, the measured value is assumed constant for each run.**

	2. AIR INFILTRATION VALUE (ACH)**
SCENARIO -1	0.17 (best from GBS default)
SCENARIO -2	Most likely value from LBNL
SCENARIO -3	Worst scenario value from LBNL
SCENARIO -4	3.5 (worst from GBS default)

**** Air infiltration value for each house is retreived from LBNL Residential Diagnostics Database as worst and most likely values. 0.17 and 3.5 ACH are the default values in GBS tool.**

SCENARIO -a	Residential 17.4 SEER/9.6 HSPF Split HP
SCENARIO -b	Residential 17 SEER/0.85 AFUE Split/Pkgd
SCENARIO -c	Residential 14 SEER/0.9 AFUE Split/Pkgd Gas
SCENARIO -d	Residential 14 SEER/8.3 HSPF Split Packaged HP

SCENARIO-i	24/7 (Single Family House)

inspect individual components of the wall, floor or roof. The only way to get infiltration value was the blower-door test which was not possible in this research.

The next section explores how to overcome these challenges.

6.2 Addressing Unknown Factors in Energy Consumption

Size of the building, orientation, windows and glazing, R-value of the building components, air infiltration value (ACH), HVAC systems and usage schedule are the factors that influence the energy consumption. Out of these factors, three of them were unknown in this analysis: R-value of the building components, air infiltration value and HVAC systems. Considering the data collected on-site and from the literature, I have developed several design options for these unknown data (Table 33).

6.2.1 Construction Materials and R-Values

Construction materials and their thicknesses are important factors that have an impact on R-value of the building components. Data on construction materials are available through on-site home inspections and interviews with residents. However, the insulation materials and the thickness of the materials are still unknown variables.

In order to estimate R-values of the components for these homes, a set of rules and assumptions was established:

- Data collected on-site demonstrates that there are two types of self-built structures: (1) wood frame homes and (2) concrete block homes. Wood frame structures comprise 2 by 4 wood stud walls with wood siding, gypsum board ceiling with wood joist system, and either 4” concrete slab or 8” wood joist flooring. On the other hand, concrete block houses are constructed using 8” concrete block walls with stucco or brick finishing, 4” concrete slab, and either concrete slab as a roof or gypsum board ceiling with wood joist system.
- Manufactured homes are categorized according to the year they were built. HUD established a federal building code on June 15th, 1976, called HUD code, which is comprised of thermal efficiency, safety, wind load, roof load and durability (Donovan 2012). To that extent, the ones built before June 15, 1976 are called mobile homes and do not meet HUD standards. However, structures built after 1976 are called manufactured homes and compliant with the code established by HUD. There is only

one recreational vehicle (RV) structure (House 9) around which a self-help structure was built. It is a fifth wheel type of RV and was built before 1976.

- Three levels of insulation were assumed for both self-help and manufactured homes: (A) components without insulation, (B) components with moderate insulation that do not still meet the building code requirements, and (C) components with a minimum level of insulation suggested by IECC 2009 for Webb County, Texas for self-built homes (Table 34) and current practice of manufactured homes suggested by Champion Homes (Champion Builders, Inc. 2014) (Table 35). The thickness of the insulation material was assumed to be the same in each building component of a single structure.
- Age of the structures on-site was assumed to determine the level of insulation of the components. The assumption is based on the date of establishing HUD code for manufactured homes that are 1976 and 1980 for self-help structures. Table 36 notes that the oldest structure is 43 years old whereas the newest one is built in 2013. To that end, if the age of the structure is between 35 and 43, it is assumed to be built with low or medium level of insulation (Scenario A or B), whereas if it is between 0 and 34, the assumption is having medium or high level of insulation (Scenario B or C).
- Concrete slab floors do not have insulation material. Therefore, it is assumed to be constant (Table 37).

Table 34: 2009 International Energy Conservation Code (IECC) Minimum Insulation Requirements for Webb County, Texas (adapted from USDOE 2014)

CLIMATE ZONE 2 (WEBB COUNTY, TX)	R-value
Wood Frame Wall	13
Mass Wall	4 or 6
Floor	13
Basement Wall	0
Slab	0
Attic	30
Crawlspace Wall	0

Table 35: Current R-values of manufactured homes (adapted from Champion Builders, Inc. 2014)

	Construction Type	R-Value	Insulation Type
Wall	2x4	R-11	Fiberglass Insulation
Floor	2x6	R-22	Fiberglass Insulation
Ceiling		R-30	Ceiling insulation

Table 36: Age of sample home structures: The ones highlighted in red represent the structures with a very high probability of having no insulation

House No.	STAGE 1	STAGE 2	STAGE 3	STAGE 4
1	31			
2	1	1		
3	24	18		
4	32	15	13	
5	25	25	25	
6	43	43		
7	14	14		
8	17			
9	3			
10	33	0		
11	17			
12	39	38		
13	38	28		
14	19			
15	39	21		
16	20			
17	8			
18	23			
19	13			
20	17			
21	13	7		
22	9	8		
23	11			
24	24			
25	13			
26	17			
27	14	11	5	1
28	14	12	11	
29	24	19	12	
30	21	21		

Table 38, Table 39, and Table 40 show a summary of component alternatives. Since the target of this study is to create Colonias BIM toolkit (CBT) to model sample homes, I created a library of components in Autodesk Revit encompassing the observed materials and constructions on-site and the assumptions and rules described above.

Table 37: Three scenarios selected for floor construction methods and insulation levels for self-help and manufactured homes (adapted from Colorado Energy 2010)

WOOD JOIST FLOOR WITH CARPET FINISHING (2 BY 8) WITH THREE ALTERNATIVE INSULATION LEVEL

OPTION A: WOOD FRAME FLOOR-NO INSULATION				
COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Lower Air Film	1.23	1.23		
SubFloor 3/4"	0.94	0.94		
Carpet+Pad	1.23	1.23		
Inside air Film	0.92	0.92		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Floor Component R-Values	4.47	5.17		
Floor Component U-Values	0.2237	0.1934		R5
Total Floor Assembly R-Value			5.065	

OPTION B: WOOD FRAME FLOOR-WITH INSULATION				
COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Lower Air Film	1.23	1.23		
SubFloor 3/4"	0.94	0.94		
3 1/2" Fiberglass Batt		11		
Carpet+Pad	1.23	1.23		
Inside air Film	0.92	0.92		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Floor Component R-Values	4.47	16.17		
Floor Component U-Values	0.2237	0.0618		R14
Total Floor Assembly R-Value			14.415	

OPTION C: WOOD FRAME FLOOR-WITH HIGH INSULATION				
COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Lower Air Film	1.23	1.23		
SubFloor 3/4"	0.94	0.94		
3 1/2" Fiberglass Batt (High Density)		15		
Carpet+Pad	1.23	1.23		
Inside air Film	0.92	0.92		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Floor Component R-Values	4.47	20.17		
Floor Component U-Values	0.2237	0.0496		
Total Floor Assembly R-Value			17.815	R18

OPTION C: WOOD FRAME FLOOR-WITH HIGH INSULATION*				
COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Lower Air Film	1.23	1.23		
SubFloor 3/4"	0.94	0.94		
3 1/2" Fiberglass Batt (High Density)		20		
Carpet+Pad	1.23	1.23		
Inside air Film	0.92	0.92		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Floor Component R-Values	4.47	25.17		
Floor Component U-Values	0.2237	0.0397		
Total Floor Assembly R-Value			22.065	R22

***This option C with R22 is only for manufactured homes.**

CONCRETE SLAB (4”) AS ONE ALTERNATIVE

COMPONENT	R-VALUE	
Lower Air Film	1.23	
Concrete 4"	0.3	
tile	0.05	
Inside air Film	0.92	
Total Floor Component R-Values	2.5	R2
Floor Component U-Values	0.4000	

Table 38: Three scenarios selected for wall construction methods and insulation levels for self-help homes and manufactured homes (adapted from Colorado Energy 2010)

WOOD STUD WALL (2 BY 4) WITH THREE ALTERNATIVE INSULATION LEVEL

OPTION A: WOOD FRAME WALL-NO INSULATION

COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Siding-Wood Bevel	0.8	0.8		
Plywood Sheating-1/4"	0.31	0.31		
3 1/2" Stud	4.38			
1/2" drywall	0.45	0.45		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Wall Component R-Values	5.94	1.56		
Wall Component U-Values	0.1684	0.6410		
Total Wall Assembly R-Value			2.217	R2

OPTION B: WOOD FRAME WALL-WITH INSULATION

COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Siding-Wood Bevel	0.8	0.8		
Plywood Sheating-1/4"	0.31	0.31		
3 1/2" Fiberglass Batt		11		
3 1/2" Stud	4.38			
1/2" drywall	0.45	0.45		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Wall Component R-Values	5.94	12.56		
Wall Component U-Values	0.1684	0.0796		
Total Wall Assembly R-Value			11.567	R11

OPTION C: WOOD FRAME WALL-WITH HIGH INSULATION

COMPONENT	R-VALUE STUDS	R-VALUE CAVITY	ASSEMBLY R-VALUE	
Siding-Wood Bevel	0.8	0.8		
Plywood Sheating-1/4"	0.31	0.31		
3 1/2" Fiberglass Batt (High Density)		15		
3 1/2" Stud	4.38			
1/2" drywall	0.45	0.45		
Percent for 16"o.c. + Additional Studs	15%	85%		
Total Wall Component R-Values	5.94	16.56		
Wall Component U-Values	0.1684	0.0604		
Total Wall Assembly R-Value			14.967	R14

CONCRETE BLOCK WALL (8”) WITH THREE ALTERNATIVE INSULATION LEVEL *(only for self-help homes)*

OPTION A: CONCRETE BLOCKS WITH STUCCO FINISH-NO INSULATION

COMPONENT	R-VALUE	
Stucco	0.08	
Concrete Block 8"	1.11	
1/2" drywall	0.45	
Total Wall Component R-Values	1.64	R1
Wall Component U-Values	0.6098	

OPTION A: CONCRETE BLOCKS WITH BRICK FINISH-NO INSULATION

COMPONENT	R-VALUE	
Brick 4"	0.44	
Concrete Block 8"	1.11	
1/2" drywall	0.45	
Total Wall Component R-Values	2	R2
Wall Component U-Values	0.5000	

OPTION B: CONCRETE BLOCKS WITH STUCCO FINISH-WITH INSULATION

COMPONENT	R-VALUE	
Stucco	0.08	
Extruded Polystrene (3/4")	3	
Concrete Block 8"	1.11	
1/2" drywall	0.45	
Total Wall Component R-Values	4.64	R4
Wall Component U-Values	0.2155	

OPTION B: CONCRETE BLOCKS WITH BRICK FINISH-WITH INSULATION

COMPONENT	R-VALUE	
Brick 4"	0.44	
Extruded Polystrene (3/4")	3	
Concrete Block 8"	1.11	
1/2" drywall	0.45	
Total Wall Component R-Values	5	R5
Wall Component U-Values	0.2000	

Table 38 Continued

OPTION C: CONCRETE BLOCKS WITH BRICK FINISH-WITH HIGH INSULATION		
COMPONENT	R-VALUE	
Stucco	0.08	
Extruded Polystrene (1")	4.8	
Concrete Block 8"	1.11	
1/2" drywall	0.45	
Total Wall Component R-Values	6.44	R6
Wall Component U-Values	0.1553	

OPTION C: CONCRETE BLOCKS WITH BRICK FINISH-WITH HIGH INSULATION		
COMPONENT	R-VALUE	
Brick 4"	0.44	
Extruded Polystrene (1")	4.9	
Concrete Block 8"	1.11	
1/2" drywall	0.45	
Total Wall Component R-Values	6.9	R7
Wall Component U-Values	0.1449	

Table 39: Three scenarios selected for ceiling construction methods and insulation levels for self-help and manufactured homes (adapted from Colorado Energy 2010 and Reysa 2012)

GYPSUM CEILING WITH THREE ALTERNATIVE INSULATION LEVELS

OPTION A: CEILING-NO INSULATION		
COMPONENT	R-VALUE	
Attic air film	0.61	
Sheating	0.5	
Inside air Film	0.61	
Total Ceiling Component R-Values	1.72	R2
Ceiling Component U-Values	0.5814	

OPTION B: CEILING-WITH INSULATION		
COMPONENT	R-VALUE	
Attic air film	0.61	
Sheating	0.5	
3 1/2" Fiberglass Batt	11	
Inside air Film	0.61	
Total Ceiling Component R-Values	12.72	R12
Ceiling Component U-Values	0.0786	

OPTION C: CEILING-WITH HIGH INSULATION		
COMPONENT	R-VALUE	
Attic air film	0.61	
Sheating	0.5	
3 1/2" Fiberglass Batt (High Density)	15	
Inside air Film	0.61	
Total Ceiling Component R-Values	16.72	R16
Ceiling Component U-Values	0.0598	

CONCRETE SLAB (4") CEILING AS ONE ALTERNATIVE

COMPONENT	R-VALUE
Lower Air Film	1.23
Concrete 4"	0.3
Inside air Film	0.92
Total Floor Component R-Values	2.45
Floor Component U-Values	0.4082

Table 40: Door and window types observed on-site

DOOR			
	Width	Height	Finish
COLONIAS-Single-Metal	30"	80"	aluminum
	34	80	
	36	80	
	38	80	
	30"	84"	
	36"	84"	
COLONIAS-Single-Wood	30	80	wood
COLONIAS-Single-Glass	36	76	
	34	80	
	36	80	
	38	80	
	36	84	
COLONIAS-Single-Panel with white trim: Colonias	30	80	wood
	36	80	
	38	80	
	34	82	
	38	82	
	36	84	
COLONIAS-Single-Panel with white trim: Colonias AL	30	80	aluminum
	36	80	
	36	82	
	34	84	
	36	84	
COLONIAS-Single-Square: 36" x 80"	36	80	
	36	84	
COLONIAS-Single-Panel: 36" x 80"	36	80	
	36	82	
COLONIAS-Single-Decorative_v2	36	80	
	38	82	
	36	84	
	38	84	
COLONIAS-Double-Glass: 72" x 82" AL	68	80	aluminum
	72	82	
COLONIAS_Single-Raised Panel with Sidelights: 36" x 80"	30	80	
	36	80	
	36	82	
	36	84	

Table 40 Continued

WINDOW			
	Width	**Height**	**Finish**
COLONIAS_Single_Hung_Aluminum_casement_w_Trim_			Aluminum
	2'	2'	
	2'	2' 4"	
	2'	2' 10"	
	2'	3'	
	2'	3' 8"	
	2'	4'	
	2' 4"	6'	
	2' 6"	3'	
	2' 8"	4' 0"	
	2' 8"	4' 4"	
	2' 10"	2' 10"	
	2' 10"	3'	
	2' 10"	3' 10"	
	2' 10"	4'	
	3'	3'	
	3'	4'	
	3'	4' 4"	
	3'	5'	
	3'	6'	
	4'	4' 4"	
COLONIAS_SingleHung_Aluminum_Casement_wo_Trim			Aluminum
	2'	2'	
	2'	3'	
	2'	4'	
	2'	5'	
	2' 6"	4' 4"	
	2' 8"	3'	
	2' 8"	4' 4"	
	2' 8"	5'	
	2'10"	3'	
	2'10"	4'	
	2'10"	5'	
	3'	4'	
	3'	5'	
	3'	6'	
	3'10"	3'10"	
	4'	4'	
COLONIAS_Single_Hung_Aluminum_w_Trim			Aluminum
	1' 2"	2'	
	2'	2' 4"	
	2'	4'	
	2' 8"	3'	
	2' 8"	4' 4"	
	3'	3'	
	3'	5'	
	4'	4'	

Table 40 Continued

COLONIAS_Single_Hung_Aluminum			Aluminum
	2'	1'	
	2'	2'	
	2'	2' 6"	
	2' 2"	1'10"	
	2' 4"	3'	
	2' 6"	2' 2"	
	2' 6"	4' 4"	
	2' 6"	6'	
	2'8"	4' 2"	
	2'10"	4'	
	3'	3'	
	3'	4'	
	3'	4' 4"	
	4'	3'	
COLONIAS-Combination Rtp with Trim_ALUMINUM			Aluminum
	2'6"	4'	
	4'	4' 6"	
	4' 10"	3'	
COLONIAS-Single-Metal			Aluminum
	3'	7'	
COLONIAS-Single-Glass			Wood
	3'	7'	
	3' 2"	6' 8"	
COLONIAS-Double-Glass			
	4' 10"	6' 8"	
Colonias_Windows_Awning			Wood
	2'	1'	
	3' 2"	7"	
COLONIAS_Casement Dbl_Aluminum			Aluminum
	2'	1'	
	2'	2'	
	2' 2"	1' 2"	
	2' 8"	1'	
	2' 8"	2'	
	2' 8"	3'	
	3'	1'	
	3'	2'	
	3'	2' 4"	
	4'	2'	
	4'	4'	
	4' 4"	3'	
	5'10"	4'	
	6'	3'	
	6'	3'4"	
	6'	4'	
	7' 10"	3'	
COLONIAS_Casement Dbl_Wood			Wood
	2'	1'	
	3'	1' 8"	
	3' 10"	3'	
COLONIAS_Casement with Trim			Wood
	1'	4' 8"	
	2'	2'	

6.2.2 Building Infiltration Values (ACH): Normalized Leakage

Air infiltration has the largest impact on heating and cooling ventilation, heating and cooling costs (Sherman and McWilliams 2007); when it gets higher, energy consumption rate due to heating and cooling increases. The ratio of leakage has been shown to be typically correlated to the year that the home is built and the floor area. However, homes of low-income residents have higher air leakage areas than other houses no matter what year they were built or what the size of the structure is (Chan et al. 2003).

Infiltration is, however, the most difficult component to get accurate results from the model because it depends on several variables such as dry-bulb temperature, wind speed and direction, air tightness of the building envelope and air flow between spaces within the building (Energy and Environment Division 1982). Such data is usually not available. Air tightness and leakage through the building envelope can be measured with a blower door test, also known as fan pressurization technique method. in which there is a fan mounted on a door to first pressurize and then depressurize the whole house (Blomsterberg 2011). This technique was first used at Princeton University, and then Lawrence Berkeley Laboratory has improved it further (Blomsterberg 2011). However, it was not possible to use this technique for this research.

To that extent, infiltration value is another important variable which is unknown in this study. Air infiltration values for sample homes in the colonias were retrieved from a database of air leakage values through building envelope of houses in the U.S. called Residential Diagnostic Database developed by Lawrence Berkeley National Laboratory (LBNL) (2011). This database is a statistical model to predict air leakage value for houses in the U.S. according to their year to build, size, location and configuration (Sherman and McWilliams 2007).

For Webb county, normalized leakage range is between 0.41 and 0.62 whereas yearly average natural air exchange rate per hour is between 0.63 and 0.88 (Sherman and McWilliams 2007). Their sample includes single-family detached homes, single family attached homes, multifamily homes and manufactured homes. Their results show that among 8,200 manufactured homes, normalized leakage[9] mean is 0.94 whereas it is 0.61 for 135,600 single family detached

[9] Normalized leakage value is assumed to be equal to infiltration value for single storey detached residential structures according to LBNL (2011).

homes. 8,532 homes out of 147,000 were selected from Texas. By referring to this database, they developed a model that computes the expected air infiltration distribution for residential structures according to 7 parameters: Floor area (SF), ceiling height (ft), year built, region, climate zone according to IECC, foundation type and duct system location. The distribution is log normal. Results demonstrate that older and smaller houses have higher normalized leakage areas than larger and newer homes.

This research refers to LBLN Residential Envelope Leakage online model for obtaining an educated guess on the infiltration value for selected 30 houses (2011). For the 30 selected homes in the colonias in Laredo, Webb County, Texas, Table 41 shows three scenarios for the normalized leakage values for each house: (1) worst, (2) most likely, and (3) best values.

Generated infiltration value numbers are based on several assumptions as offered by LBNL. According to LBNL Residential Climate Zone Map, Webb County is located inside Climate Zone 2 Dry region. The ceiling height is assumed to be 8 feet for each house. Floor area used is calculated by Revit. Foundation type shows a variety in the selected homes: (1) slab, (2) pier and beams (unconditioned/ vented crawlspace) and (3) both. If a house has a concrete slab foundation, “slab” option was selected from the menu, whereas if it is wood frame pier and beam structure, “unconditioned basement/vented crawlspace” option was selected. In Autodesk Revit, each house was modeled as separate masses/spaces according to the year they are built and the type of structure. This allowed me to assign different infiltration values for different parts of the structure considering the year and the type (Table 41). However, if a house is a combination of a slab, and pier and beam structure, infiltration value for each structure was obtained separately according to their foundation types. On the other hand, the duct system location for these houses is assumed to be always “outside the conditioned space.”

For alternative scenarios, worst and most likely values were used since these self-built structures are substandard constructions and built improperly. Besides the worst and most likely values obtained from the LBNL model, Green Building Studio (GBS) engine assigns 0.17 ACH and 3.5 ACH values as default worst and best values for each home.

Table 41: Annual Infiltration Rate (ACH) for 30 colonias houses (adapted from Lawrence Berkeley National Laboratory 2011)

TIGHTNESS OF THE BUILDING-NORMALIZED LEAKAGE (95%)**											
		PIER AND BEAM STRUCTURES					CONCRETE SLAB STRUCTURES				
House No	TOTAL SF*	SF *	Year to Build	worst case	most likely	best case	SF*	Year to Build	worst case	most likely	best case
1	1,169	1,169	1982	1.7	0.5	0.15					
2	1,293	753	2012	1.3	0.35	0.1	540	2012	1.1	0.25	0.09
3	1,948						460 1488	1989 1995	1.55 1.1	0.475 0.3	0.15 0.08
4	1,303	524	1981	1.9	0.6	0.175	237 542	1998 2000	1.3 1.1	0.4 0.3	0.1 0.09
5	1,644	355	1988	1.9	0.6	0.2	1289	1988	1.35	0.4	0.1
6	2,011	441	1970	2.2	0.725	0.225	1570	1970	1.55	0.45	0.1
7	849	849	1999	1.5	0.4	0.09					
8	947						947	1996	1.2	0.35	0.09
9	1,339	846	2010	1.3	0.35	0.1	493	2010	1.1	0.3	0.095
10	822	485	1980	1.85	0.6	0.175	337	2013	1.15	0.3	0.09
11	1,755						1755	1996	1	0.3	0.08
12	1,526	171	1974	2.3	0.75	0.25	1355	1974	1.6	0.5	0.15
13	1,109	500	1975	2.2	0.7	0.225	609	1985	1.55	0.45	0.15
14	446						446	1994	1.3	0.35	0.1
15	764	638 126	1974 1992	2.15 1.6	0.7 0.5	0.225 0.15					
16	906	872	1993	1.4	0.4	0.09					
17	1,232						1101	2005	1	0.3	0.8
18	1,917	326	1990	1.55	0.45	0.15	1353	1990	1.1	0.3	0.09
19	1,088						979	2000	1	0.3	0.08
20	2,896						1408	1996	1.1	0.3	0.85
21	1,536						1404	2000	0.95	0.25	0.07
22	1,842						698 968	2004 2000	1.1 1	0.3 0.3	0.08 0.08
23	1,311						1190	2002	1	0.3	0.075
24	1,110	827	1989	1.75	0.55	0.15	214	1989	1.6	0.5	0.15
25	748						735	2000	1.05	0.3	0.08
26	351	304	1996	1.55	0.45	0.15					
27	1,359						697 431 178	2002 2008 2008	0.975	0.25	0.075
28	1,854						616 928 114	1999 2002 2001	1.2 1.05	0.35 0.3	0.1 0.08
29	2,028						819 137 819	1989 1994 2001	1.5 1.3 1.05	0.45 0.4 0.3	0.125 0.09 0.08
30	1,085						955	1992	1.2	0.35	0.09

* Area of homes were caluclated by considering inside the building shell

** For the normalized leakage value, duct system location is assumed inside the unconditioned space such as attic or basement. For wood frame pier and beam structures, "unconditioned basement or vented crawlspace" option was selected whereas for concrete slab structures, slab was selected. Webb County was located inside Climate zone 2 and dry region according to the LBNL Residential climate zone map.

One of the limitations was that Autodesk Revit assigns a default infiltration value to the project according to its design. Exporting the Revit model as a gbXML file to GBS and changing the value from gbXML file is the only way to control this value.

6.2.3 HVAC Systems

Data on Table 42 shows that 10% of the houses do not have an air conditioning system, whereas 53.3% has central air conditioning system, and 36.6% has partial air conditioning system. Assumptions on types of AC systems used in the selected 30 homes were based on the options available in Revit and GBS tools (Figure 20).

Table 42: Air conditioning systems available in 30 homes

COLONIA	AIR CONDITIOINING SYSTEMS	NO. OF HOUSES
Green Colonia		15
	Ceiling Fans	1
	Ceiling Fans, Stand Alone Fans	1
	Central AC	7
	Central AC, Stand Alone Fans	1
	Partial AC	5
Red I		8
	Ceiling Fans	1
	Central AC	6
	Partial AC	1
Red II		7
	Central AC	2
	Partial AC	4
	Partial AC, Stand Alone Fans	1
TOTAL		30

Alternatives are (1) No heating or cooling systems, (2) Residential 17 SEER/9.6 HSPF Split Heat Pump, (3) Residential 17 SEER/0.85 AFUE Split/Packaged, (4) Residential 14 SEER/0.9 AFUE Split/Packaged Gas, and (5) Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump (Table 33). One of the HVAC systems was assigned in Autodesk Revit, and the models were exported with these selected options. The other HVAC options were added as design alternatives in GBS user interface for each gbXML file exported for run.

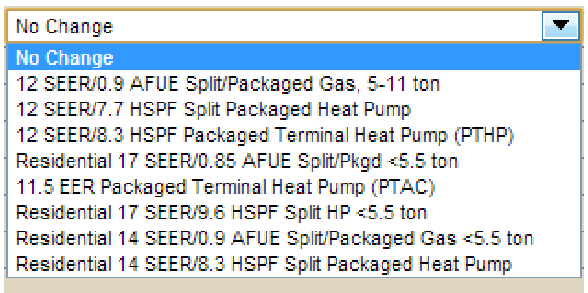


Figure 20: GBS Design alternative HVAC system options list

In Autodesk Revit, under Energy Settings tab, having no air conditioning is not an option, nor is it in GBS under design alternatives menu. It is only available under Project Defaults tab in GBS. Therefore, these 3 homes without any AC system were run in GBS engine by assigning a template with no heating and cooling system. The other homes, on the other hand, were run in GBS with four types of residential AC systems which are available in GBS and Revit.

Another confronted limitation was the lack of option on simulating window AC units[10]. Therefore, the same 4 HVAC options were assigned to the structures whether they have central HVAC systems or window units or both.

[10] GBS reads Window AC units as a type of window (Large double-glazed windows (reflective coating) - industry with a U-Value: 2.92 W / (m^2-K), SHGC: 0.13, Vlt: 0.07. Therefore, they were removed from all models.

6.2.4 Building Schedule

As these structures are for residential use, schedule is assumed to be 24 hours for 7 days. It was assigned in Autodesk Revit.

6.3 Computer-Aided Modeling Methods through Acquisition of Expertise in Using Autodesk Revit

In BIM, users define objects by geometric and non-geometric features (Eastman et al. 2008). Rules and parameters enable users to control the objects. In Autodesk Revit, there is a hierarchy in defining objects: (1) categories, (2) families, (3) types and (4) instances (Figure 21). Wall, floor, roof, ceiling, window and door are examples of categories. Revit families have an assigned category that controls the visibility of the objects in different views and scheduling. Autodesk Revit has predefined object families for users including (a) predefined system families that already exist with their parameters in the project, (b) loadable families which can be created from scratch, edited and loaded by the user into the project by changing the parameters and (c) in-place families that are defined by the user and are specific to the project. For instance, under the door category, there are door families such as single flush door and double-flush door. Under families, there are specific object types with their own parameter values that make them different from other types. Materials and size are the parameters that define different door types. Each individual object in the project is called an instance.

By using the data collected through interviews and on-site inspections and considering the assumptions and rules above, each house was modeled by using Autodesk Revit 2014. The modeling process adopts three-steps: developing a library of materials appropriate to homes in the colonias; creating a template file for all houses; modeling houses based on field survey data.

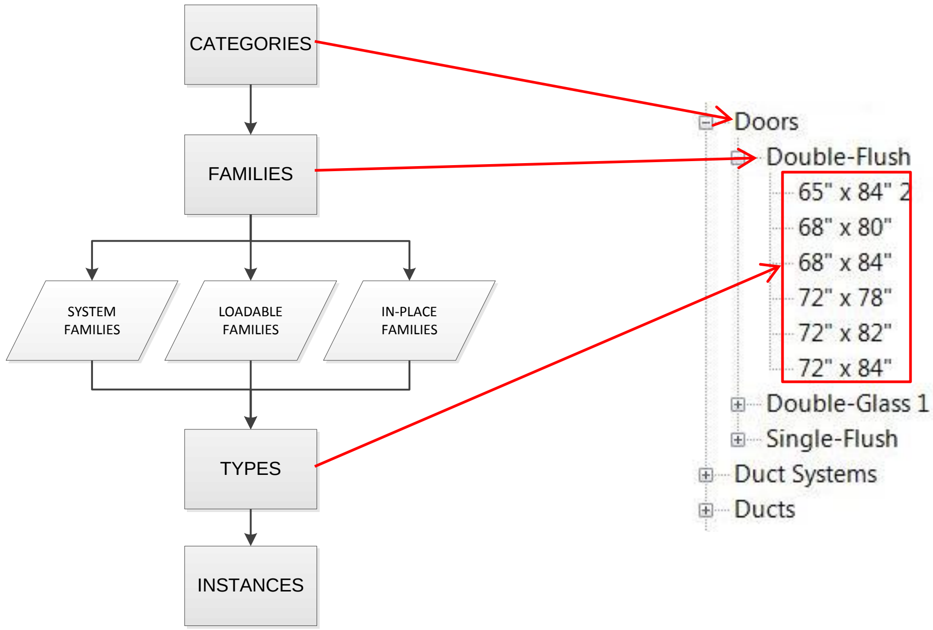


Figure 21: Conceptual map of object category, family, type and instance in Autodesk Revit

6.3.1 Creating New Materials and Library of Families for Colonias According to the Alternative Scenarios: Colonias BIM Toolkit (CBT)

Autodesk Revit has its own embedded material libraries: (1) Autodesk Materials and (2) AEC Materials (Figure 22). However, as the houses in the colonias are self-built by using improper materials and construction methods (OAG 2011; HUD 2003; SOS 2012; Ward 1999; Ward and Peters 2007), the existing libraries in Revit have been found insufficient to model these structures. To overcome this challenge, I have created a new material folder for colonias including both the available materials that are observed in the sample houses, and newly created ones (Figure 23). New materials were generated based on the data materials documented.

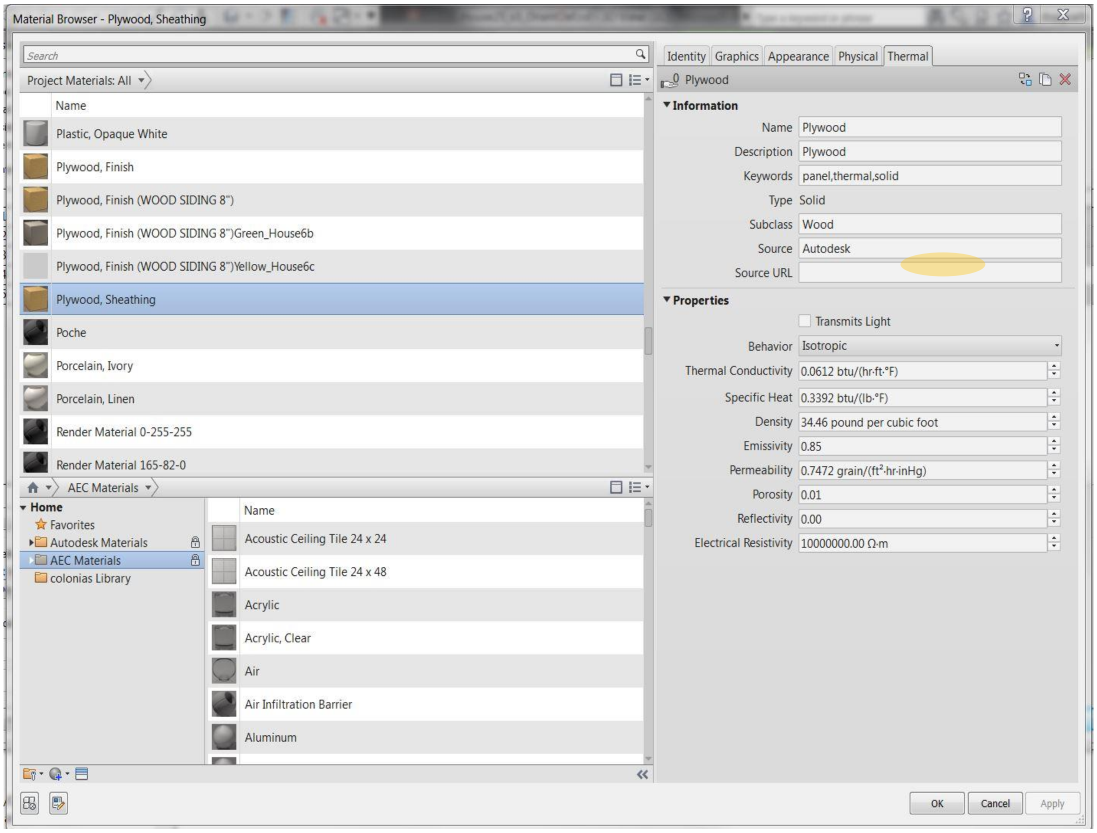


Figure 22: Embedded materials library in Autodesk Revit

To model 30 houses in the colonias, a new set of materials were created and several were borrowed from the existing Revit libraries to construct a material library (Table 43). Autodesk Revit provides thermal properties for its existing materials. The thermal properties include conductivity, specific heat, density, emissivity, permeability, porosity, reflectivity, and electrical resistivity. The thermal property values of available materials were compared to the ones provided by DOE-2 Basics (Simulation Research Group 1991) and found to be very close. Therefore, for new materials, thermal property values were derived from DOE-2 Basics.

Table 43: Materials, their thermal properties and the sources (adapted from Simulation Research Group 1991 and Autodesk 2014)

Wall Materials	Thickness	Conductivity Btu-Ft/Hr-Ft2-F	Density Lb/ft3	Specific Heat Btu/Lb-F	Resistance Hr-Ft2-F/Btu	Source
Concrete Block, Heavy Weight, Hollow						
	8"	0.606	69	0.2	1.1	DOE-2 BASICS
Brick						
		0.312	96.76	0.2		AUTODESK
Stucco						
		0.416	116.12	0.2		AUTODESK
Soft Lumber*						
		0.0693	30.96	0.0454		AUTODESK
Wood Siding-Clapboard						
	3/4"	0.0693	30.65	0.0454	0.9	AUTODESK
Gypsum Board						
		0.3756	68.57	0.2		AUTODESK
Rigid Insulation						
		0.0202	1.44	0.3511		AUTODESK
Plywood, Sheating						
		0.0612	34.46	0.3392		AUTODESK
Fiberglass Batt						
		0.011	2	0.2197		AUTODESK
Floor Materials	**Thickness**	**Conductivity Btu-Ft/Hr-Ft2-F**	**Density Lb/ft3**	**Specific Heat Btu/Lb-F**	**Resistance Hr-Ft2-F/Btu**	**Source**
Concrete, Heavy Weight Dried Aggregate, 140 lbs						
		0.7576	140	0.2	1.1	DOE-2 BASICS
Wood Joist/Rafter Layer						
		0.0693	0.07	0.0454		AUTODESK
Plywood Sheating						
	1/2"	0.0612	34.46	0.3392	0.6803	AUTODESK
Floor Finishes						
Ceramic Tile	1/4"	0.4622	106.13	0.203	0.02	AUTODESK
Vinyl Composite Tile	1/4"	0.4108	74.91	0.1997	0.05	AUTODESK
Hardwood	1/4"	0.104	39.33	0.5696	0.11	AUTODESK
Fiberglass Batt						
		0.011	2	0.2197		AUTODESK
Roof Materials	**Thickness**	**Conductivity Btu-Ft/Hr-Ft2-F**	**Density Lb/ft3**	**Specific Heat Btu/Lb-F**	**Resistance Hr-Ft2-F/Btu**	**Source**
Concrete, Heavy Weight Dried Aggregate, 140 lbs						
		0.7576	140	0.2	1.1	DOE-2 BASICS
Wood Joist/Rafter Layer						
		0.0693	0.07	0.0454		AUTODESK
Wood Sheating, partical board-high density 3/4"						
		0.9833	75	0.31		DOE-2 BASICS
Asphalt Shingle						
		0.2889	106.13	0.2388		AUTODESK
Ceiling Materials	**Thickness**	**Conductivity Btu-Ft/Hr-Ft2-F**	**Density Lb/ft3**	**Specific Heat Btu/Lb-F**	**Resistance Hr-Ft2-F/Btu**	**Source**
Gypsum Board						
		0.3756	68.57	0.2		AUTODESK
Fiberglass Batt						
		0.011	2	0.2197		AUTODESK

By using the new library of materials, I developed a new library of system families and components that are observed in the inspected colonias homes. System families comprise floor, wall, ceiling, and roof whereas component families include windows and doors. All windows were modeled as single pane window.

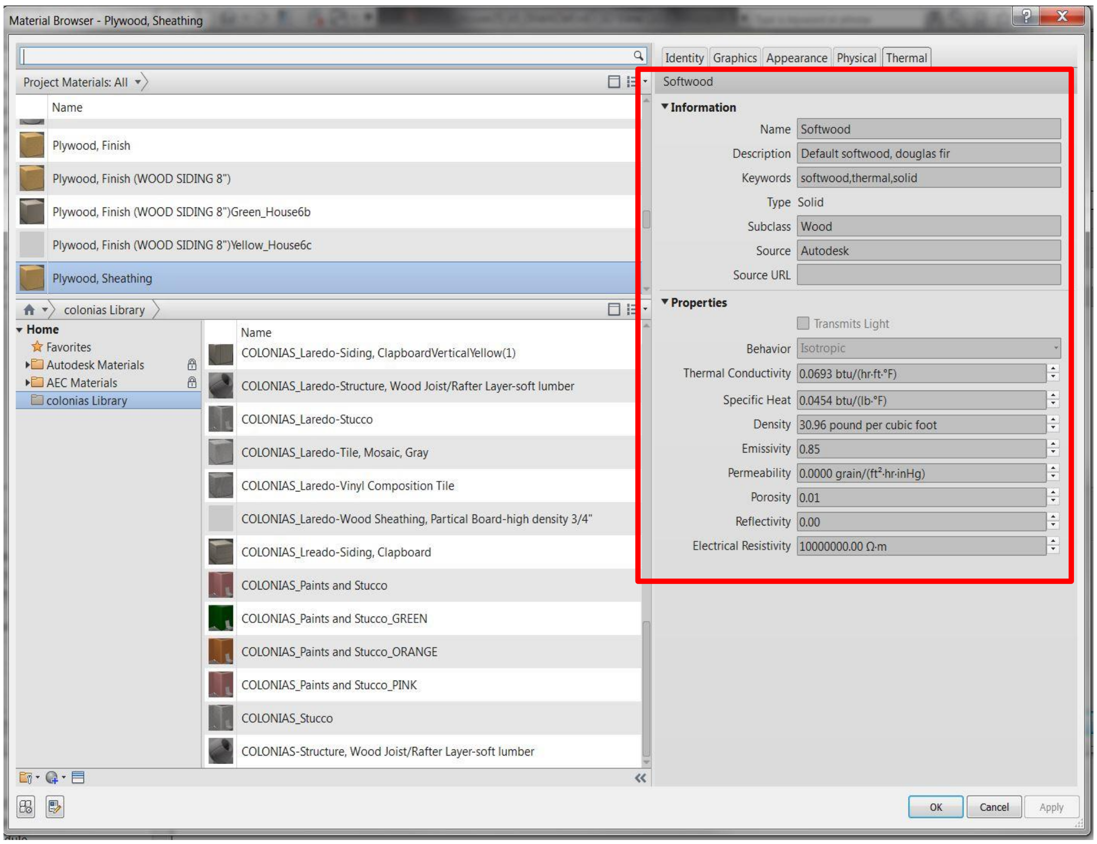


Figure 23: Colonias materials library folder created for colonias houses based on the data collected on-site in the colonias

6.3.2 Creating a Project Template File

Using a template enables users to save time, and be consistent among all projects (Autodesk 2013). In this study, I have created a template from scratch to express the typical elements and parameter values for houses in the colonias. The template includes (1) project parameters which can hold information collected for each house during on-site inspections and interviews (Figure 24), (2) project information which is shared with all houses and holds information on energy settings (Figure 25), (3) project location (Figure 26), (4) sheets, (5) materials created specific for these houses, (6) a new library of system families and components with embedded data on cost and thermal properties, and (7) the schedules that enable me to take-off the quantities and calculate the costs of the components as a future implementation.

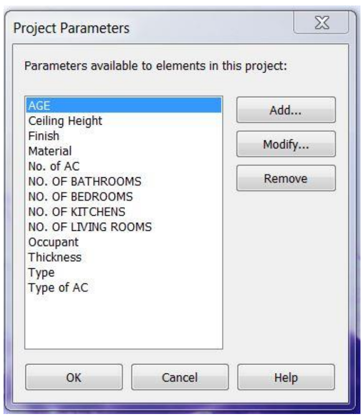


Figure 24: Project parameters

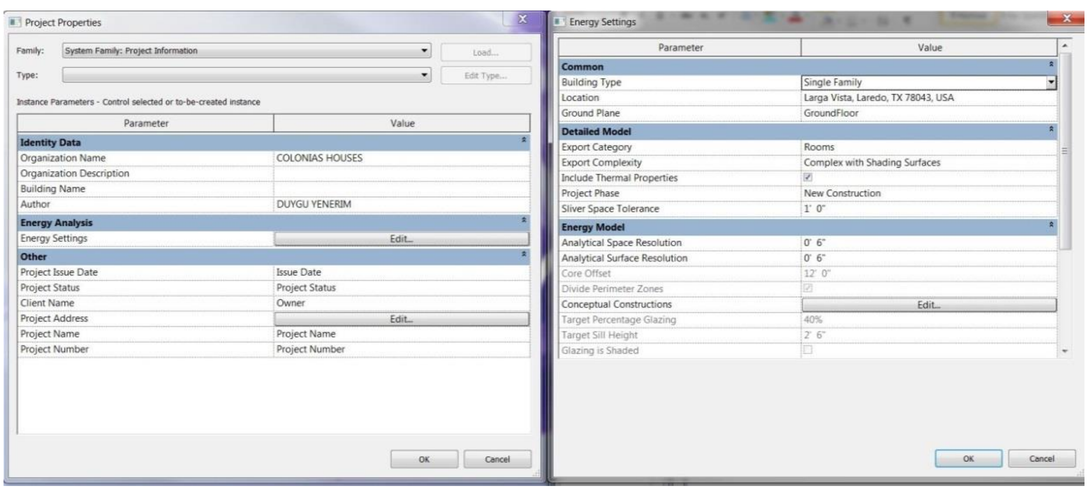


Figure 25: Project properties

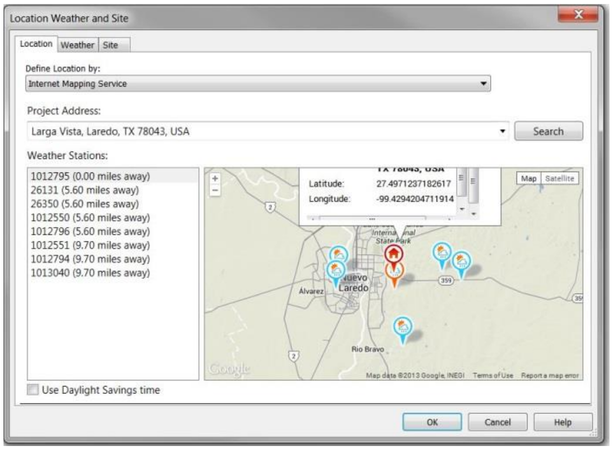


Figure 26: Project location set to Laredo Texas

6.3.3 Testing the Method by Modeling the Existing Houses

The template created with integrated library of system and component families were used to model 30 selected houses from three colonias in Laredo, Texas. The measurements, observations of construction materials and techniques, and face-to-face interviews with the residents were used as the building descriptions to develop the models in Autodesk Revit 2014.

The form of the structures with measurements, their orientation, and their relationship with the ground (being on or above the ground) are the factors considered during mass modeling. Based on the data on building stages gathered from interviews, the structure constructed in each stage was modeled as a separate mass. This enables me to add different information to the parameters such as the age of the structure, materials, cost and so forth.

Table 44: Creating a BIM of home step by step

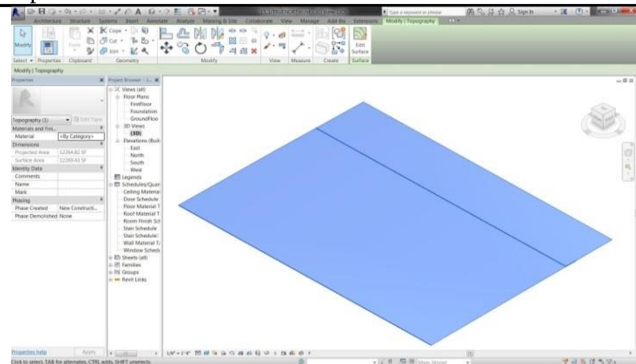
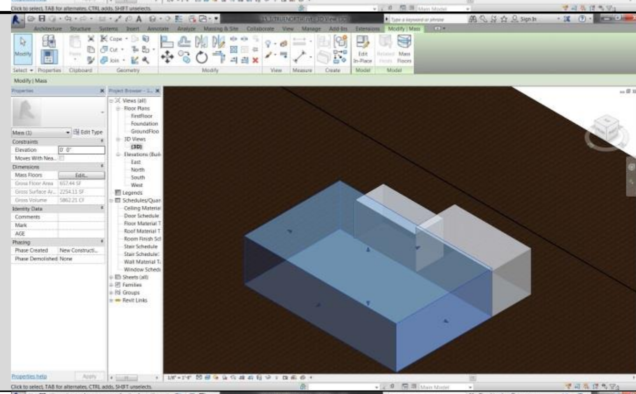
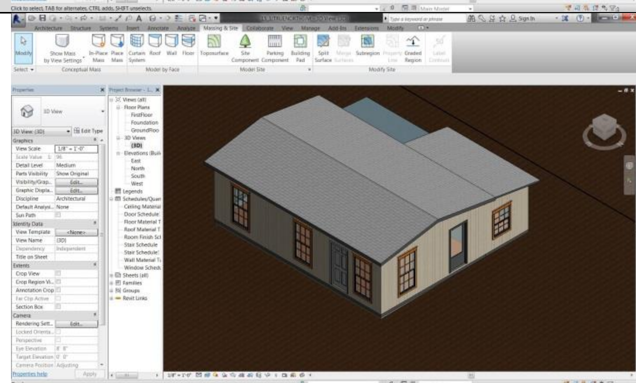
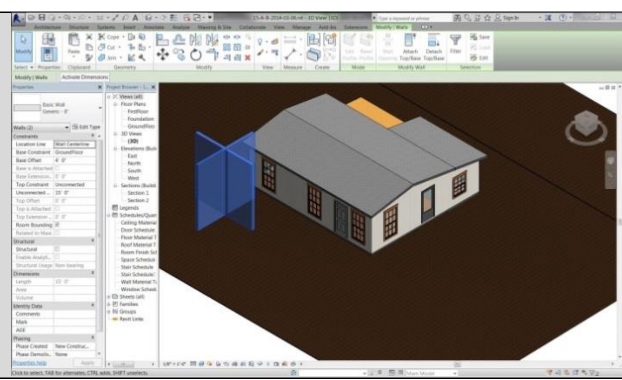
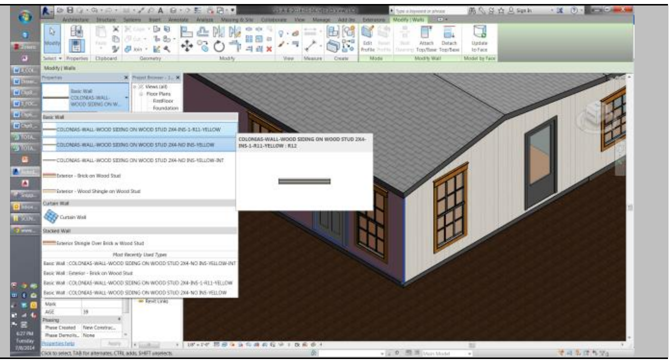
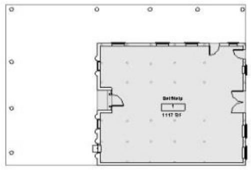
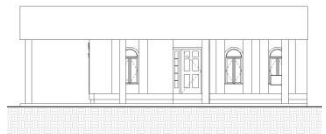
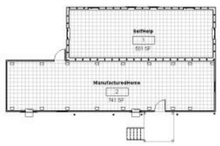
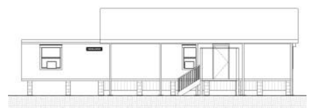
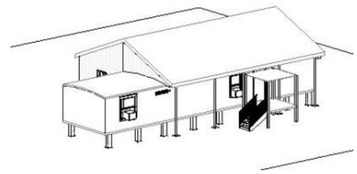
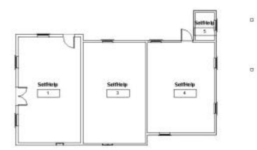
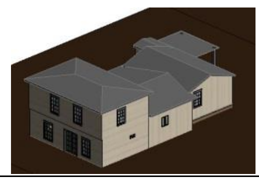
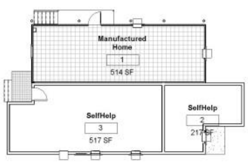
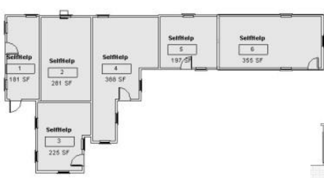
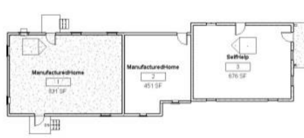
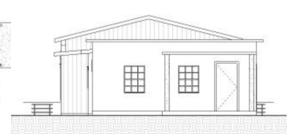
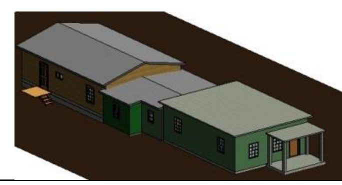
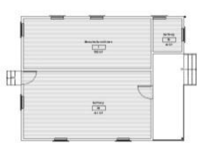
STEP 1: Drawing a toposurface	
STEP 2: Drawing conceptual mass objects	
STEP 3:Adding walls, roofs, floors, doors, and windows	
STEP 4: Drawing Trees	

Table 44 Continued

STEP 5: Conduct parametric studies by varying types of walls, roofs, floors, doors, and windows	
STEP 6: Analyzing Results	

Mass modeling phase was followed up with adding building elements. In this step, the data collected on construction materials and techniques came to the stage. First, appropriate system families, floors, walls, ceilings and roofs, selected from the developed library were added to the surface of the mass model. Second, component families from the developed library such as doors and windows were nested on the wall families.

Table 45: BIM models of 30 selected houses developed by using the developed template with embedded library for colonias

House No.	Plan	Elevation	3D
1			
2			
3			
4			
5			
6			
7			

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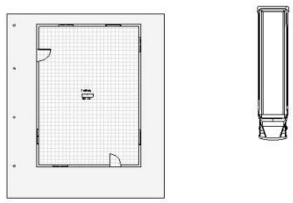
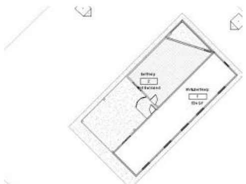
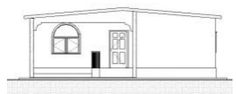
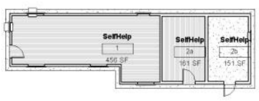
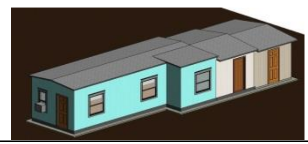
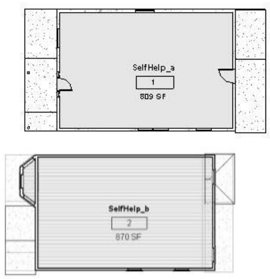
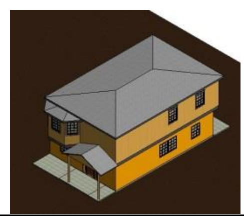
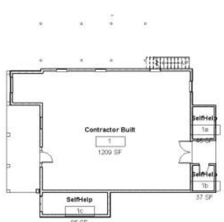
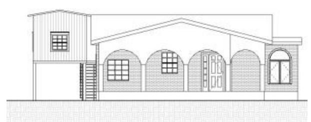
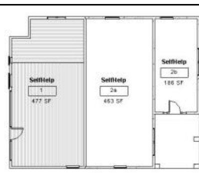
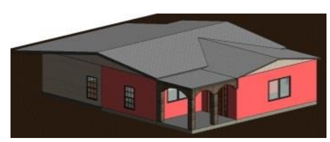
8			
9			
10			
11			
12			
13			

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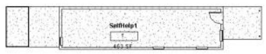
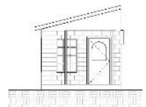
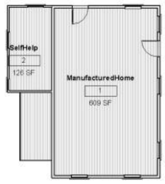
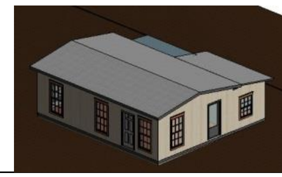
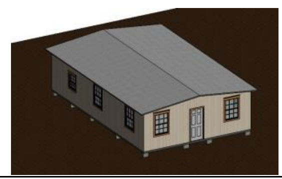
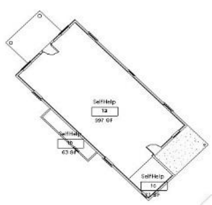
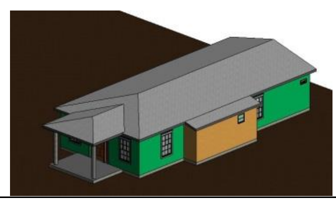
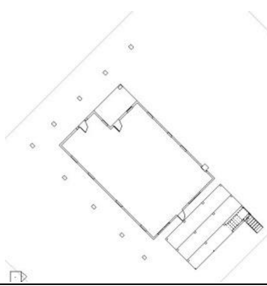
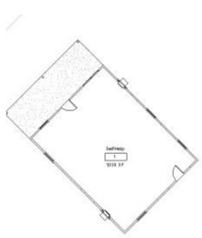
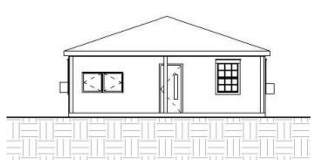
14			
15			
16			
17			
18			
19			

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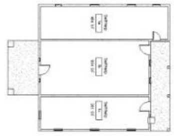
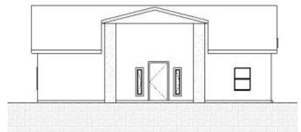
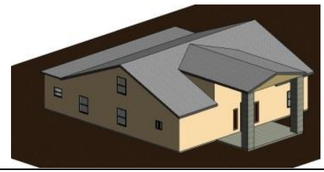
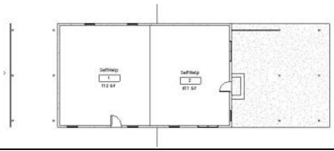
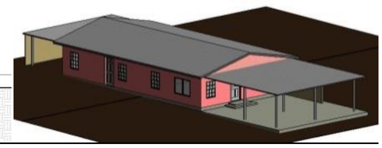
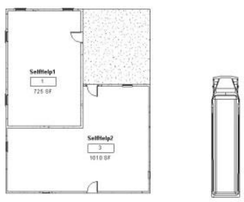
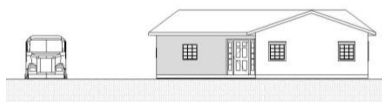
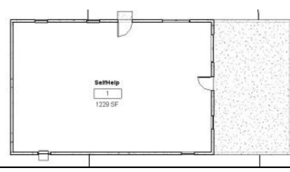
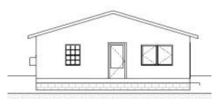
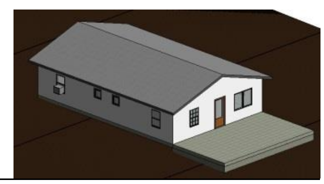
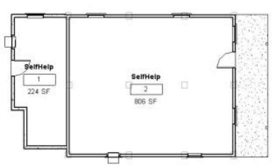
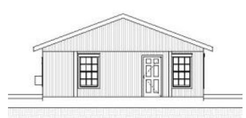
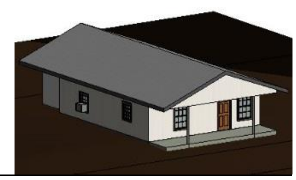
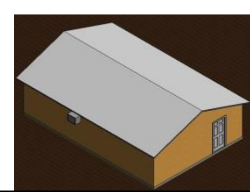
20			
21			
22			
23			
24			
25			

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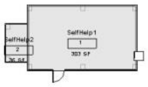
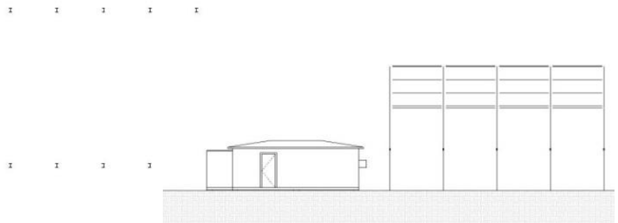
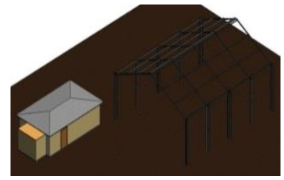
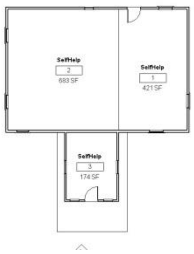
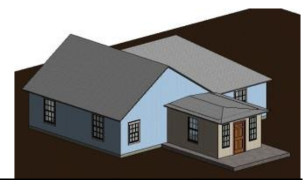
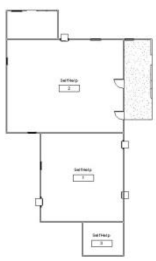
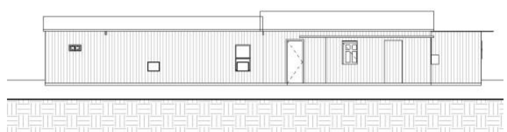
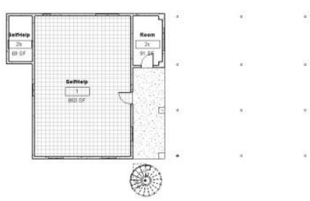
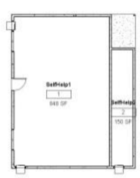
26			
27			
28			
29			
30			

As I did not have permission to collect data on the interior spatial configuration of the homes, interior elements were excluded from this study. However, the face-to-face interviews with the residents provided information on the number of rooms and their functions. This information was made available in the project parameters.

Table 45 demonstrates the BIM models of 30 homes. By using the Colonias BIM Toolkit, modeling 30 houses from on-site sketches and measurements took 90 hours with moderate effort that I found considerably efficient. I estimate that the whole community of Green Colonia, consisting 126 homes can be modeled within a 25 to 30 days by one user.

Last two steps in Table 44 have been performed for conducting building performance analysis of each house. I have tested each alternative scenario for each building component and run building performance analysis.

6.4 Building Performance Analyses of Sample Homes

The last step of this study was to calculate/estimate building performance of the selected 30 colonias homes by using available data. BIM models created by utilizing Autodesk Revit 2014 were exported to Autodesk GBS web-based open analysis tool which runs DOE-2 in the cloud.

6.4.1 Export Method of BIM Models from Autodesk Revit to Autodesk GBS

Autodesk Revit 2014 has four methods to export BIM model to Autodesk GBS database for building performance analysis:

(1) Using Revit User Interface:
   a. Energy analysis by using conceptual mass models
   b. Energy analysis by using building element mode
(2) Exporting BIM model as a gbXML file to GBS database:
   a. Room-base export category
   b. Space-base export category

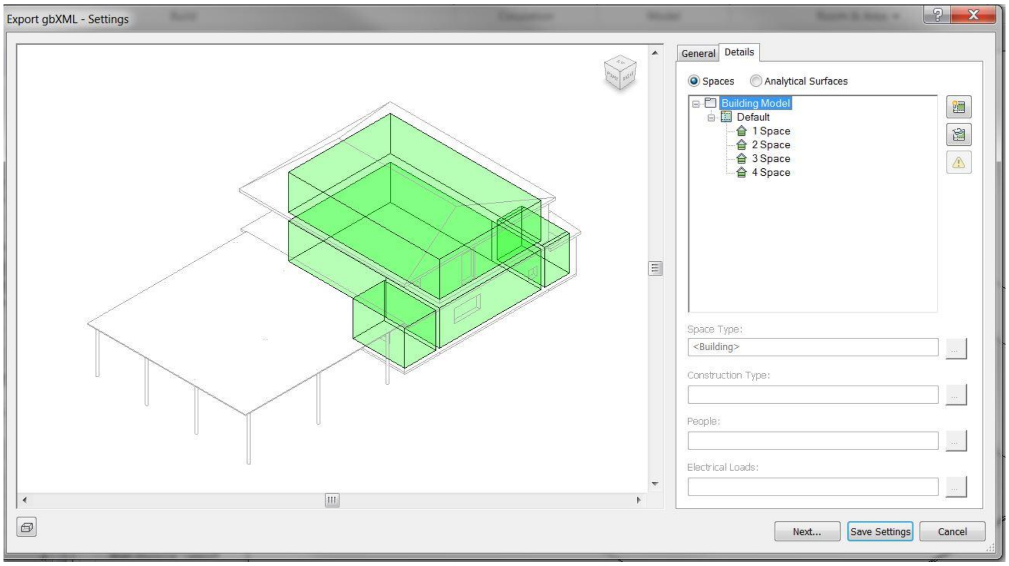


Figure 27: Exporting BIM model as a gbXML file to GBS database through space-based export category

In this study, I have exported BIM models as a gbXML file by using space-based category due to a number of advantages (Figure 27). Except for using conceptual mass models in Revit User Interface (UI), the other three options allow users to export the model with the thermal properties of the building materials used in the model. However, Autodesk Revit assigns a default air infiltration value for projects considering the selection of building and system components, location and square footage of the structures. In order to intervene in the air infiltration value, the only way is adding three lines of script on the gbXML file generated by space base export from Autodesk Revit. HVAC systems and schedule can be adjusted from Autodesk Revit UI or Autodesk GBS UI.

For each house, 20 scenarios were run for a total of 600 analyses. Figure 28 describes the process of the performing building analysis of each house. In Revit, two construction type (R-value) options were assigned and transferred to Autodesk GBS as a gbXML file. Two gbXML files were edited to assigned two options of infiltration values to each space, and four gbXMLs were created. These four gbXMLs were imported to Autodesk GBS online engine. Each gbXML has carried one of the HVAC options (Residential 17 SEER/9.6 HSPF Split HP<5.5 ton) assigned in Autodesk Revit UI. Within the Autodesk GBS UI, three more HVAC options were assigned and run. By default, GBS engine creates two infiltration options which were kept.

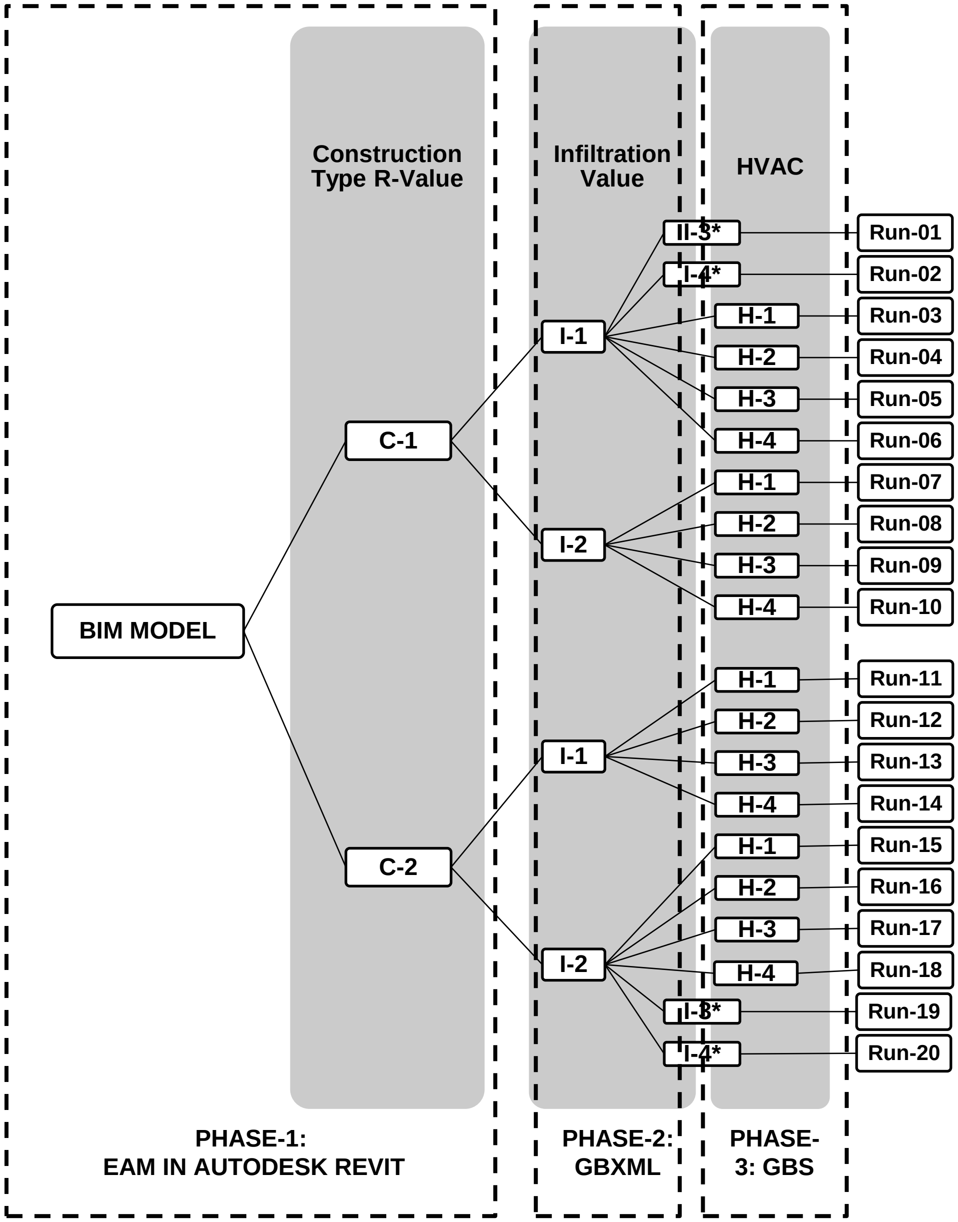


Figure 28: A conceptual diagram showing the process of building performance analysis by utilizing Autodesk Revit and Autodesk GBS

6.4.2 Testing Scenarios in terms of Building Performance

I have tested each scenario on a simple building to check whether the way of modeling each case is reflected in the results and to decide on the level of detail in models (Table 46).

First, I have tested different building component materials to the test case. The improvements in the building components were reflected in the energy use intensity (EUI) results. Second, the relationship between building and the site was tested and the change in EUI was observed. Third, I tested two scenrios on building schedule which was followed by testing scenarios on mechanical equipment, and HVAC systems. Each scenario results in different EUI values.

Table 46: Test of scenarios for energy simulation

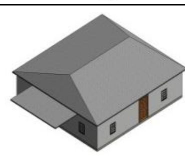
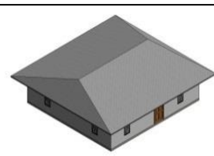
PROJECT NO	CHANGING PART	MODELS	EUI	TOTAL ANNUAL COST			√/ X
1	Base Model		75.5	1441	354	1795	
CHANGING BUILDING CONSTRUCTION OF BUILDING COMPONENTS							
2	Improved Wall Material (6" Concrete Wall)		60.4	1184	256	1440	√
3	Improved Wall Material (8" Concrete Wall)		55.7	1108	225	1333	√
4	Improved Wall Material (8" Concrete Wall) & Shading (Additional)		54.1	1078	217	1295	√
5	Roof (Not Improved)		101.8	1920	485	2405	√
6	Floor (Not Improved) (10")		85.1	1579	413	1993	√

Table 46 Continued

BUILDING ON/OFF GROUND							
7	Adding a Site		85.1	1579	413	1993	no change
8	Building on the Ground (Floor is under the ground level)		79.4	1562	356	1918	√
9	Building off the Ground (20")		9.4	1483	382	1865	√
10	Building off the Ground (12")		84.1	1562	408	1970	√
11	Building on the Ground (Floor is built on the ground level)		88	1626	429	2056	√
BUILDING OPERATING SCHEDULE							
12	BASE CASE_24/7		113.5	1490	752	2242	
13	12/7		90	1246	575	1821	√
MECHANICAL EQUIPMENTS							
14	BASE CASE-Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 eff		113.5	1490	752	2242	
15	Central VAV, Electric Resistance Heat, Chiller 5.96 COP		97.6	3109	53	3162	√
16	Residential 17 SEER/9.6 HSPF Split HP <5.5 ton		49.9	1527	47	1574	√
17	Residential 14 SEER/0.9 AFUE Split/Packaged Gas <5.5 ton		77.7	1343	409	1753	√

6.5 Whole Building Energy Use

Having developed ways to account for the energy transfer in building components, the study could address whole building energy use. The process is the main scope of this study. Results were documented in two categories: (1) for each individual home and (2) for 30 homes together.

6.5.1 Individual Homes

Figure 29 demonstrates the variation of EUI values for each house according to the 20 scenarios. Table 47 provides minimum, median and maximum values for EUI and annual energy, electricity and fuel costs per house. Form, orientation, construction type and materials, age, fenestration ratio and orientation, infiltration value, and mechanical systems are the factors that were taken into consideration while calculating EUI in this study.

Results indicate that House 5, 13 and 16 are the structures that do not have an AC system installed. Therefore, their EUI values show no change in the value and have the lowest one.

As the R-value of the components and the infiltration value are related to the age of the structure , House 6, 10, 12, and 15 have the potential to have very high EUIs. If the structure is old, then one of the scenarios for construction materials and methods is not having any insulation at all. If the structure is a wood framed one, then the building performance is very low. The difference between not having insulation (Scenario A) and having moderate insulation that nevertheless does not meet minimum requirements by codes (Scenario B) is large for wood framed structures. On the other hand, if it is a concrete block structure, the difference is small.

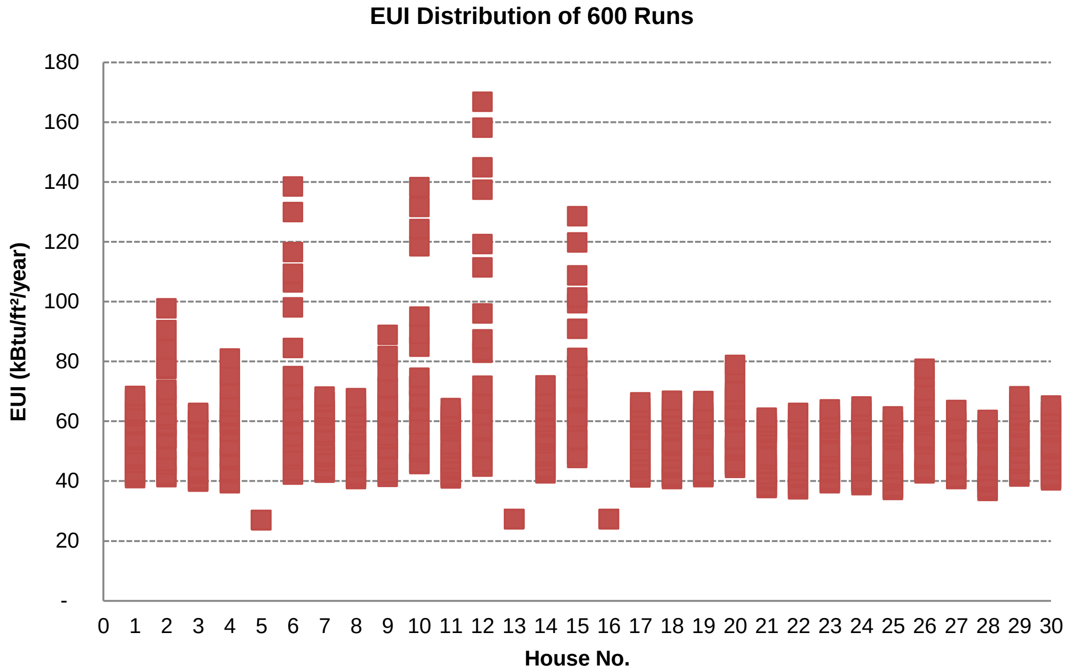


Figure 29: Difference between EUI values according to the 20 different scenarios for each house

House 15 is a combination of a manufactured home (39 years old) and a small wood framed pier and beam self-help attachment (21 years old). EUI for various scenarios ranges between 48 and 128 kBtu/ft²/year which may be a result of age of the structure, and construction methods. Likewise, House 12, whose EUIs fluctuate between 45 and 167 (kBtu/ft²/year) is comprised of an elevated detached manufactured home (39 years old) and self-help additions (38 years old) to the main builder-built structure. House 10, on the other hand, is a mixture of two pier and beam wood frame self-help structures and concrete block self-help structure that were built 33 years ago. Simulations suggest that EUI of that house is from 46 to 138 (kBtu/ft²/year). Moreover, the EUI values of House 9 which has an old RV integrated into a wood framed on concrete slab self-help structure (3 years old) is calculated between 41 and 89 (kBtu/ft²/year).

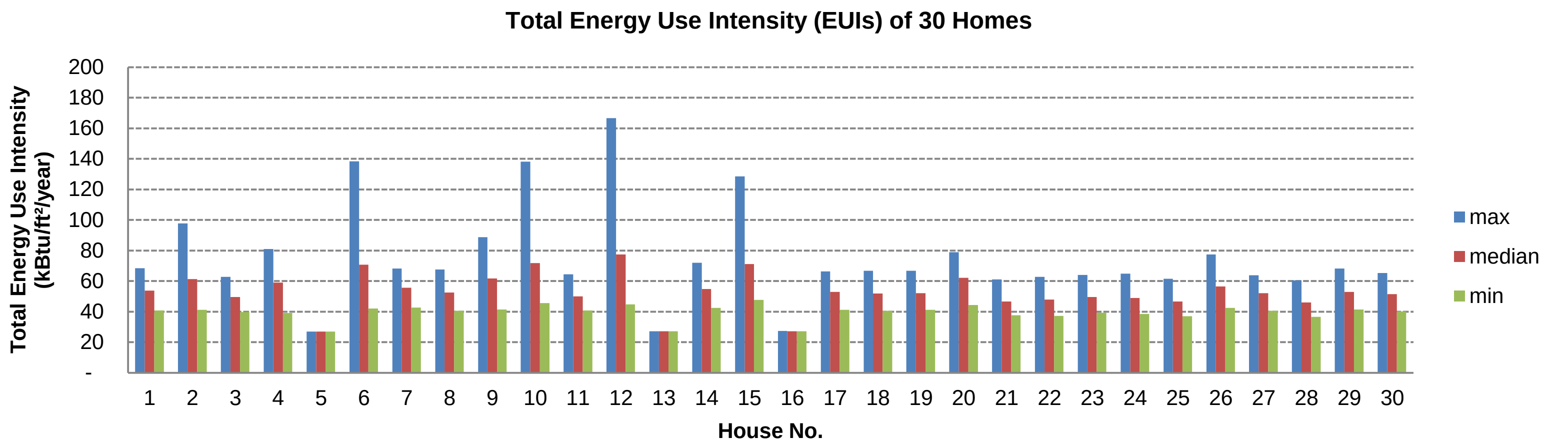
Table 47: GBS energy analysis results of 30 homes

House No.	Total Annual Electricity Cost ($)*			Total Annual Fuel Cost ($)**			Total Annual Energy Cost ($)			Total Annual Elec Use (kWh)			Total Annual Fuel Use (Therm)			Total Energy Use Intensity (kBtu/ft²/year)		
	max	min	med	max	min	med	max	min	med	max	min	med	max	min	med	max	min	med
1	2,234	1,395	1,776	135	49	55	2,369	1,445	1,832	20,163	12,594	16,030	13	5	5	68	41	54
2	3,336	1,544	2,235	348	53	61	3,684	1,598	2,295	30,107	13,937	20,168	33	5	6	98	41	61
3	3,720	2,288	2,806	147	73	82	3,868	2,361	2,888	33,576	20,653	25,324	14	7	8	63	40	50
4	2,835	1,474	2,112	268	54	61	3,102	1,528	2,173	25,583	13,307	19,058	25	5	6	81	39	59
5	1,229	1,221	1,225	80	80	80	1,309	1,301	1,305	11,089	11,017	11,053	8	8	8	27	27	27
6	7,464	2,514	4,244	856	75	85	8,320	2,588	4,330	67,366	22,686	38,307	81	7	8	138	42	71
7	1,640	1,061	1,417	82	36	41	1,722	1,097	1,458	14,799	9,577	12,792	8	3	4	68	43	56
8	1,729	1,112	1,362	135	43	49	1,864	1,156	1,410	15,609	10,040	12,288	13	4	5	68	41	52
9	3,142	1,618	2,283	317	55	62	3,459	1,673	2,345	28,356	14,604	20,603	30	5	6	89	41	62
10	3,201	1,093	1,762	235	35	40	3,437	1,128	1,802	28,893	9,869	15,903	22	3	4	138	46	72
11	3,165	2,090	2,490	171	73	83	3,336	2,163	2,572	28,565	18,859	22,469	16	7	8	64	41	50
12	6,965	2,001	3,347	654	61	69	7,618	2,062	3,415	62,858	18,061	30,205	62	6	7	167	45	77
13	807	798	802	57	56	56	864	854	859	7,285	7,200	7,242	5	5	5	27	27	27
14	846	549	672	77	20	23	923	569	695	7,636	4,951	6,062	7	2	2	72	43	55
15	2,583	1,066	1,550	291	32	36	2,874	1,098	1,587	23,314	9,620	13,990	28	3	3	128	48	71
16	635	632	634	45	45	45	680	677	678	5,731	5,706	5,719	4	4	4	27	27	27
17	1,973	1,310	1,731	148	50	56	2,121	1,359	1,788	17,808	11,819	15,627	14	5	5	66	41	53
18	3,054	1,984	2,415	224	71	80	3,277	2,055	2,495	27,561	17,910	21,796	21	7	8	67	41	52
19	1,783	1,172	1,414	124	44	50	1,907	1,217	1,464	16,092	10,579	12,766	12	4	5	67	41	52
20	2,975	1,822	2,574	263	62	70	3,238	1,884	2,644	26,846	16,444	23,235	25	6	7	79	44	62
21	2,365	1,518	1,818	144	62	70	2,509	1,580	1,888	21,345	13,699	16,410	14	6	7	61	38	47
22	2,850	1,786	2,208	201	71	79	3,052	1,856	2,288	25,726	16,117	19,931	19	7	8	63	37	48
23	2,079	1,348	1,636	142	54	60	2,221	1,402	1,696	18,767	12,169	14,763	13	5	6	64	39	50
24	1,833	1,151	1,411	133	47	53	1,966	1,199	1,464	16,540	10,390	12,734	13	4	5	65	39	49
25	1,241	778	951	80	33	38	1,321	812	989	11,204	7,022	8,587	8	3	4	62	37	47
26	610	368	458	64	14	16	675	382	473	5,509	3,322	4,130	6	1	1	77	43	57
27	2,321	1,543	2,028	139	58	66	2,461	1,601	2,094	20,950	13,927	18,307	13	6	6	64	41	52
28	2,786	1,751	2,140	160	70	79	2,946	1,822	2,219	25,141	15,806	19,310	15	7	8	60	37	46
29	3,305	2,162	2,638	245	74	84	3,550	2,236	2,721	29,830	19,509	23,806	23	7	8	68	41	53
30	1,701	1,105	1,447	118	43	49	1,818	1,148	1,496	15,350	9,970	13,057	11	4	5	65	40	51
TOTAL	76,407	42,255	55,585	6,083	1,594	1,779	82,490	43,849	57,364	689,598	381,365	501,672	577	151	169			

Although House 1was built 31 years ago, its EUI is comparatively lower than the other older homes by being in between 41 and 68 (kBtu/ft²/year). Furthermore, House 2, consisting of a 1 year old self-help addition and a manufactured home, shows a wide range of EUI: from 41 to 98 (kBtu/ft²/year).

To that end, it can be extracted that having a manufactured home which is over 30 years old on-site has a major negative impact on building performance. Building as a pier and beam structure with being 30 years old or more also is likely to indicate high energy consumption. However, there are some ways to reduce energy consumption as seen in House1. House1 has a very large covered porch on west and north facades and has a signifcantly lower energy consumption. Therefore, shading is found to be a very important strategy to reduce energy consumption in Laredo.

The minimum EUIs are around 36 to 47 whereas the maximum values for each house ranges from 60 to 166 (Figure 29). Figure 29 shows that when considering the square footage of the structures, House 6 has the potential of having the highest energy bill. It is followed by House 12. The average EUI, on the other hand, was calculated with more than 180 runs and found to be 53 (kBtu/ft²/year). Data shows that 171 is the highest value whereas 27 is the lowest one (Figure 31).



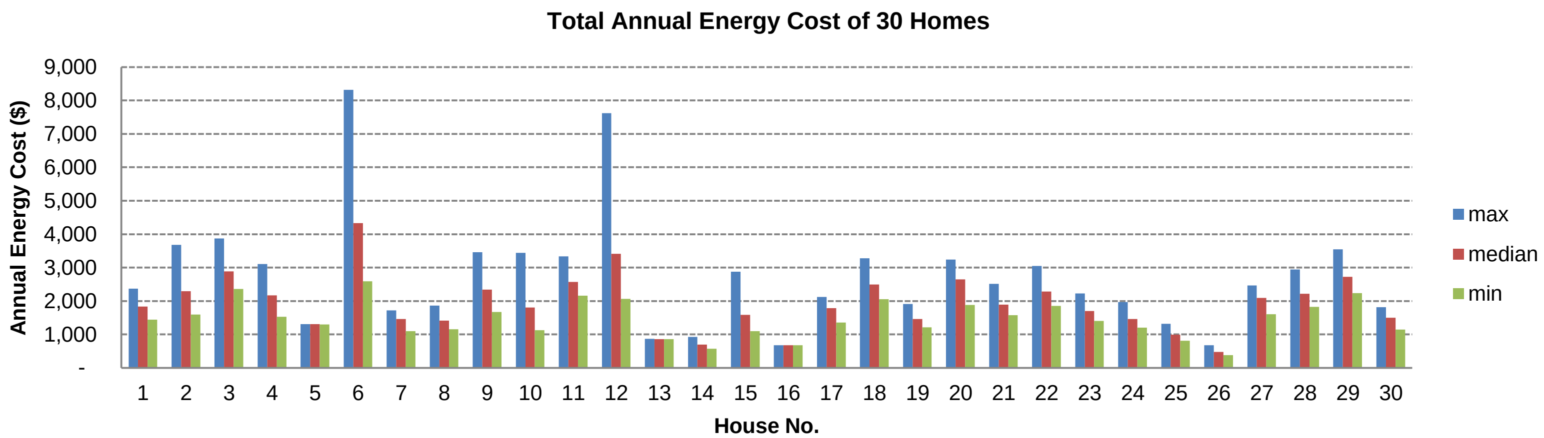


Figure 30: Minimum, median and maximum values of total energy use intensity, and total annual energy costs including electricity and fuel costs of 30 homes

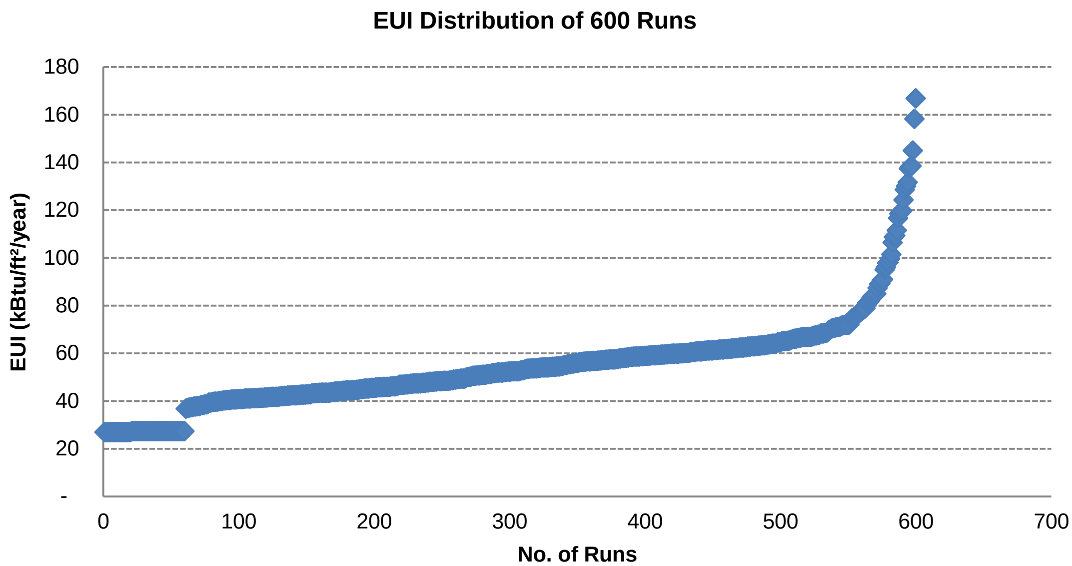


Figure 31: EUI values of 20 scenarios for each 30 homes

Figure 31 demonstrates the distribution of 600 runs that include 20 runs for each of the 30 homes. The distribution indicates that most commonly observed EUI ranges between 40 and 60 (kBtu/ft²/year). It means the possibility of having EUIs between 40 and 60 is very high for each home.

6.5.2 Results for 30 Homes Together

Figure 32 demonstrates aggregated total annual electricity and fuel cost of 30 homes for 20 scenarios. In order to have an educated guess on the total annual energy cost of these 30 homes together, all of the 20 scenarios applied to each house were summed under each category: Option 1-Best case and Option2-Worst case. Maximum annual energy cost for 30 houses in total is $84,078 (annual electricity use is 703,300 kWh/year and annual fuel use is 583 therm/year) when the electricity cost per kWh is assumed as $0.11 and fuel cost per therm by $1.05. This number was generated by applying each house (a) the worst R-values which are A, no insulation, and B, moderate insulation depending on the year that the structure was built, (b) worst infiltration values by referring to the LBNL database, and (c) Residential 14 SEER/8.3 HSPF Split/Packaged HVAC system. On the other hand, if all structures were built with Option 1 (having moderate or high insulation and R-values, having the lowest infiltration value 0.17 ACH, and Residential 17 SEER/9.6 HSPF Split HP<5.5 ton HVAC system), the total annual energy cost is $44,556 (annual electricity use is 387,748 kWh/year and annual fuel use is 151 therm/year). This difference may end up with $39,522 annual energy cost in total.

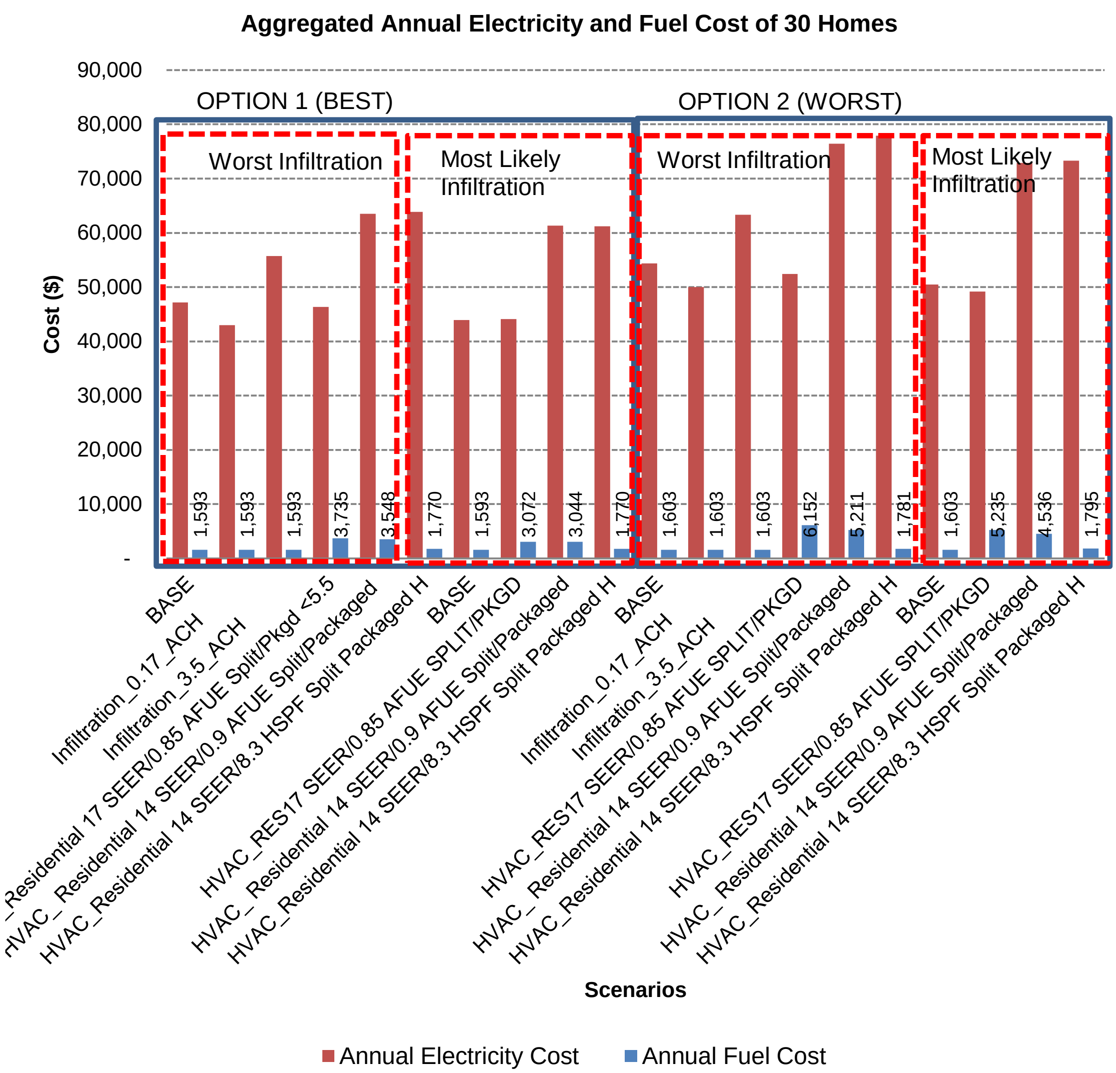


Figure 32: GBS energy analysis results of 20 scenarios of 30 homes categorized according to best and worst options

Results indicate that the median aggregated annual energy cost for the selected homes is $60,243 (annual electricity use is 527,575 kWh/year and annual fuel use is 169 therm/year).

Results demonstrate that difference between having no insulation (Scenario A) and having moderate insulation (Scenario B), which still does not meet requirements, is higher than the difference between having moderate insulation (Scenario B), and high insulation (Scenario C) that is very close to the requirements. Infiltration, on the other hand, is another important factor on building performance. Results show that if these structures are built as tight houses with 0.17 ACH, their energy use will be lower, whereas if they are built as loose structures with 3.5 ACH, their energy use will be higher. For most cases, the difference between 0.17 ACH scenario and the most likely infiltration value scenario is relatively low.

HVAC systems results in an important fluctuation in the numbers; if these structuresve Residential 14 SEER/0.9 AFUE Split/Packaged type of HVAC system, their energy use is much higher than other options and likewise, if they have Residential 17 SEER/0.9 AFUE Split/Packaged HVAC system, their energy use is much lower than other systems.

6.6 Estimating Community Energy Use

Data above was used to estimate the energy use of whole communities: Green Colonia, Red I and Red II. According to Attorney General of Texas (OAG), Green Colonia has 126 lots that have been occupied, whereas the number for Red I is 66 and Red II is 44 (Abbott 2010). I triangulated this data with google maps and found that there are 126 structures located in Green Colonia, 80 for Red I and 84 for Red II.

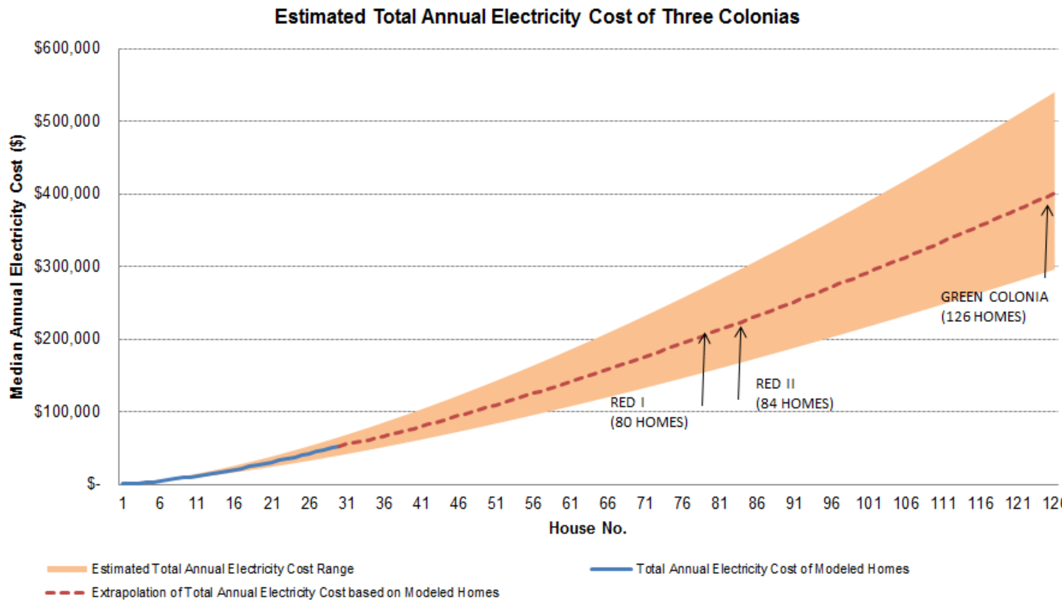


Figure 33: Estimated total annual electricity cost ($) of three colonias

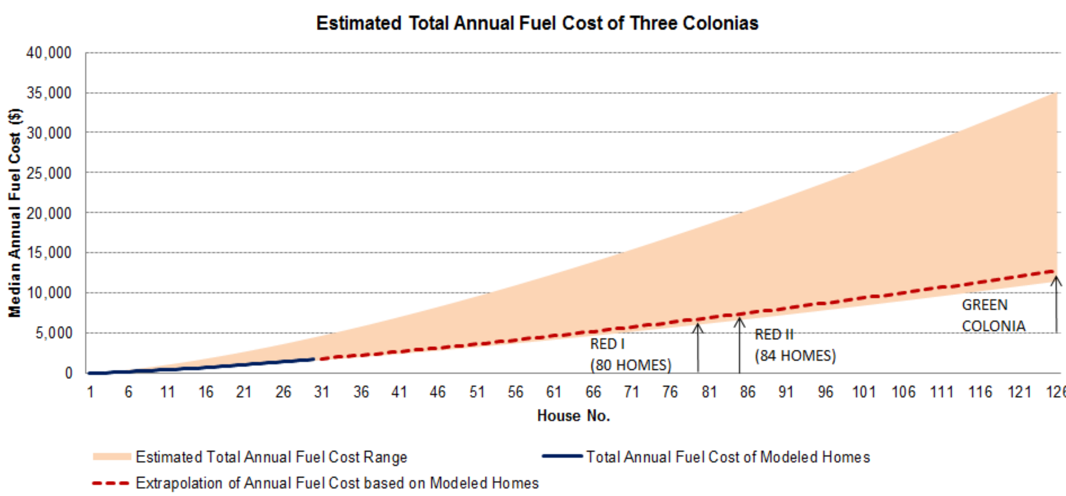


Figure 34: Estimated total annual fuel cost ($) of three colonias

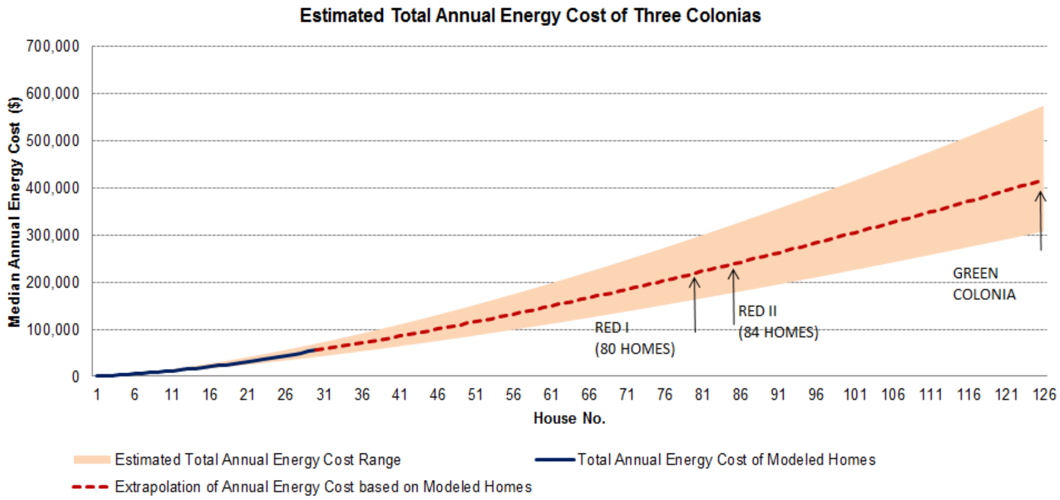


Figure 35: Estimated total annual energy cost ($) of three colonias that mean aggregated cost of electricity and fuel

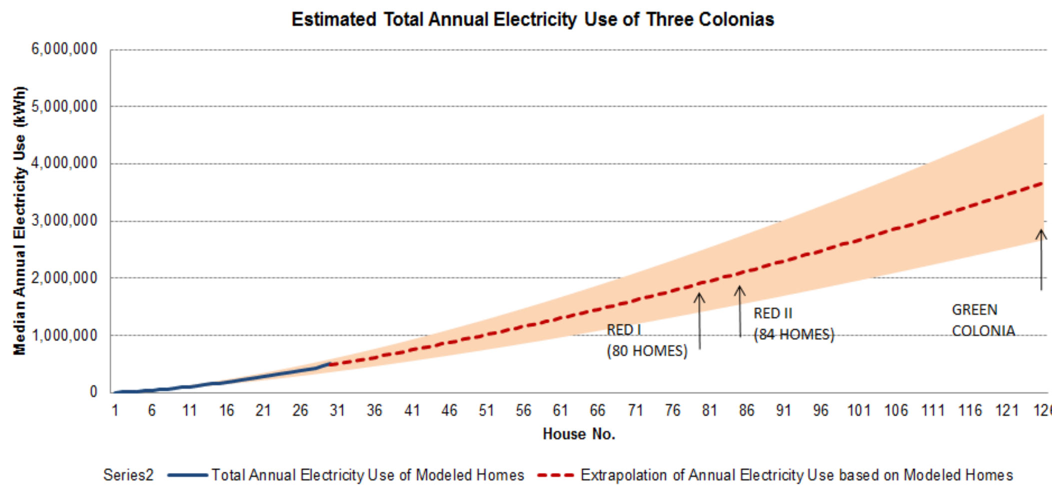


Figure 36: Estimated total annual electricity use (kWh) of three colonias

Figure 33, Figure 34, Figure 35, and Figure 36 give the estimated numbers for total annual electricity, fuel and energy cost, and electricity use. The estimated electricity use for Green Colonia is above 3,500,000 (kWh), which may be reflected in electricity cost as $400,000. For Red I and Red II, on the other hand, the electricity use may be 1,800,000 and 2,000,000 (kWh). The median annual electricity cost was extrapolated for Red I is $200,000 and for Red II is $225,000.

6.7 Limitations and Generalizability

This study was built on the findings from home inspections of 30 homes and face-to-face interviews with their residents in Laredo, Texas (Section 4). Although the field survey provided a significant amount of data, it could not identify the R-values of the building components, tightness of the building, and the type of HVAC systems which are required in order to simulate building performance. In order to overcome these challenges, I have developed guidelines and made several assumptions regarding the literature and building code.

Three scenarios were developed for R-values of the building components: (A) components without any insulation (B) components with moderate insulation which do not still meet the building code requirements, and (C) components with a minimum level of insulation suggested by IECC 2009 for Webb County, Texas for self-built homes and current practice of manufactured homes suggested by Champion Homes (Champion Builders, Inc. 2014). Infiltration values of homes were derived from an extensive database on housing called the U.S. Residential Diagnostic Database developed by Lawrence Berkeley National Laboratory (LBNL) (2011). I tested four options for HVAC systems available in Autodesk Revit and Autodesk GBS. At the end, 20 scenarios were developed and tested for each house to estimate potential energy use.

As a result of the different scenarios, the analysis provides estimated potential energy consumption in a range rather than pinpoint estimates. A comparison of the energy analyses derived from the scenarios allows identifying the most likely EUI of selected homes and identifying the factors that have a major impact on EUI. In order to have more accurate results, blower door test can be applied to determine infiltration values. Moreover, more detailed structural analysis can be applied to identify the R-value of the components of each house.

Identifying the HVAC system type and its current status is another important issue to be considered.

Autodesk Revit library was found to be insufficient to model these types of informal structures. By utilizing Revit's function of creating new materials and libraries, I have created a new library of components in Revit by referring to DOE-2 Basics' thermal property values of materials (Simulation Research Group 1991). Modeling HVAC systems was another limitation of Autodesk Revit tool. Although several homes have window AC units, this option is not available in Autodesk Revit. Therefore, I have tested only four options of HVAC systems which were already present in the tool.

The CBT was developed for modeling 30 homes in Laredo, Texas. It was found to be successful for rapid modeling and estimating energy consumption of homes. This method can be expanded to the other colonias in U.S. Moreover, it can be applied to other informal settlements all over the world by following a similar process, starting from collecting data on existing homes, developing a BIM based toolkit and performing energy consumption analysis.

6.8 Summary and Conclusions

Monitoring and documenting the architecture of existing colonias housing and their energy consumption is a an important challenge. In the context of modeling informal settlements, several studies in the literature utilize GIS to manage, monitor and predict residents' health, expansion of the colonias communities, and growth of the resources (Davidhizar and Bechtel 1999; Mier et al. 2008; Parcher and Humberson 2009; USDA-RD 2011; Reimers-Arias 2009). GIS is a very powerful tool that combines spatial and non-spatial data to manage and solve spatial problems by visualizing data (Lo and Yeung 2007). BIM, on the other hand, is a recent advancement in Architecture, Engineering and Construction (AEC) Industry which allows users to represent buildings components with integrated data. BIM has the potential to make a positive impact on modeling informal houses to support visualization, design, and analysis. It is a complementary technology to GIS.

This part of the study has contributed a design kit called Colonias BIM Toolkit (CBT) that allows rapid modeling of colonias homes and building performance analysis of the modeled homes. Use of BIM with self-built non-formal homes in the colonias is a new practice. Although there are several studies that focus on energy use of colonias residents (Gharaibeh et al. 2009; Machado 2006), the energy use at Green Colonia , Red I and Red II, are unknown. This section, through CBT, serves as another contribution to addressing this gap in the literature on calculating or estimating energy use of existing colonias homes. Moreover, according to the literature, self-help upgrading approach is suggested as being more sustainable and affordable (Bredenoord and Verkoren 2010; Goethert and Hamdi 1988; Joshi and Sohail Khan 2010; Kowaltowski et al. 2006; Sengupta 2010; Turner 1972; 1977; UN-Habitat 2003; Yap and De Wandeler 2010). 3-dimensional models of the houses may allow residents to understand and have an active role in the decision-making process on upgrading interventions.

CBT was built upon the findings of field survey of 30 colonias homes in three colonias (Section 4). CBT is an Autodesk Revit template which includes material definitions, wall types, roof types, floor types, window types, door types, trees, views and sheets. Each building component type implements the alternatives developed in this study (Table 33). The process of creating BIM models of colonias homes includes five steps: (1) creating a new project using the template, (2) drawing a toposurface, (3) drawing conceptual mass objects based on the measurements collected on-site, (4) adding walls, roofs, floors, doors and windows based on the data collected during home inspections, and (5) drawing trees. By utilizing the CBT, I was able to model 30 homes in 90 hours. It would have taken two or three times more to model them without CBT.

In this study, modeling and analyses were implemented with limited amount of data. Accuracy was not the main consideration of this study. In order to calculate building performance of each house, I conducted parametric studies by changing types of walls, roofs, floors, doors, and windows in Autodesk Revit and exporting each option as a separate gbXML file to Autodesk GBS to analyze the results. 20 scenarios were run for each home. The potential EUI of each house was calculated to be in a range between 40 and 60 (kBtu/ft^2/year) according to 20 scenarios whereas the aggregated annual electricity use of each colonias were estimated as 3,500,000 (kWh) for Green Colonia, 1,800,000 for Red I and 2,000,000 (kWh) for Red II.

CBT could be beneficial for federal or local programs that provide assistance to colonias residents to improve construction or modification of homes. The toolkit may enable stakeholders to rapidly model houses in the three communities that were included in this study. It may also be useful beyond these three communities. BIM representation of the homes may allow U.S. Housing and Urban Development (HUD) or Texas Department of Housing and Community Affairs (TDHCA) to monitor the existing energy use and the change in energy use after the additions or improvements to the house, and to monitor the cost of the additions or improvements to homes. These projected and estimated numbers for energy consumption would be useful for local and regional stakeholders to monitor these types of substandard houses and make robust implementations to reduce or control energy consumption.

In the following section, this method is used to design a one bedroom-one bathroom (231SF) addition to colonias homes. The method is a guide for decision support on low-cost sustainable design and strategies.

7 A BIM-BASED METHOD FOR IDENTIFYING BEST PRACTICES IN LOW-COST ENERGY EFFICIENT HOUSING DESIGN

This section presents a test of using the Colonias BIM Toolkit to support design by using two examples of designing low-cost energy efficient additions to colonias houses in Laredo, Texas. From a sample of 30 homes, I have selected two houses as the subjects for a design exercise. One house is a concrete self-help constructed structure and the other is a manufactured home with a wood frame self-help addition, in order to explore variation the use of the method for design. The design problem was to add a 231 square foot structure that includes one bedroom with closet and one bathroom to an existing home.

The design process involves designing the addition using BIM software, varying the model parametrically to produce many schemes, simulating the energy use and computing the consturction cost of each scheme, and then selecting the optimum solution. The process was built upon the following two foundations explored in previous sections: (1) existing architecture of colonias houses in Laredo, Texas (Section 4), and (b) sustainable, low-cost residential design and construction techniques and strategies for colonias (Section 5). Autodesk Revit 2014 was utilized as the BIM technology to create models of the homes and additions, and Autodesk Green Building Studio (GBS) web-based tool was used for building performance analysis. For cost analysis, RS-Means Residential 2011 and Home Depot web page were used.

This section presents three steps. First, I developed a problem statement of the rules for the design of the addition. Then I developed a new BIM library of system family and building components to represent the suggested construction methods and techniques for the addition. Lastly, I have tested the expert suggestions for energy efficient design by simulating the performance of the additions to identify the best solutions.

7.1 Setting the Rules for the Design of the Addition

The aim was to design an addition including one bedroom and one bathroom to the selected test cases. This subsection describes the reasons behind the decision on the size and form of the addition, and the size and location of the fenestrations on the addition.

7.1.1 Size and Form of the Addition

I have performed a literature review to identify the square footage of the addition. International Residential Code (IRC), and Americans with Disabilities Act (ADA)requirements for accessible design are the references that I used to set the minimum square footage of the addition. For instance, according to IRC, minimum room area should be 70 square feet and width longer than 7 feet (IRC 2009). Additionally, the bathrooms designed according to the ADA standards were taken into consideration.

Habitat for Humanity affiliates has designed several sample house plans following IRB and ADA standards. Considering, IRB, ADA standards and the sample plans designed by Habitat for Humanity affiliates, I have set the size of the addition to be 231 square feet.

Several assumptions and constraints played an important role in developing the scenarios on location and form of 231 square foot addition:

- The width of the addition should not be less than 7 feet (IRC 2009).
- Location of the exterior doors is one of the constraints for the placement of the addition. However, if the addition blocks an existing window, I have removed that window.
- Since House 30 is a concrete block structure on a concrete slab, the additions were modeled as concrete block walls (R-4), concrete slab (R-1), ceiling (R-30) and asphalt shingle roof (R-7) (Table 53). On the other hand, House 15 is a wood frame structure on pier and beams. Therefore, the additions for that house were modeled as a wood frame structure (R-13), ceiling (R-30) and asphalt shingle roof (R-7) (Table 53).
- The floor of House 30 was modeled as sitting on the ground whereas the floor of House 15 was modeled as off the ground to conform with the height of the existing structure.
- The shape of the roof was adjusted according to the location and shape of the addition. . Roof type was selected as a gable roof. The determinant for decision on the roof slope was the ceiling height of the addition. When extending the roof of existing structure, if the ceiling height of the addition was not less than 8 feet, then I used the same slope of the existing structure. However, if the ceiling height was less than 8 feet, a new roof was created.
- The length of the overhangs for each house was determined according to the overhangs of the existing structures. For House 30, it is 1’ 5” whereas for House 15, it is 1’0”.

- The infiltration value of the addition to each house is determined according to a database of air leakage values through building envelope of houses in the U.S. which is called Residential Diagnostic Database developed by Lawrence Berkeley National Laboratory (LBNL) (2011). They developed a statistical model to predict air leakage value for the residential families in U.S. (Sherman and McWilliams 2007) according to seven parameters: floor area (SF), ceiling height (ft), year built, region, climate zone according to IECC, foundation type and duct system location (Table 48).

Table 48: Annual Infiltration Rate (ACH) for the existing structures and the additions of the test cases (adapted from Lawrence Berkeley National Laboratory 2011)

TIGHTNESS OF THE BUILDING-NORMALIZED LEAKAGE (95%)**						
	SF *	Year to Build	Space ID	worst case	most likely	best case
15	638	1974	1	2.15	0.7	0.225
	126	1992	2	1.6	0.5	0.15
	231	2014	3			0.1
30	955	1992	1,2	1.2	0.35	0.09
	231	2014	3			0.075

7.1.2 Size and Location of the Fenestrations on the Addition

The decision on the size and location of the fenestration was based on the IRC and the focus group discussion conducted with six experts discussed in Section 5. According to IRC Section R310, every sleeping room should have one or more operable emergency and rescue window openings. These windows should have a minimum 5.7 square feet net clear opening with a minimum of net 24 inches height and 20 inches width. On the other hand, experts have suggested several strategies on fenestration, such as reducing the size of windows as much as possible.

Regarding the code requirements on egress windows and suggestions by experts, I have selected two minimum sized windows to be added to the structure:

(1) One 34-inch width and 48-inch height double hung window with double glazing low-e clear glass for the bedroom, and

(2) (2) One 24-inch width and 36-inch height double hung window with double glazing low-e clear glass, for the bathroom.

I have tested the location of the windows according to several pre-set rules. Data from the focus group identifies the rules:

- No window on the west facade.
- Place windows on the north facade unless the addition is attached to the main house from its north facade.
- If north facade is not available for window placement, then place the window on the south facade.
- If neither north nor south facade is available for window placement, then place windows on the east facade.

7.2 Design Scenarios for the Additions

UN-Habitat (2011) and our focus group (Section 5) list several proven passive, low-cost and low-energy strategies which need to be optimized according to the climate and residents' comfort expectations. The process of designing a low-cost, energy efficient addition to a colonias home unfolds in 7 phases: (1) form and location of the addition, (2) shading, (3) construction materials, and design of mechanical systems including (4) HVAC systems, (5) behavioral set points, (6) domestic hot water strategies, and (7) water catchment (Figure 37). Figure 37 demonstrates the hierarchical decision-making process. The best option identified from each phase has been used to determine the options for the next phase. The characteristics of the main house, the available options in the GBS and the focus group results are the factors that form the number of options. Both energy and cost are considered during the selection of best option.

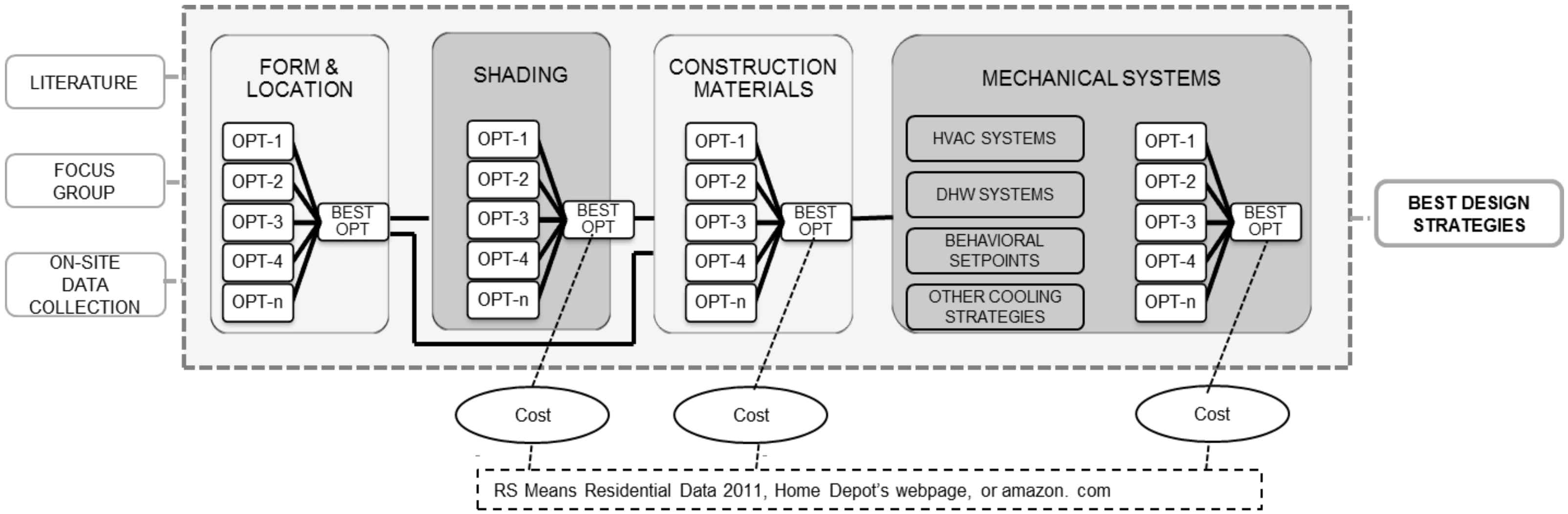


Figure 37: Conceptual map of the analysis process of practice suggestions by experts and the literature

7.2.1 Form and Location of the Addition

There are 11 design options for each house developed by considering the set of rules listed above for form and orientation (Table 49 and Table 50).

7.2.2 Shading and Fenestration Strategies

In terms of shading, (1) extension of the roof overhangs of the whole structure, (2) addition of a covered porch, (3) construction of a shading structure on top of the existing house known as a double roof, (4) planting trees, and (5) installing exterior shutters on the windows have been considered for the test cases (Table 51 and Table 52). Experts suggested that these strategies could be suitable for colonias houses. According to the on-site survey, constructing a second roof on top of the existing roof is often adopted in the sample homes. However, landscaping is not common in these homes.

To that extent, I developed 17 options for House 15 and 16 for House 30.

In addition to the shading strategies, I have also tested scenarios on upgrading windows glazing on both the addition and the existing structure:

- Replacing the existing windows on the whole house with low-e double glazed windows while keeping the size same
- Installing exterior shutters on the windows on the whole house with low-e double glazed windows while keeping the size same
- Replacing the existing windows, reducing window sizes and installing low-e double glazed windows (for House 15, 36” by 36” and for House 30, 34” by 48” and 24” by 36” are the replaced window sizes)

Table 49: Form and orientation options for the addition to House 15

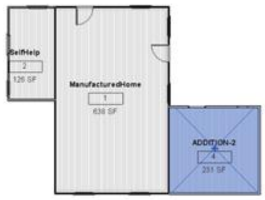
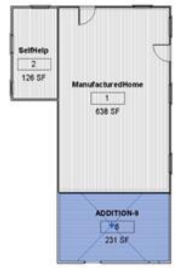
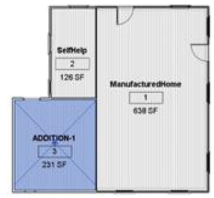
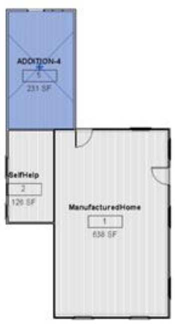
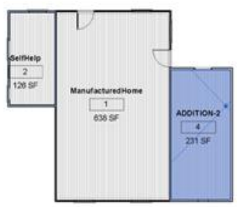
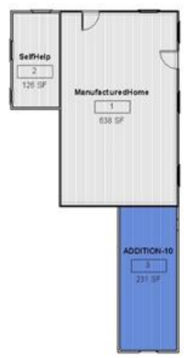
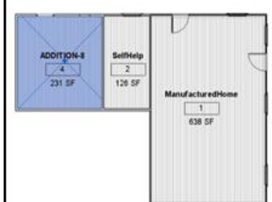
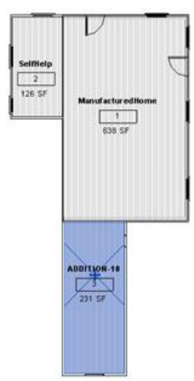
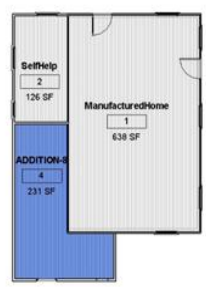
HOUSE NO. 15				
	NORTH	EAST	SOUTH	WEST
A	 5	 2	 9	 1
B	 4	 3	 10	 7
C		 6	 11	 8

Table 50: Form and orientation options for the addition to House 30

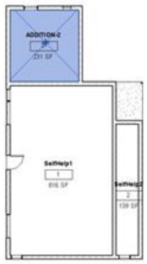
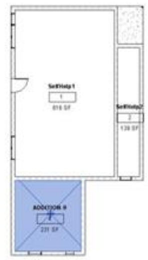
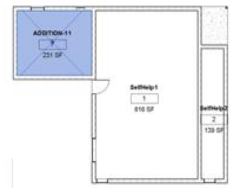
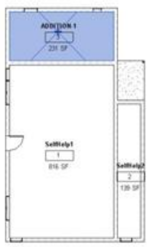
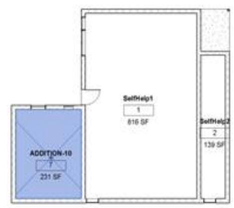
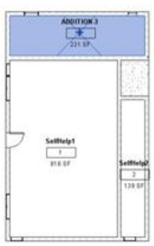
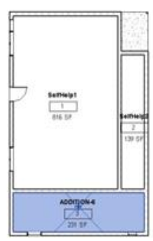
HOUSE NO. 30				
	NORTH	EAST	SOUTH	WEST
A	 2	 5	 9	 11
B	 1	 8	 7	 10
C	 3		 6	
D	 4			

Table 51: Shading scenarios of House 15

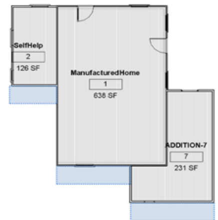
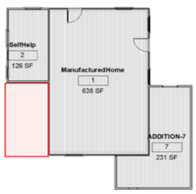
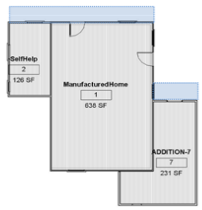
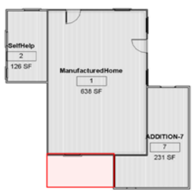
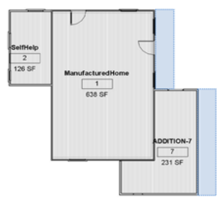
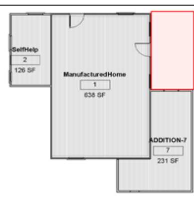
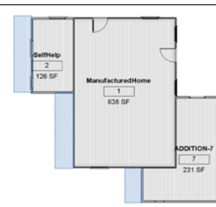
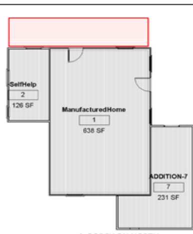
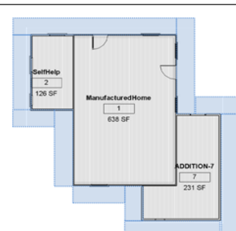
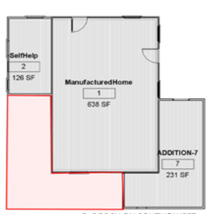
SCENARIO NO	SHADING PLANS	SCENARIO NO	SHADING PLANS
0	 0- BASE CASE	6	 6- OVERHANGS ON SOUTH
1	 1- PORCH ON WEST	7	 7- OVERHANGS ON NORTH
2	 2- PORCH ON SOUTH	8	 8- OVERHANGS ON EAST
3	 3- PORCH ON NORTH EAST	9	 9- OVERHANGS ON WEST
4	 4- PORCH ON NORTH	10	 10- OVERHANGS ON ALL FACADES
5	 5- PORCH ON SOUTH&WEST		

Table 51 Continued

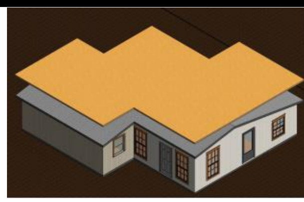
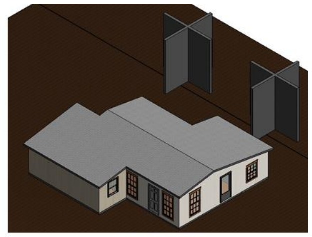
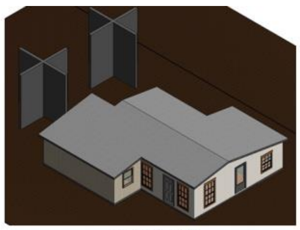
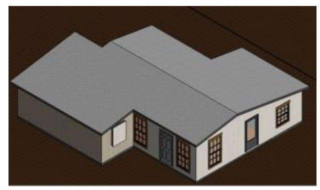
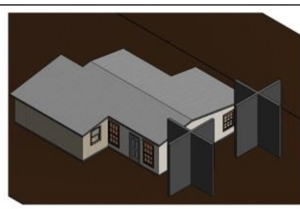
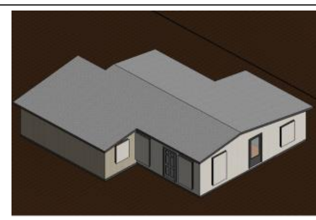
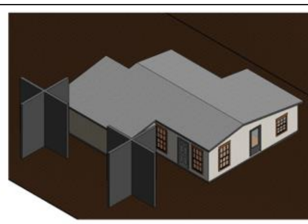
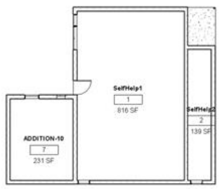
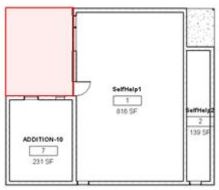
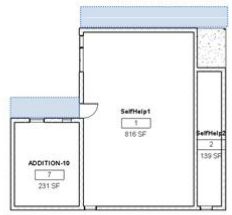
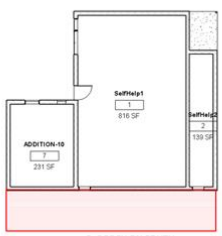
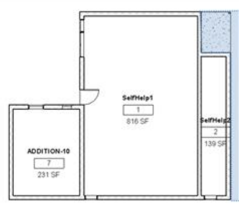
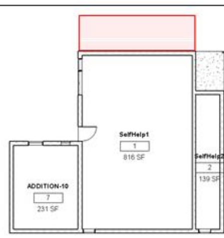
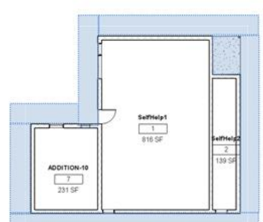
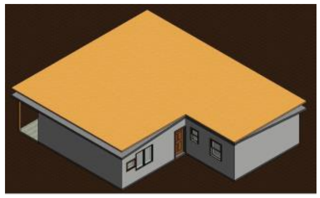
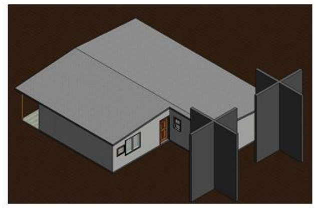
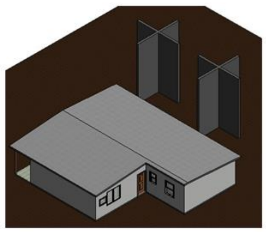
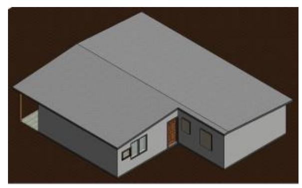
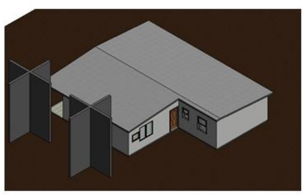
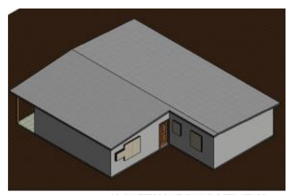
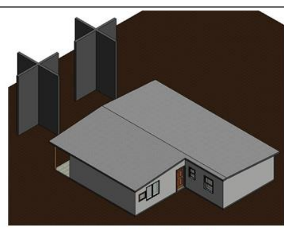
SCENARIO NO	SHADING PLANS	SCENARIO NO	SHADING PLANS
11	 11- DOUBLE ROOF	15	 15- TREES ON THE WEST
12	 12- TREES ON THE SOUTH	16	 16- EXTERIOR SHUTTERS ON THE ADDITION
13	 13- TREES ON THE NORTH	17	 17- EXTERIOR SHUTTERS ON THE WHOLE STRUCTURE
14	 14- TREES ON THE EAST		

Table 52: Shading scenarios of House 30

SCENARIO NO	SHADING PLANS	SCENARIO NO	SHADING PLANS
0	 0- BASE CASE	5	 5- OVERHANGS ON SOUTH
1	 1- PORCH ON NORTH WEST	6	 6- OVERHANGS ON NORTH
2	 2- PORCH ON SOUTH	7	 7- OVERHANGS ON EAST
3	 3- PORCH ON EAST	8	 8- OVERHANGS ON WEST
4	 4- PORCH ON NORTH	9	 9- OVERHANGS IN ALL DIRECTIONS

* Electricity cost per kWh is $0.11 by default.

Table 52 Continued

SCENARIO NO	SHADING PLANS	SCENARIO NO	SHADING PLANS
10	 10- DOUBLE ROOF	14	 14- TREES ON THE WEST
11	 11- TREES ON THE SOUTH	15	 15- EXTERIOR SHUTTERS ON THE ADDITION
12	 12- TREES ON THE NORTH	16	 16- SHUTTERS ON THE WHOLE STRUCTURE
13	 13- TREES ON THE EAST		

7.2.3 Building Envelope and Materials

Table 53 demonstrates expert suggestions on construction types which are checked according to the International Energy Conservation Code (IECC) Minimum Insulation Requirements for Webb County, Texas (Table 54). Experts prefer advanced framing for wood frame pier and beam structures as opposed to conventional standard framing. As advanced framing uses less material than the conventional framing, it reduces the framing cost which makes it more appropriate for colonias residents. It also is more energy efficient, increasing R-value and reducing infiltration.

Table 53: Construction type options suggested by experts

OPTIONS	WALL CONCRETE BLOCK WALL	ADVANCED FRAME WALL	FLOOR CONCRETE SLAB	PIER AND BEAM	CEILING
1	R-4	R-13	R-1	R-13	R-30
2	R-6	R-19		R-19	
3		R-24		R-24	

	WINDOWS	DOORS
	vinyl double pane low-e glass	storm doors metal doors

Table 54: 2009 International Energy Conservation Code (IECC) minimum insulation requirements for Webb County, Texas (adapted from USDOE 2014)

CLIMATE ZONE 2 (WEBB COUNTY, TX)	
	R-value
Wood Frame Wall	13
Mass Wall	4 or 6
Floor	13
Basement Wall	0
Slab	0
Attic	30
Crawlspace Wall	0

House 15 has been tested with three options shown on Table 53 whereas House 30 has been analyzed based on options1 and 2.

7.2.4 Mechanical Systems

Mechanical systems include HVAC systems and other cooling systems, behavioral set points, domestic hot water systems and water catchment strategies.

HVAC Systems

Although ductless mini split air conditioning systems are strongly suggested for these homes by experts, I was not able to test their effectiveness since Autodesk Revit, and GBS do not have this system as a selectable option. Only four heating and cooling system options were available for residential homes in Autodesk GBS two of which with 14 and the other two with

17 seasonal energy efficiency ratio (SEER). SEER 14 and 17 are the most preferred systems for residential homes. For each system, one gas furnace and one heat pump options were tested. Systems include furnaces with average fuel utilization efficiency (AFUE) 0.9 for SEER 14 and 0.85 for SEER 17. On the other hand, systems with 8.3 heating seasonal performance factor (HSPF) for SEER 14 and 9.6 for SEER 17 were utilized.

Table 55: HVAC system options

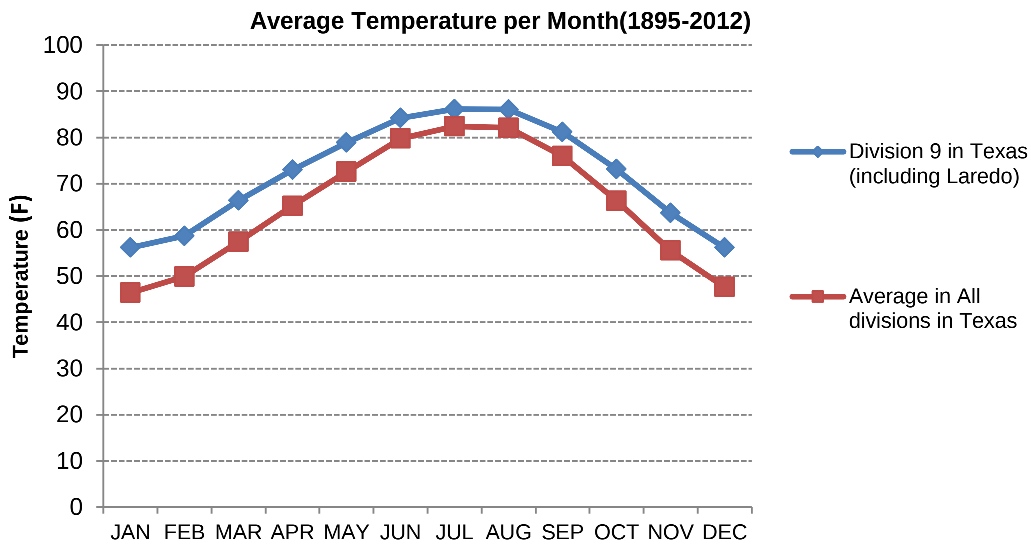
HVAC System Options
Residential 17.4 SEER/9.6 HSPF Split HP
Residential 17 SEER/0.85 AFUE Split/Pkgd
Residential 14 SEER/0.9 AFUE Split/Pkgd Gas
Residential 14 SEER/8.3 HSPF Split Packaged HP

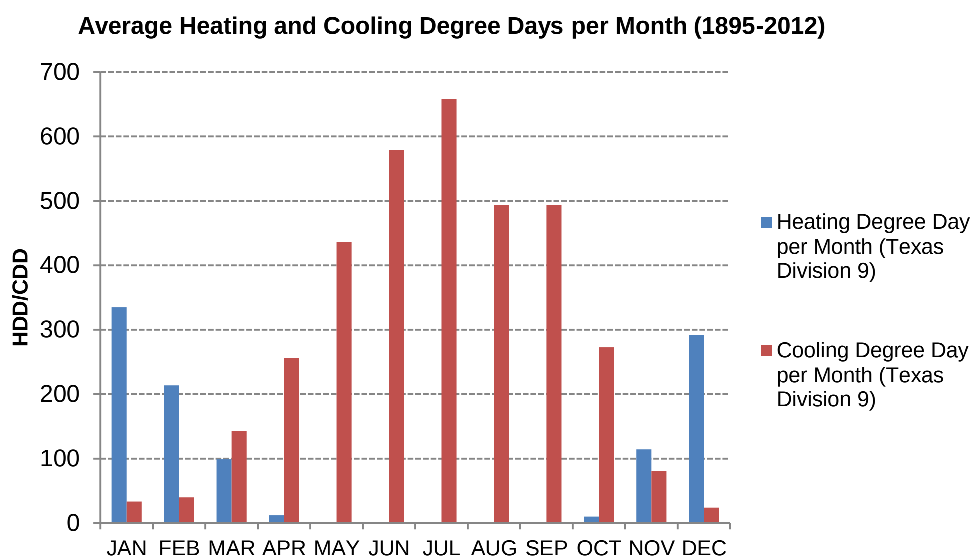
Mini-split type mechanical systems offer multiple indoor units that can be installed in different rooms with a single outdoor unit. To that end, experts described the benefits of these systems as allowing users to adjust the indoor temperature according to their use of space.

Behavioral Set Points and Other Heating and Cooling Strategies

As it was discussed during the focus group (section 5), colonias residents in the United States want to live in a house which looks similar to a U.S. resident's house. Therefore, installing an HVAC system is very common and wanted by the residents. However, in other informal settlements around the world, *barrios, tugurios, favelas, bidonvilles, gecekondus,* or *kampongs*, installing HVAC system is not widely used.

As illustrated in Figure 38, Laredo is listed under climate division 9 by U.S. Department Commerce, National Oceanic and Atmospheric Administration (2013b). It has more cooling degree days (3509.6) than heating degree days (1076). Therefore, the electricity for cooling is one of the major expenses for colonias residents in Laredo.





Data Source: http://www.ncdc.noaa.gov

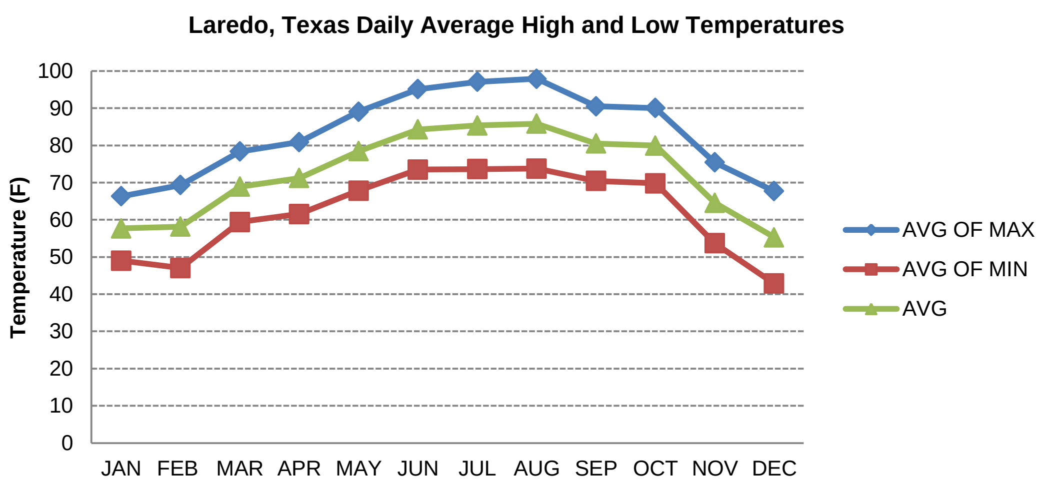
Figure 38: Climate data for Texas climate division 9 including Laredo, TX (adapted from US Department of Commerce 2014)

One strategy for managing energy consumption is to adjust the set points for heating and cooling, expanding the range of acceptable temperatures. For colonias, this range can be extended, considering practices in other informal settlements located in other countries. Two scenarios were tested: (1) ASHRAE standards, (2) behavioral set points. According to

ASHRAE standards, for occupied space, dry bulb temperature should be between 70˚F and 75˚ F with relative humidity that does not exceed 50% (Zhivov 2014). In this study, by adapting passive design strategies, I assumed the interior dry bulb temperature set points can be extended to 60˚F and 80˚F.

The graph in Figure 39 shows the average minimum and maximum dry bulb temperatures in Laredo. The median of these two values has been calculated in order to identify the months that require heating and cooling. In January, February and December, the median temperature is below 60 ˚F. Therefore, residential structures need heating. On the other hand, May, June, July, August, September and October are the months when cooling the structure are required.

Eliminating an HVAC system is an important strategy to seek for these residential structures. To that end, other cooling strategies are evaporative cooling and Energy Recovery Ventilations (ERV) or house dehumidifiers. For heating, thermal mass of the structure plays an important role.



Data Source: http://www.ncdc.noaa.gov

Figure 39: Daily average high and low temperatures in Laredo, Texas (adapted from US Department of Commerce 2013)

Domestic Hot Water Strategies: Solar Collectors

There are several solar thermal water heater systems that do not use electricity or gas for generating domestic hot water. They are more expensive than the conventional water heaters. However, in the long run, residents save money by using free sunshine for heating their water. Another strategy is to use a heat pump for hot water heaters and manifold hot water distribution systems, which the experts claim to be good strategies.

7.3 BIM Implementation and the Challenges

The same steps with modeling existing homes which were discussed in Section 6 were followed in this section. The same template was used and modified for the best practices. The process included (1) creating new materials and library and (2) performing building performance analysis.

Autodesk Revit 2014 has two options to run energy analyses on a Revit model: (1) energy analysis by using conceptual mass models, and (2) energy analysis by using building element mode. In this study, I used building element mode which reads the thermal properties of building materials that I chose or created. However, I came across several challenges while performing energy analysis suing Autodesk Revit tool and GBS.

7.3.1 Creating a New Library and New Materials for Best Practices

Not all of the materials needed for modeling houses in the colonias are included in the libraries provided by Autodesk Revit. Therefore, while some of these materials are directly borrowed from the embedded Autodesk Materials library, some were developed from scratch. They are all located under a new folder called “Colonias Materials” in Revit.

This is the same process followed for creating a library for existing homes which was described in Section 6.

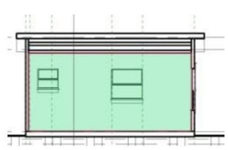
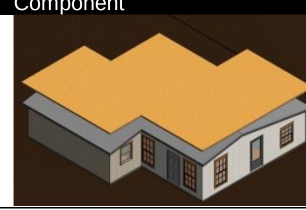
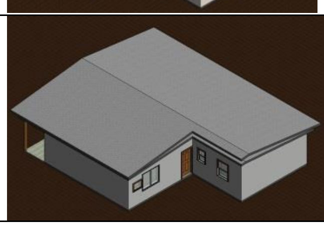
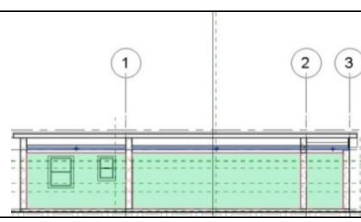
7.3.2 Challenges in Revit and GBS

A number of structures have unique design solutions such as building another roof on top of a manufactured house, or covering an RV with gypsum to make it embedded to the attached self-built house.

In terms of building performance analysis in GBS, modeling a double roofed structured presented a challenge. DOE-2 as the back engine of GBS allows users to model one roof on top of another roof. One solution may be assigning the original roof as an interior object and the additional roof as an exterior object. Another technique one may be to identify the space between original roof and additional roof as a plenum that does not require any lighting or air conditioning.

In Revit, however, I came across several challenges on modeling the double roof (Table 56). First I tried drawing a second roof on top of the original one. However, GBS did not recognize it. Then I atempted to model a plenum. Revit processes a space or a room which has walls, ceiling and floor. Therefore, in order to identify a plenum, I remodeled the original ceiling as a floor and placed a ceiling on top of it. I defined the space in between as a plenum. Unfortunately, this method did not work in GBS either. The results generated by GBS are higher than the base case although it should have been the opposite. To that extent, I placed a floor on top of the structure, and I picked wood deck as the material. This method produced an appropriate shadow on top of the roof to simulate the ability of a double roof to remove radiant gains.

Table 56: Challenges on modeling double roof

House	Two Roof Components	Plenum Space	Floor on top of the Roof Component
15			
30			

Placing trees for shading were another challenge in Revit and GBS (Table 57). I first placed tree components, but GBS did not recognize them. In order to overcome the challenge, I have applied a common CAD drawing method which is to symbolize trees as cross shaped walls. I have elevated them from the ground by 4-feet with a width and height of 15-feet. Modeling the louvers or baffles on the windows was another challenge. Autodesk Revit does not offer this type of shading as an option. Therefore, I have followed the similar principle of modeling the trees. I have placed a wood frame wall with no insulation on the windows (Table 58) which acts as an exterior shutter by protecting the windows from the sun.

Last, GBS sets the interior dry bulb temperature set points for cooling and heating according to ASHRAE standards by default. The gbXML file exported from Autodesk Revit does not have any line stating the set points. In order to make adjustments on the set points, users should export the gbXML file that was run in GBS, which has additional lines filled by default. In this gbXML, I have changed the values for cooling and heating set points and run it in GBS again.

Table 57: Challenges on modeling trees

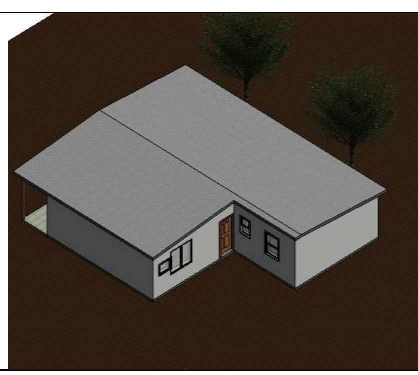
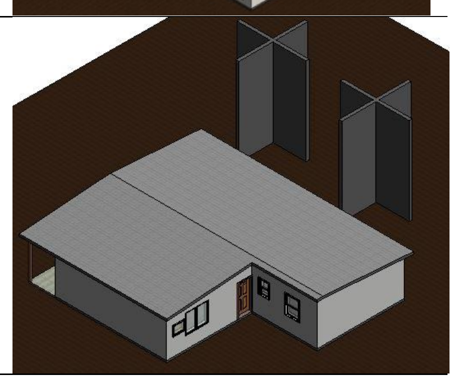
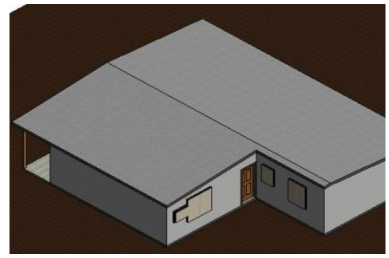
House	Tree as a Site Component	Cross Shape Wall Components
15		
30		

Table 58: Challenges on window shutters

House	Shutters as a Wall Component	House	Cross Shape Wall Components
15		30	

There were other challenges in modeling mechanical systems. For instance, ERVs, mini-split systems and solar water heaters are not available in the Autodesk Revit or GBS's library. These challenges were accepted as the limitations of the tool that I have been using in this study.

7.4 Results: Identifying the Best Practice Scenarios for Two Case Studies

7.4.1 Results for Form and Location of the Addition

Figure 40 demonstrates the GBS EUI results of 11 design alternatives for House 15. East-C is found to be the best options in terms of energy efficiency. The reason behind this result is that House 15 has openings on each facade, and the manufactured home structure, since it was built in 1974, has a lower R-value than the self-help structure. To that end, the options which are adjacent to the manufactured home have lower EUI values than the others by increasing the overall R-value of the exterior walls (Figure 40).

In East-C option, two existing window openings on the manufactured structure have been removed in order to place the addition, and this has been found to be the best option for House 15. The addition, in this case, has a bedroom window on the north facade whereas the bathroom window is on the south.

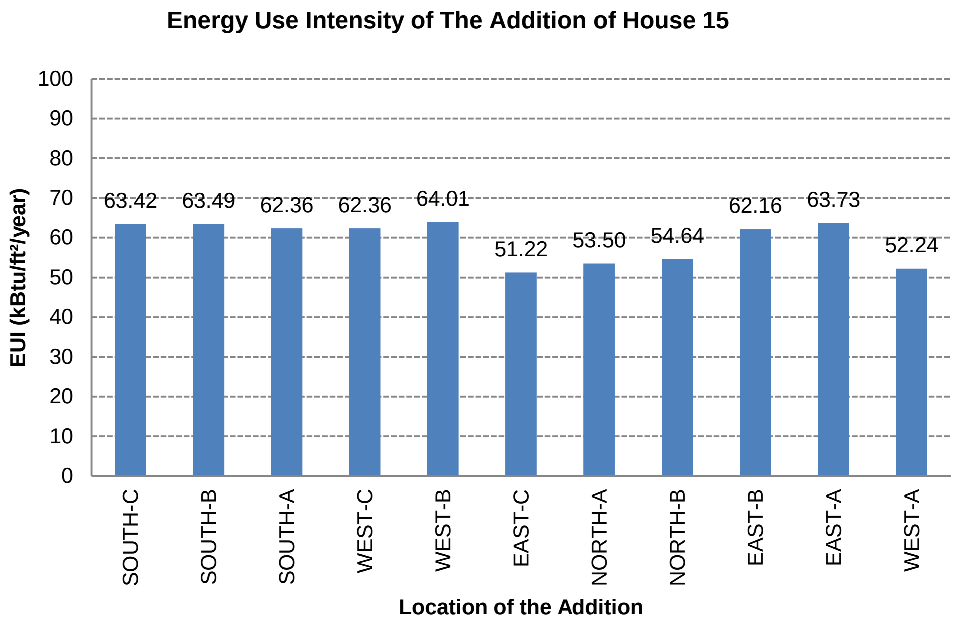


Figure 40: Energy use intensity results of the scenarios of form and location of the addition to House 15.

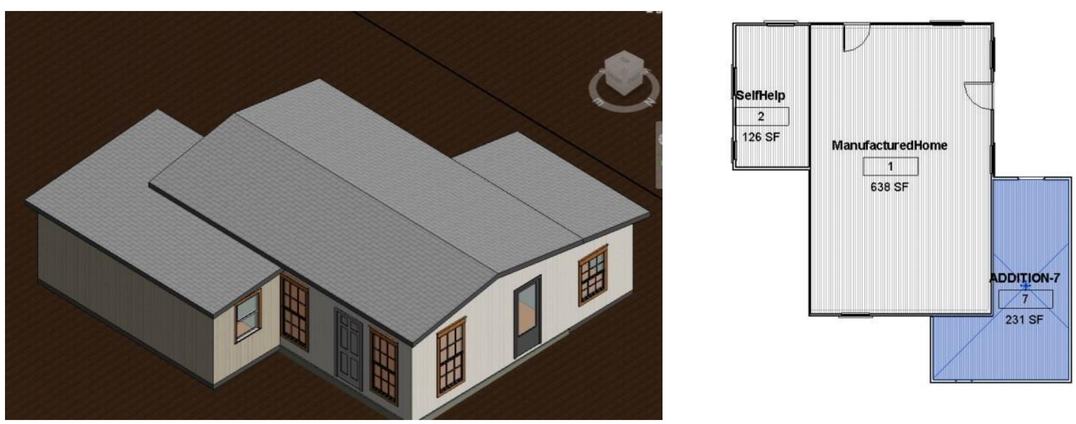


Figure 41: House 15 with East-C option addition: 3-dimensional image and plan

Figure 41 shows the building performance analyses results of 11 alternative design scenarios of the addition to House 30.

The difference across EUIs in the design scenarios is not significant. The reason can be that House 30 is a concrete structure which has a greater thermal mass than House 15. In addition to that, the number of windows and their sizes are less than House 15. House 30 has window openings on the south and west facades. The ones on the south are leaner than the ones on the west. To that extent, West-B option provides the best results since one of the larger openings has to be removed in order to place the addition (Figure 43).

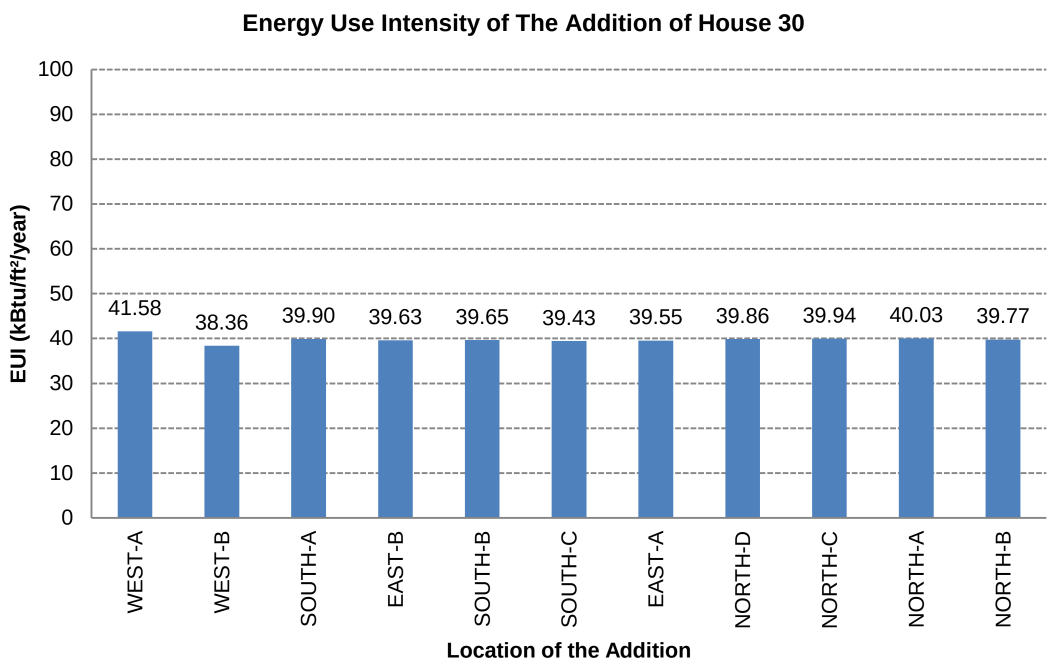


Figure 42: Energy Use Intensity results of the scenarios of form and location of the addition to House 30.

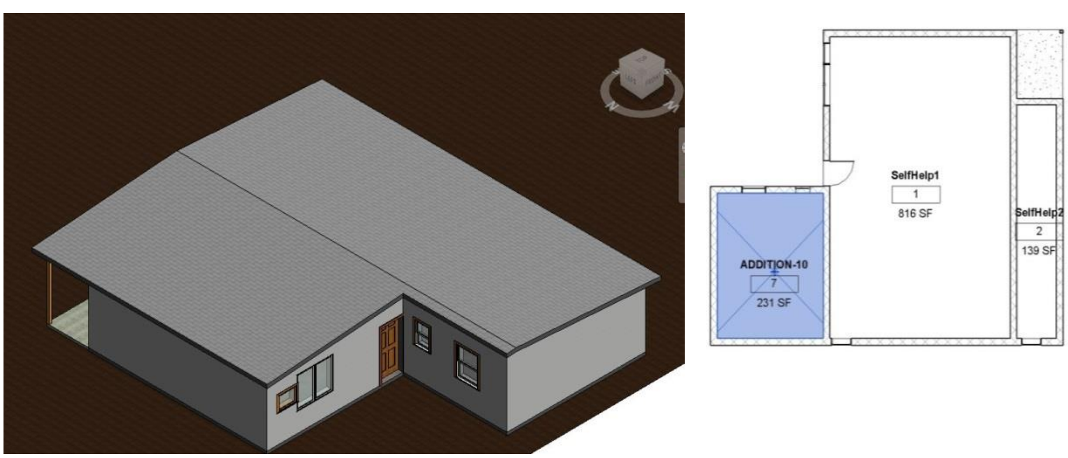


Figure 43: House 30 with West-B option addition: 3-dimensional image and plan

The results above have been performed according to ASHRAE standards on indoor minimum and maximum dry bulb temperature.

7.4.2 Shading and Fenestration Strategies

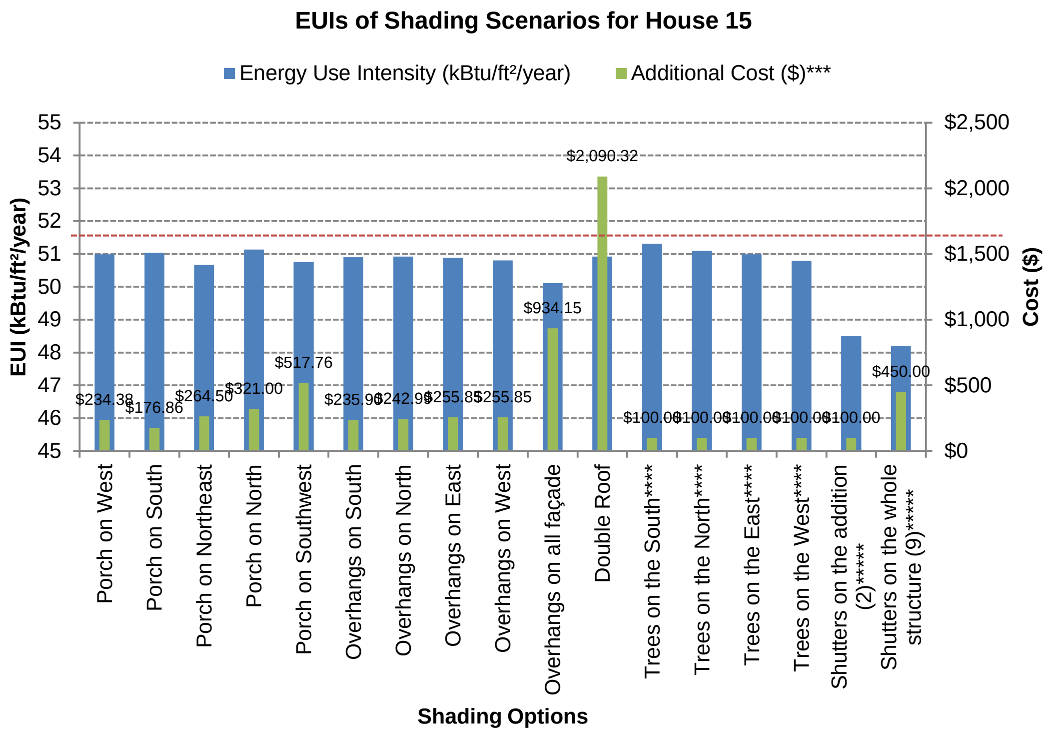
After selecting the best option for the design of the addition, I have tested several shading options on that design. Costs associated with the improvements are assumed to be amortized over a period of 10 years with no interest.

For House 15, according to Figure 44, five strategies stand out:

(1) EUI can be reduced by 6.36% by installing exterior shutters on the windows of the whole structure. This house has very large openings that spread out to all facades. In terms of cost, if residents apply this strategy, their annual savings would be $99.39 whereas their annual payment for the shutters would be $45.
(2) Installing shutters on the windows of the addition reduces EUI by 5.6%.
(3) Extending overhangs of the whole structure was found to reduce the EUI by 2.29%. However, this strategy will add to the cost. Extending overhangs in all directions may cost $934.15.
(4) Building a porch on the Northeast may cost $264.50 and reduce EUI by 1.15%.
(5) Planting trees on the west side can be another good strategy to lower the energy consumption by 1%. The cost of a tree can be around $50 at Lowe’s.

For House 15, the most affordable solution can be planting trees on both West and East facades which will reduce the energy consumption by 2%. In addition to that, adding a porch on the northeast (1%) or extending the roof overhangs in all directions (2%) can be the next strategies to adopt. As experts suggested, using reflective surfaces such as metal or license plates for roof overhangs and extension of the roof is a good and affordable strategy for these residents. It will reduce the cost of the construction.

Residents should avoid planting trees on the south facade as it may increase the energy consumption. Overall, for House 15, since it has fenestration on all facades and low quality of materials, the strategy selection does not have a drastic impact on EUI reduction. In order to increase the impact, it would be better to combine two or more strategies.



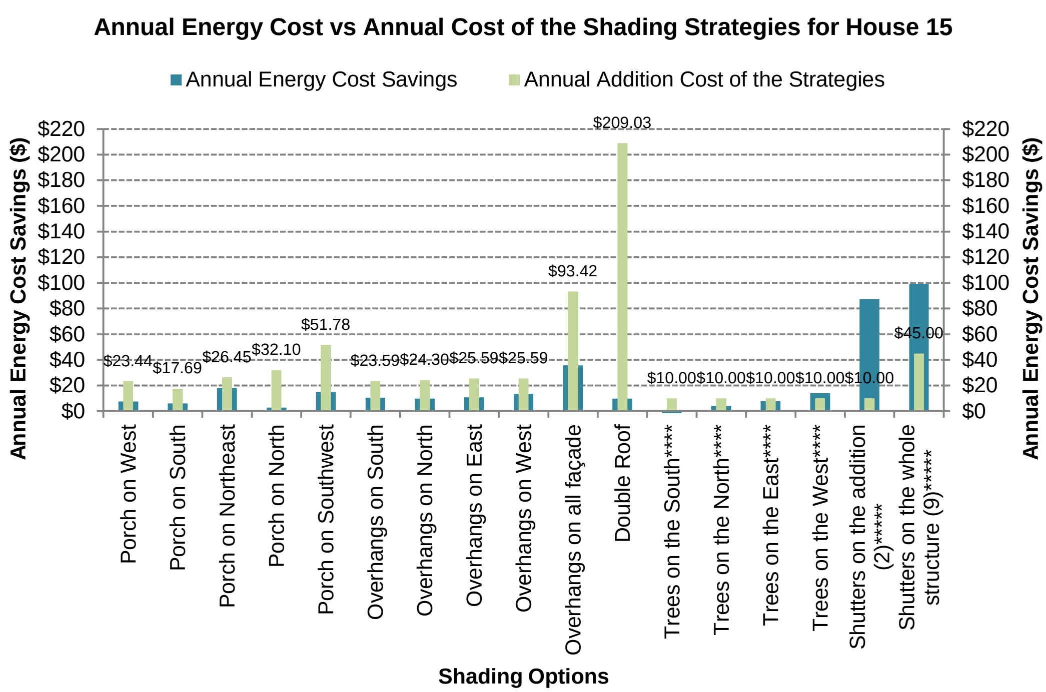
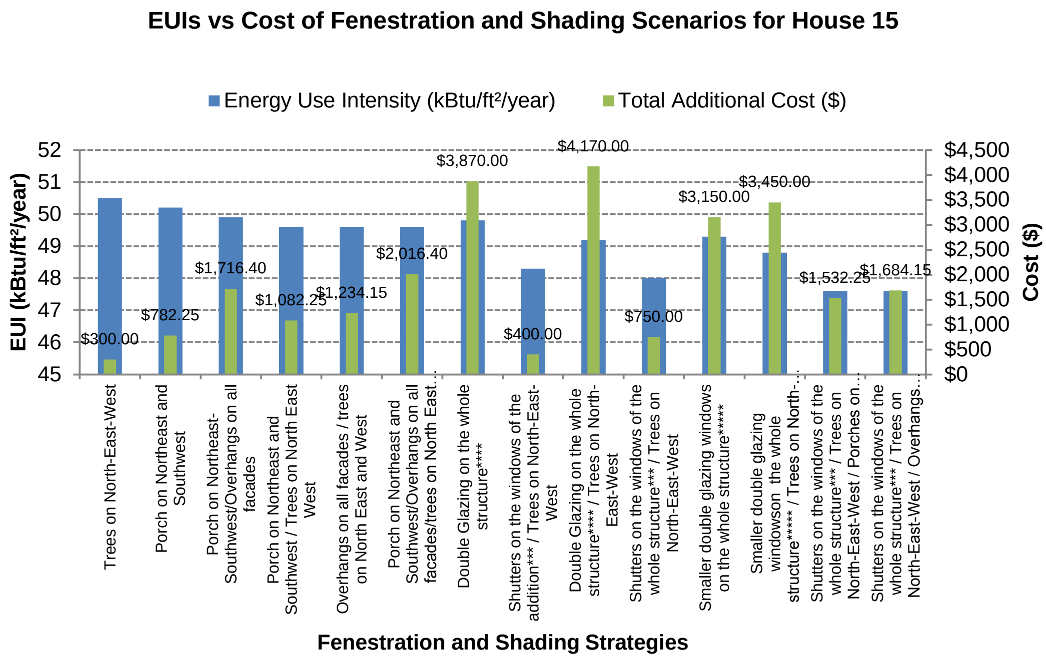


Figure 44: Energy savings and cost of the shading scenarios for House 15.



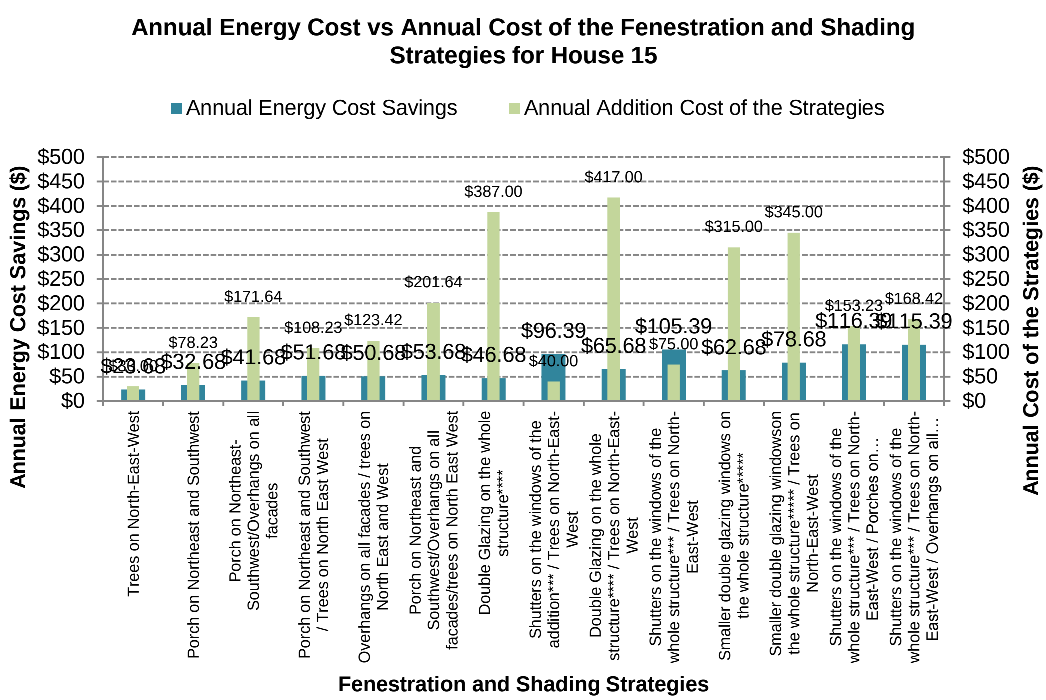
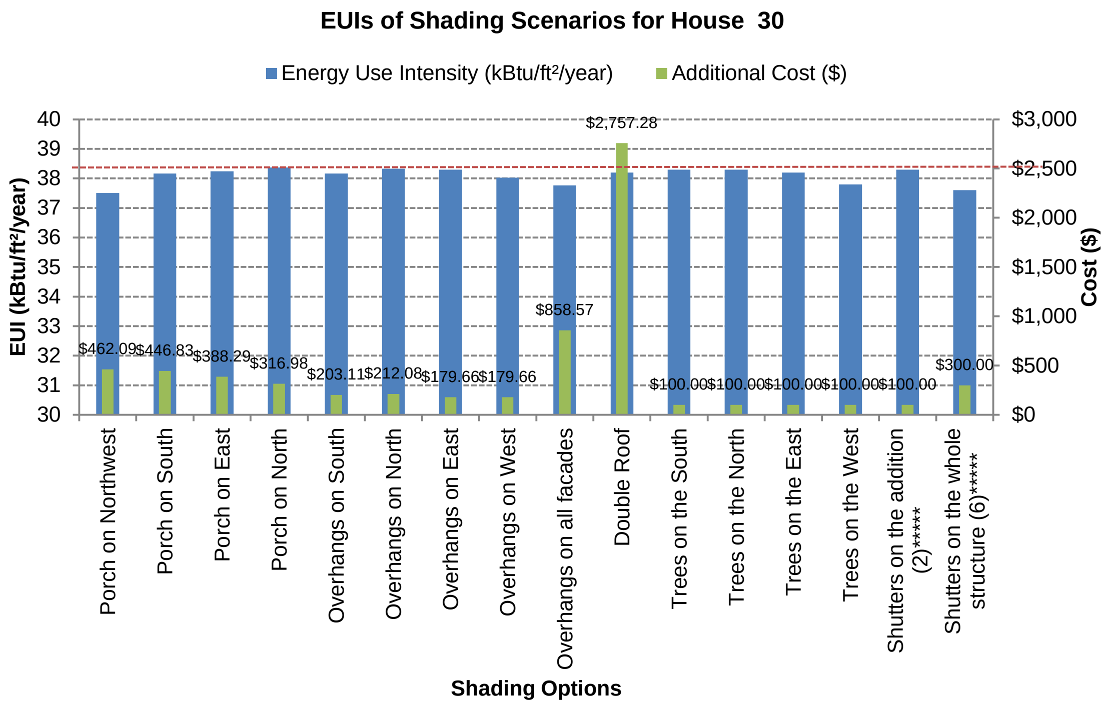


Figure 45: EUI and cost distribution for combination of shading and fenestration scenarios for House 15

Figure 45 demonstrates the results for the scenarios on combinations of the strategies discussed above. The most advantageous strategy is to plant trees on North, East and West facades and install shutters. The savings in terms of energy cost is more than the annualized payment for the strategies. It is possible to increase the savings by constructing a covered porch or extending the roof overhangs. However, the price for this strategy is more than the annual savings.

For House 30, Figure 46 and Figure 47 demonstrate that the best solution was constructing a covered porch on the northwest facade, installing shutters on the windows of the whole structure, planting trees on the west, and extending overhangs on all facades.

(1) Results indicate that a covered porch on the Northwest facade reduces EUI by 2.2% in total whereas the annual energy cost savings are $32.80. The reason behind the change in numbers is having most of the openings located on that facade. However, in terms of cost efficiency, it may not be the best strategy. Application of the strategy may cost $462.09 which can be translated to an annual cost of $46.21. On the other hand, building a covered porch has social benefits as it was emphasized during the focus group and observed in the colonias during on-site data collection. A covered porch creates an outdoor space for the residents. Therefore, this strategy can be classified as a good one for this house.
(2) Installing shutters on windows around the whole structure reduces the EUI by 1.98% and is another best practice that this study suggests. The annual cost of the shutters ($30) is almost on par with the annual savings.
(3) Another good strategy is to plant trees on the west side. Planting trees is the most affordable option which can be implemented together with building a covered porch or extending the roof overhangs. Building a porch on the north side may result in increasing the energy consumption for this case.
(4) These strategies are followed by extending overhangs on all facades which can lower the EUI by 1.56%. However, it duplicates the cost of building a covered porch. In that sense, it may not be an appropriate strategy for this house.



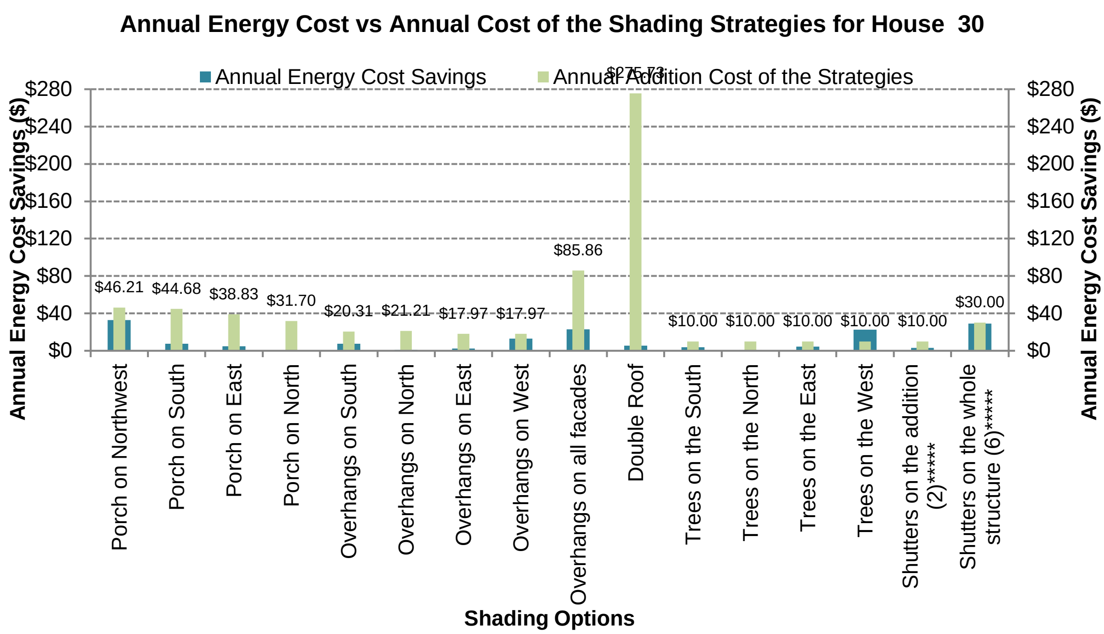
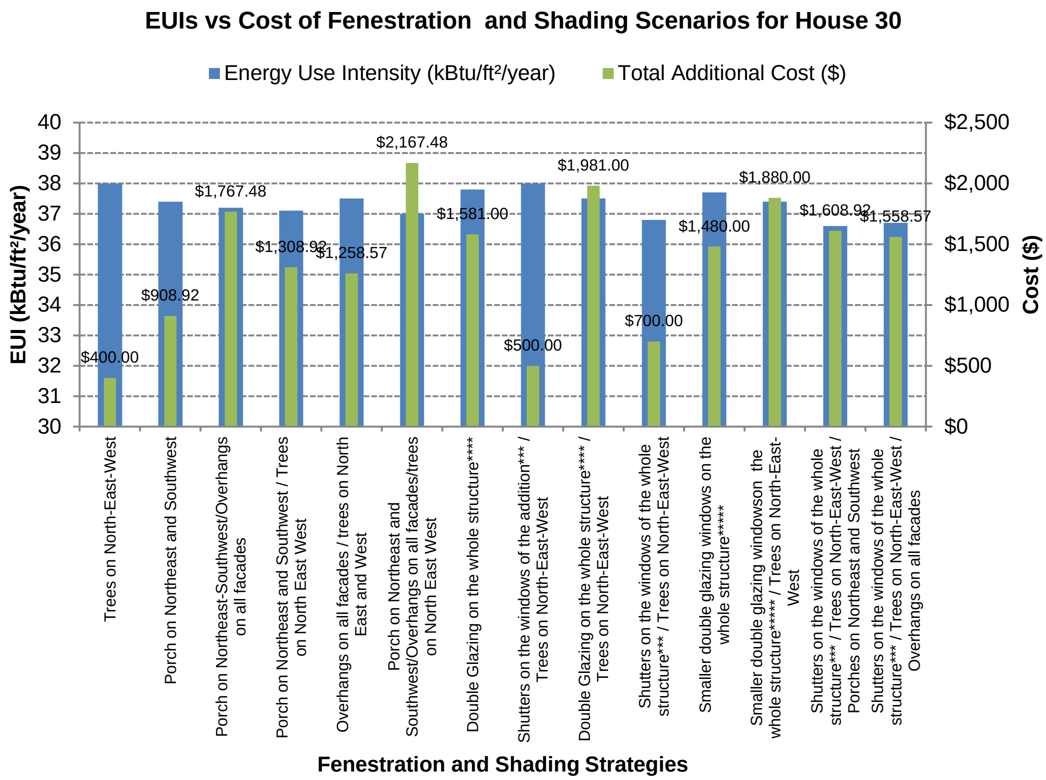


Figure 46: Energy savings and cost of the shading scenarios for House 30



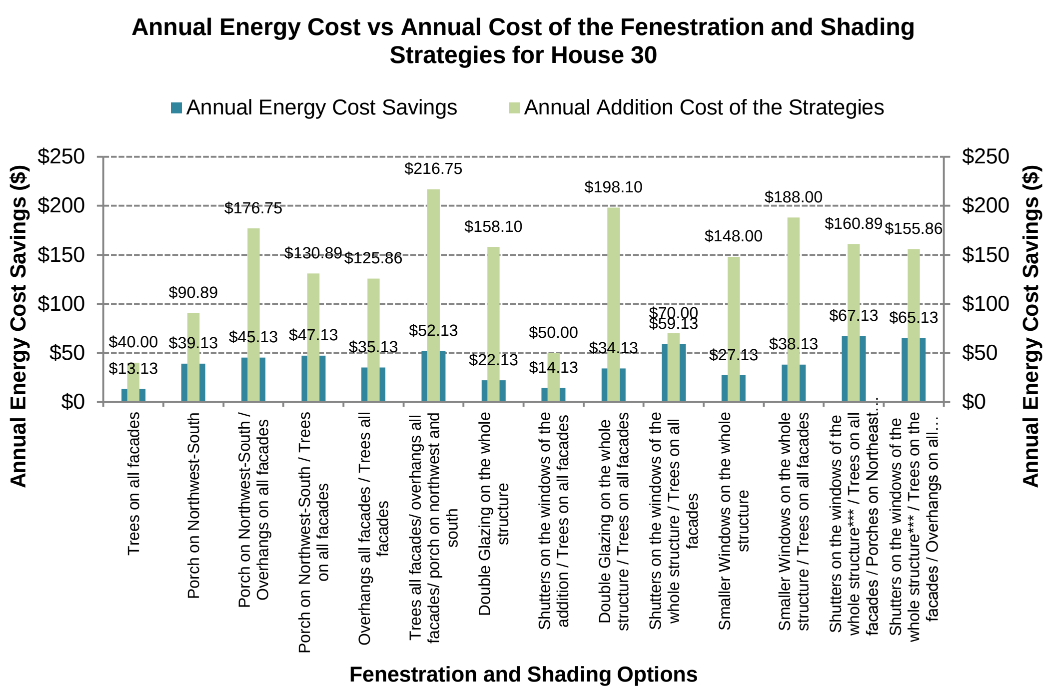


Figure 47: EUI and cost distribution for shading and fenestration scenarios for House 30

After exploring the costs of the strategies and their impact on energy consumption individually, I have tested several possible combinations of them (Figure 47). Installing shutters together with planting trees is the best choice by optimizing cost and energy efficiency. Although the best savings comes with the last two options, which are either installing a covered porch or extending the roof overhangs, the annual payments of these strategies are very high.

To sum up, it is important to consider the strategies carefully. They may not always reduce the energy consumption. For instance, for these two cases, building a porch on north facade and planting trees on the south side may increase the energy use instead of reducing it. Data demonstrates that window openings are the key consideration on shading strategies. However, reducing the window sizes on the existing structures by replacing them with double pane low-e windows requires a significant amount of money and knowledge on installation and construction. In that sense, it was found not be appropriate for colonias residents and their homes.

7.4.3 Building Envelope and Materials

Several construction material options were tested on the additions for both cases. Results revealed that there is a great difference between having no insulation and having a moderate one. However, in House 15, the impact of upgrading from R-13 to R-19 or R-24 on annual electricity cost is $20 and $40 respectively. Similarly, there is only $1 saving in annual electricity cost by improving the walls from R-4 to R-6 in House 30. The impact of upgrading only the 231 square foot structure rather than the whole house is non-existent.

To that extent, after the consideration of the cost of the insulation materials, these cannot be classified as low-cost strategies to reduce energy use. As it was suggested by experts, there are several other low- to no-cost insulation materials that colonias residents could make use of such as old cloths, and recycled papers.

Table 59: Energy analysis results of the scenarios on construction of the addition for House 15.

Scenario No.	Construction Type Options	Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Annual Elec Use (kW)	Annual Fuel Use (Therm)	EUI (kBtu/ft²/year)	Cost of Insulation Material ($)***	Annual Cost ($/10 years)
1	R-13(walls and floor),R30(Ceiling)	1,517.68	45.71	1,563	13,697	43.34	51.22	4,554.50	455.45
2	R-19(walls and floor),R30(Ceiling)	1,506.00	45.00	1,551	13,593	43.34	51.00	7,103.00	710.30
3	R-24(walls and floor),R30(Ceiling)	1,496.00	45.00	1,542	13,506	43.34	50.80	10,500.99	1,050.10

*** Electricity cost per kWh is $0.11 by default.**

**** Fuel cost per Therm is $1.05 by default**

***** Since other materials are same, only insulation material make difference. The cost was calculated according to RS Means Residential Cost Data 2011.**

Table 60: Energy analysis results of the scenarios on construction of the addition for House 30.

Scenario No.	Construction Type Options	Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Annual Elec Use (kW)	Annual Fuel Use (Therm)	EUI (kBtu/ft²/year)	Cost of Insulation Material ($)***	Annual Cost ($/ 10 years)
1	R-4(walls),R-1(Slab),R30(Ceiling)	1,311.53	53.59	1,365.13	11,836.95	50.82	38.36	1,048.00	104.80
2	R-6(walls),R-1(Slab),R30(Ceiling)	1,309.33	53.59	1,362.93	11,817.09	50.82	38.37	1,789.36	178.94

* Electricity cost per kWh is $0.11 by default.

** Fuel cost per Therm is $1.05 by default

*** Since other materials are same, only insulation material make difference. The cost was calculated according to RS Means Residential Cost Data 2011.

Table 61: Energy analysis results of HVAC scenarios for House 15

HVAC System Options	Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Annual Elec Use (kW)	Annual Fuel Use (Therm)	Energy Use Intensity (kBtu/ft²/year)	COST ($)
HVAC_RES 17 SEER/9.6 HSPF Split HP <5.5 ton	$1,517.68	$45.71	$1,563.39	13,697.48	43.34	51.22	$3,138.75
HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	$1,321.90	$321.91	$1,643.82	11,930.54	30.52	71.45	$2,250.30
HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	$2,145.54	$266.37	$2,411.91	19,364.04	25.26	91.60	$2,737.15
HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	$2,273.16	$51.42	$2,324.58	20,515.91	48.76	75.10	$4,600.00
MAX VALUE	$2,273.16	$321.91	$2,411.91	20,515.91	48.76	91.60	$4,600.00
MIN VALUE	$1,321.90	$45.71	$1,563.39	11,930.54	25.26	51.22	$2,250.30
MEDIAN	$1,831.61	$158.90	$1,984.20	16,530.76	36.93	73.27	$2,937.95

*** 3 Ton 17.5 Seer Goodman Heat Pump System - DSZC180361 - AVPTC42D14 is listed $2940.26 in amazon.com**
****4 Ton 14 Seer Goodman 80,000 Btu 80% Afue Gas System - GSX130481 - CAPF4860C6 - GME80805CN - TX5N4 is listed 2250.30 in amazon.com**
*****4 Ton 14.5 Seer Bryant Heat Pump System - 213BNA048000 - FX4DNF049T00 is listed $2,737.15 in amazon. com**
*****4 Ton 14.5 Seer Bryant Heat Pump System - 213BNA048000 - FX4DNF049T00 is listed $2,737.15 in amazon. com**

Table 62: Energy analysis results of HVAC scenarios for House 30

HVAC System Options	Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Annual Elec Use (kW)	Annual Fuel Use (Therm)	Energy Use Intensity (kBtu/ft²/year)	COST ($)
HVAC_RES 17 SEER/9.6 HSPF Split HP <5.5 ton*	$1,311.53	$53.59	$1,365.13	11,836.95	50.82	38.36	$3,138.75
HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas**	$1,922.40	$102.49	$2,024.89	17,350.19	97.18	58.14	$2,250.30
HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump***	$1,915.09	$60.29	$1,975.38	17,284.18	57.17	54.58	$2,737.15
HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd****	$1,315.35	$103.86	$1,419.21	11,871.40	98.48	42.48	$4,600.00
MAX VALUE	$1,922.40	$103.86	$2,024.89	17,350.19	98.48	58.14	$4,600.00
MIN VALUE	$1,311.53	$53.59	$1,365.13	11,836.95	50.82	38.36	$2,250.30
MEDIAN	$1,615.22	$81.39	$1,697.29	14,577.79	77.17	48.53	$2,937.95

*** 3 Ton 17.5 Seer Goodman Heat Pump System - DSZC180361 - AVPTC42D14 is listed $2940.26 in amazon.com**
****4 Ton 14 Seer Goodman 80,000 Btu 80% Afue Gas System - GSX130481 - CAPF4860C6 - GME80805CN - TX5N4 is listed 2250.30 in amazon.com**
*****4 Ton 14.5 Seer Bryant Heat Pump System - 213BNA048000 - FX4DNF049T00 is listed $2,737.15 in amazon. Com**
*****4 Ton 14.5 Seer Bryant Heat Pump System - 213BNA048000 - FX4DNF049T00 is listed $2,737.15 in amazon. Co**

Table 63: Energy analysis results of behavioral set points for House 15

Scenario No.	Construction Type Options	Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Annual Elec Use (kW)	Annual Fuel Use (Therm)	Energy Use Intensity (kBtu/ft²/year)
1	BASE CASE (EAST-C ADDITION)	$1,517.68	$45.71	$1,563.39	13,697.48	43.34	51.22
2	Behavioral set points (60-80)	$1,186.93	$42.74	$1,229.67	10,712.33	43.34	40.73
3	Behavioral set points (60-80) & best shading	$1,082.12	$42.74	$1,124.86	9,766.39	43.34	37.49

*** Electricity cost per kWh is $0.11 by default.**
**** Fuel cost per Therm is $1.05 by default.**

Table 64: Energy analysis results of behavioral set points for House 30

Scenario No.	Construction Type Options	Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Annual Elec Use (kW)	Annual Fuel Use (Therm)	Energy Use Intensity (kBtu/ft²/year)
1	BASE CASE (WEST-B ADDITION)	$1,311.53	$53.59	$1,365.13	11,836.95	50.82	38.36
2	Behavioral set points (60-80)	$1,115.15	$53.59	$1,168.75	10,064.56	50.82	33.26
3	Behavioral set points (60-80) & best shading	$1,072.99	$53.59	$1,126.58	9,684.04	50.82	32.16

*** Electricity cost per kWh is $0.11 by default.**
**** Fuel cost per Therm is $1.05 by default.**

7.4.4 Mechanical Systems

HVAC Systems

Results demonstrate that designing mechanical systems properly has a major impact on energy consumption (Table 61 and Table 62). For House 15, the difference between the maximum and minimum EUIs of options can be as high as 52% whereas, for House 30, it is 79%. Therefore, careful designing of the mechanical system is very crucial regarding energy consumption.

Tools used in this study do not allow modeling of multi-zone mini split air conditioning systems. Focus group experts suggested using 1.5 tons for 600 to 800 square foot homes and 2 tons for 800 to 1200 square foot homes. The cost of the most affordable two zone systems is $2,600 in Home Depot.

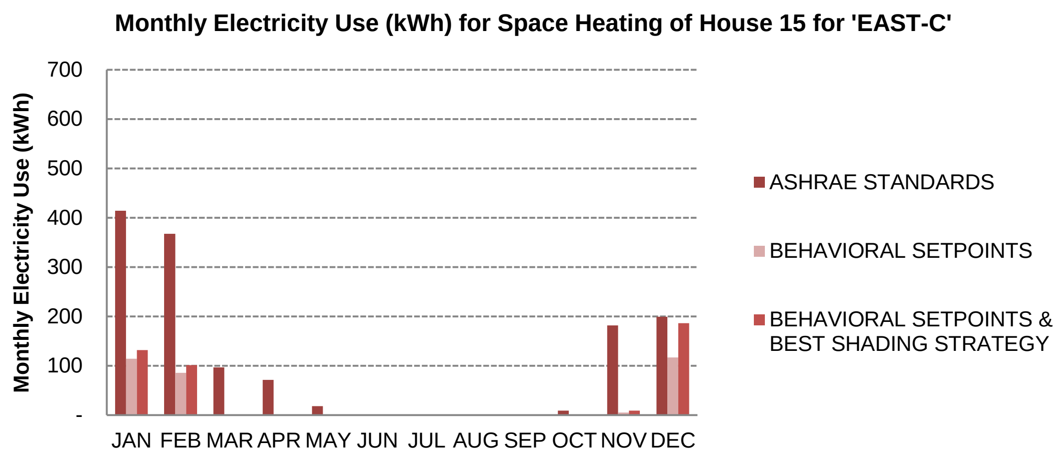
Behavioral Set Points and Other Heating and Cooling Strategies

In this subsection, two scenarios were tested and compared. The difference between ASHRAE standards and behavioral set points for interior dry bulb temperature results in 55.7% savings in electricity consumption for House 15 and 44.2% for House 30. The savings are very significant as illustrated in Table 63 and Table 64.

Results represented in Figure 48 indicate that according to behavioral set points, residents only require running heating system in January, February and December. Their electricity consumption for heating can be reduced by 76.3%. Likewise for the cooling systems, residents can use 47.8% less electricity than ASHRAE standards. May, June, July, August, September and October are the months the residents may need their cooling systems run according to the results below.

If one of the best shading strategies in terms of cost and energy use efficiency (installing shutters on the windows of the whole structure and planting trees on North-East-West) was tested according to the behavioral set points (60˚F for heating and 80˚F for cooling), the residents in House 15 can save 68% in heating loads and 62% in cooling loads when compared to ASHRAE standards base case (Figure 48).

House. 30, on the other hand, has the most significant savings in electricity consumption for heating (Table 60); residents may save 95% electricity for heating if they extend their heating set point to 60˚F. However, their cooling load can only be reduced by 37% if they stretch the cooling set point to 80˚F. In other words, the EUI will be reduced by 13.30% in total (Table 64 and Figure 49).



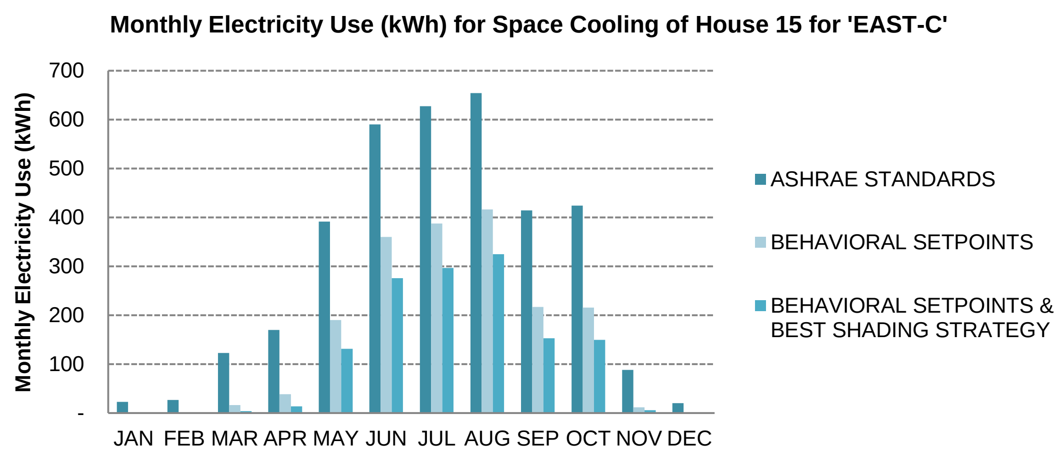


Figure 48: Monthly electricity consumption for space heating (top) and cooling (bottom) for House 15 according to two scenarios: ASHRAE standards (base case) and behavioral set points

If the residents apply one of the best shading strategies discussed above (installing shutters on the windows of the whole structure and planting trees on all facades) together with extending the interior temperature set points, the savings can be as high as 90% for heating and 48.7% for cooling. It means the EUI will be 16.16% less than the base case (Table 64).

To that extent, stretching indoor temperature set points for heating and cooling by leaning to passive design technologies including shading and natural ventilation plays an important role in terms of reducing electricity consumption. By the shading strategies, residents can save in terms of cooling loads which are the major load in Laredo due to its climate conditions.

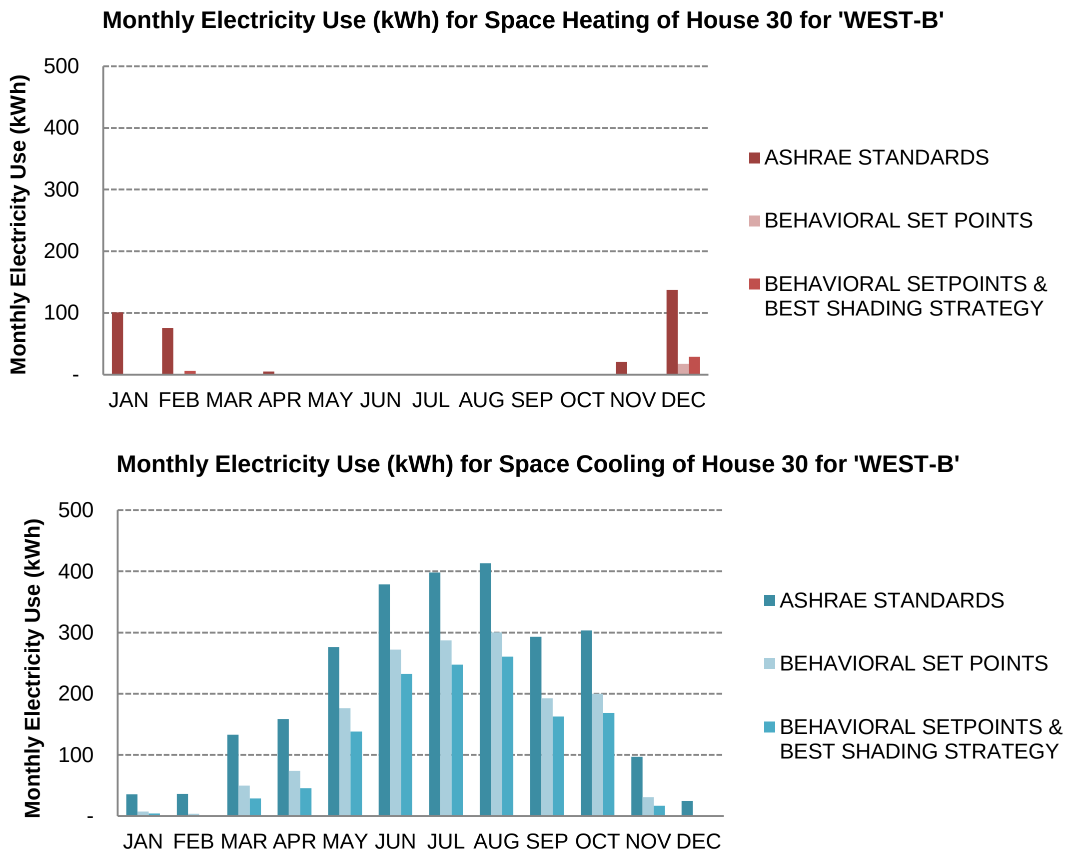


Figure 49: Monthly electricity consumption for space heating and cooling for House 30 according to two scenarios: ASHRAE standards (base case) and behavioral set points

Another strategy can be eliminating HVAC systems completely and utilizing an evaporative cooling system that uses perspiration to cool the space. The basic principle of this system is to use “recovered” or “free energy”(Chengqin, Nianping, and Guangfa 2002). Dry bulb and wet bulb temperatures are crucial for evaporative cooling systems. Wet bulb temperature is the determinant for reducing dry bulb temperature (Breezair 2014). Energy is required for evaporation, which is changing the state of water from liquid to water vapor. This energy is compensated by an adiabatic process. This process works by air which enters the system and gives up heat energy to trigger the vaporization of the water in the system. The system has two fans: one for vacuuming the air inside the system and one for drawing the air outside the system. Evaporative systems are either with ducts or without ducts. In terms of energy use, these alternative systems use 90% less electricity than refrigerated units and 40% less than the conventional evaporative air conditioning systems with ducts (Breezair 2014). In Home Depot, an average system for a 1,600 square foot home costs around $600 to $700[11].

Domestic Hot Water Strategies

If the residents install solar water heater systems, they will save energy in terms of fuel. If House 15 and 30 have 17SEER, 9.6 HSPF Split Heat pump system installed their homes, House 15 will save 43.34 therm used for domestic hot water, whereas House30 will save 50.82 therm (Figure 50 and Figure 51). To that extend, residents in House 15 will save 3% in their total annual energy cost while residents in House 30 will save 4%.

Residential gas water heaters price ranges between $250 and $1,500 in Home Depot.

[11] http://www.homedepot.com/b/Heating-Venting-Cooling-Air-Conditioners-Coolers-Evaporative-Coolers/N-5yc1vZc4lr?Ns=P_Topseller_Sort%7C1

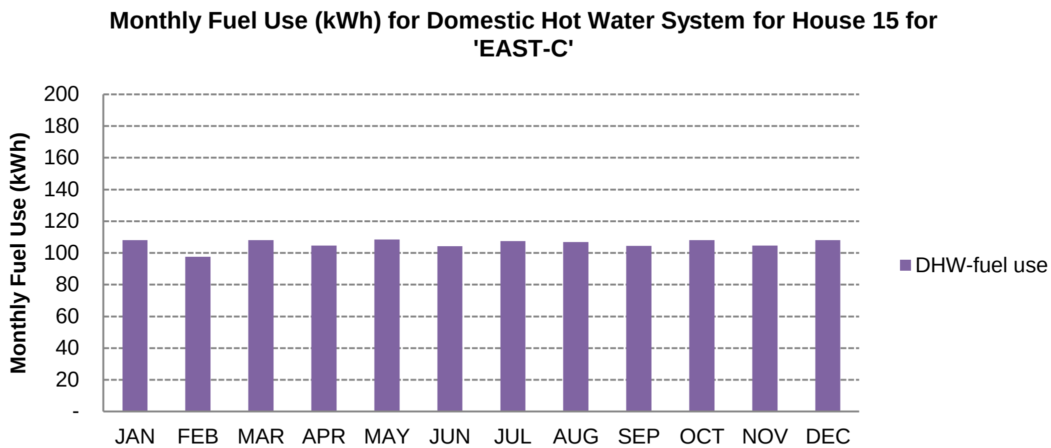


Figure 50: Monthly fuel usage for domestic hot water in House 15 with a conventional heat pump

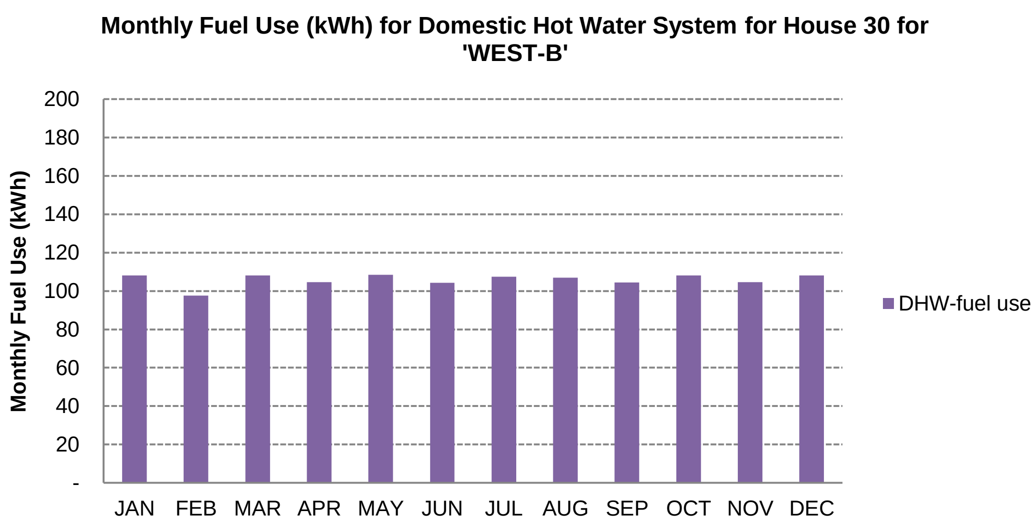


Figure 51: Monthly fuel usage for domestic hot water in House 30 with a conventional heat pump

Rainwater Catchment and Water Reuse

The focus group experts as well as the literature state that rainwater catchment, and wastewater re-use in flushing the toilets are the strategies that can promote sustainability in a while having a low cost (UN-Habitat 2011). Literature suggests several projects on water reuse such as; ceramic water filter which costs $10 to 15 (AFH (Architecture for Humanity) 2006) and earth ships for a community (Earthship Biotecture 2014). In addition to those projects, one expert suggested putting a 5,000 gallon tank on the lot for rain water collection. The price for that tank is $2,476.95 in plastic-mart.com.

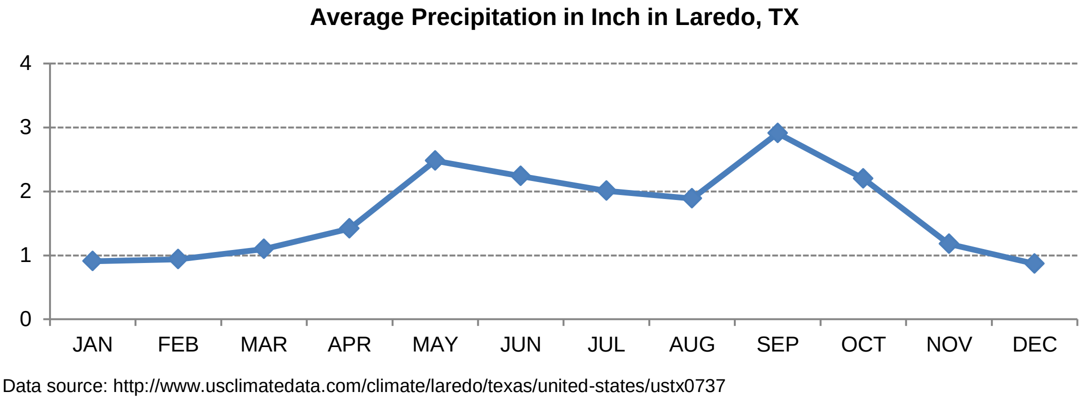


Figure 52: Average precipitation in inch for Laredo, TX (adapted from Your Weather Service 2014)

Residents of House 15 declared that their monthly payment for water is $80 whereas the residents living in House 30 did not respond this question. To that extent, purchasing a water tank may seem not affordable at first glance. However, in the long run, the purchase will pay for itself.

The captured water can be used for evaporative cooling systems and irrigation in Laredo, TX (Figure 52).

7.5 Discussion on the Selected Three Scenarios

By considering the best strategies listed above, three scenarios for both cases were tested. Table 65 and Table 66 demonstrate three selected options for each case and their total energy cost savings and the cost of the strategies. Mechanical systems were found to have the biggest impact on the overall performance of the house. Passive strategies such as installing evaporative cooling systems, solar thermal water heaters, water catchment and reuse systems, and extending the interior dry bulb temperature set points to 60˚F for heating and 80˚F for cooling are the ones that this study suggests.

All of the electricity and fuel costs and the savings were calculated according to the following default prices: $ 0.11 per kWh for electricity and $0.15 per Therm for fuel use. The savings may be more in the future as electricity and fuel prices increase.

7.5.1 Scenario 1

The first scenario tested the following conditions:

(1) Constructing the additions with the highest insulation: Using R-24 for walls and floors and R-30 for the ceiling in the wood framed house (House 15) and using R-6 for walls, R-1 for the floor and R-30 for the ceiling in the concrete block house (House 30).
(2) Installing shutters on the addition only for House15 and on the whole structure for House 30.
(3) Extending the indoor dry bulb temperature between 60 ˚F and 80 ˚F with a residential 17 SEER/9.6 HSPF Split HP <5.5 ton HVAC system

Results show that the annual energy savings for House 15 will be $1,369.77 whereas their annual payments for the combined strategy will be $1,373.97.

For House 30, their annual payment for strategies will be $522.81 whereas their savings will be $1,011.24.

7.5.2 Scenario 2

In this scenario, I have tested if residents keep the construction R-values lower and apply a combination of shading strategies. The rest was kept the same as the first scenario. The results demonstrate that residents in House 15 have annual energy savings 0.25% less than they have in scenario 1. However, their annual payments for the strategies become 38.5% less than the one in scenario 1. To that end, this scenario is better than the previous one for House 15.

House 30, on the other hand, the annual energy savings in scenario 1 is 2.75% less than the one in scenario 2. However, the payment for strategies is 6.53% more in scenario 1 which means scenario 2 is more energy efficient and cost effective.

Table 65: Three of the best selected options of sustainable, low-cost strategies for House 15 showing total energy savings in dollars and the cost of the strategies

HOUSE NO. 15												
	Strategies	Annual Elec Cost ($)**	Annual Fuel Cost ($)***	Annual Energy Cost ($)	Energy Use Intensity (kBtu/ft²/year)	Savings in EUI (kBtu/ft²/year)	Cost of the Strategy	Savings in Annual Energy Cost ($)	Annual Addition Cost of the Strategies	OPTION-1	OPTION-2	OPTION-3
FORM												
worst	WEST-B	$1,930.15	$45.71	$1,975.86	64.01	-	-	-	-			
best	EAST-C	$1,517.68	$45.71	$1,563.39	51.22	12.79		$412.47	-	√	√	
HVAC												
worst	HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	$2,145.54	$266.37	$2,411.91	91.60	-	$2,737.15	-	$273.72			
best	HVAC_RES 17 SEER/9.6 HSPF Split HP <5.5 ton	$1,517.68	$45.71	$1,563.39	51.22	40.38	$3,138.75	$848.52	$313.88	√	√	√
MATERIALS												
worst	R-13(walls and floor),R30(Ceiling)	$1,517.68	$45.71	$1,563.39	51.22	-	$4,554.50		$455.45		√	√
best	R-24(walls and floor),R30(Ceiling)	$1,496.00	$45.00	$1,542.00	50.80	0.42	$10,500.99	$21.39	$1,050.10	√		
SHADING												
worst	No shading	$1,517.68	$45.71	$1,563.39	51.22			-	-			
best individual strategies	Porch on Northeast	$1,499.73	$45.71	$1,545.44	50.67	0.55	$264.50	$17.95	$26.45			
	Overhangs on all façade	$1,481.82	$45.71	$1,527.53	50.12	1.11	$934.15	$35.86	$93.42			
	Trees on the West	$1,503.69	$45.71	$1,549.39	50.79	0.43	$100.00	$13.99	$10.00			√
	Shutters on the addition (2)	$1,430.00	$45.71	$1,476.00	48.50	2.72	$100.00	$87.39	$10.00	√		
	Shutters on the whole structure (9)	$1,418.00	$45.71	$1,464.00	48.20	3.02	$450.00	$99.39	$45.00			
best combination of strategies	Shutters on the windows of the addition / Trees on North-	$1,421.00	$45.71	$1,467.00	48.30	2.92	$400.00	$96.39	$40.00			
	Shutters on the windows of the whole structure / Trees on North-East-West	$1,412.00	$45.71	$1,458.00	48.00	3.22	$750.00	$105.39	$75.00		√	
	Trees on North-East-West / Porches on Northeast and Southwest	$1,402.00	$45.71	$1,447.00	47.60	3.62	$1,532.25	$116.39	$153.23			
	Shutters on the windows of the whole structure / Trees on North-East-West / Overhangs on all facades	$1,402.00	$45.71	$1,448.00	47.60	3.62	$1,684.15	$115.39	$168.42			
BEHAVIORAL SET POINTS AND OTHER COOLING SYSTEMS												
	ASHRAE STANDARDS (RES 17 SEER/9.6 HSPF Split HP <5.5 ton)	$1,517.68	$45.71	$1,563.39	51.22	-	$3,138.75	-$1,563.39	$313.88			
best	Behavioral Set Points	1186.92614	42.7394052	1229.66555	40.73	10.50	$0.00		0	√	√	
	Evaporative Cooling System	$151.77	$0.00	$151.77	-	-	$600.00	$1,411.62	$60.00			√
DHW SYSTEMS												
worst	Heat Pump	$1,517.68	$45.71	$1,563.39	-	-			$0.00	√	√	
best	Solar Thermal Water Heater	$1,517.68	$0.00	$1,517.68	-	-	$250.00	$45.71	$25.00			√
RAIN WATER CATCHMENT AND WATER COLLECTION*												
best for reuse	ceramic filter	-	-	-	-	-	$10-15	-	$1-1.5		√	√
best for catchment	5000 gallon tank	-	-	-	-	-	$2,476.95	-	$247.70		√	√
						TOTAL ANNUAL ENERGY SAVINGS				**$1,369.77**	**$1,366.38**	**$2,319.84**
						TOTAL COST OF THE STRATEGIES				**$1,373.97**	**$844.33**	**$864.33**

* Rain water catchment and water collection strategies are not included in the total calculation. It promotes savings in water cost.

** Electricity cost per kWh is $0.11 by default.

*** Fuel cost per Therm is $1.05 by default.

Table 66: Three of the best selected options of sustainable, low-cost strategies for House 30 showing total energy savings in dollars and the cost of the strategies

HOUSE NO. 30												
Strategies		Annual Elec Cost ($)*	Annual Fuel Cost ($)**	Annual Energy Cost ($)	Energy Use Intensity (kBtu/ft²/year)	Savings in EUI (kBtu/ft²/year)	Cost of the Strategy	Savings in Annual Energy Cost ($)	Annual Addition Cost of the Strategies	OPTION-1	OPTION-2	OPTION-3
FORM												
worst	WEST-A	$1,435.31	$53.59	$1,488.90	41.58	-	-	-	-			
best	WEST-B	$1,311.53	$53.59	$1,365.13	38.36	3.22	-	$123.77	-	√	√	√
HVAC												
worst	HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	$1,922.40	$102.49	$2,024.89	58.14	-	$2,250.30	-	$225.03			
best	HVAC_RES 17 SEER/9.6 HSPF Split HP <5.5 ton	$1,311.53	$53.59	$1,365.13	38.36	19.78	$3,138.75	$659.76	$313.88	√	√	√
MATERIALS												
worst	R-4(walls),R-1(Slab),R30(Ceiling)	$1,311.53	$53.59	$1,365.13	38.36	-	$1,048.00		104.8		√	√
best	R-6(walls),R-1(Slab),R30(Ceiling)	$1,309.33	$53.59	$1,362.93	38.37	-0.01	$1,789.36	$2.20	178.936	√		
SHADING												
worst	No shading	$1,311.53	$53.59	$1,365.13	38.36	-	-	-	-			
best individual strategies	Porch on Northwest	$1,278.73	$53.59	$1,332.32	37.51	13.72	$462.09	$32.80	$46.21			
	Overhangs on all facades	$1,288.56	$53.59	$1,342.15	37.76	13.46	$858.57	$22.97	$85.86			
	Trees on the West	$1,289.00	$53.59	$1,342.59	37.80	13.42	$100.00	$22.53	$10.00			√
	Shutters on the addition (2)	$1,309.00	$53.59	$1,362.00	38.30	12.92	$100.00	$3.13	$10.00			
	Shutters on the whole structure (6)	$1,283.00	$53.59	$1,336.00	37.60	13.62	$300.00	$29.13	$30.00	√		
best combination of strategies	Trees all facades/ overhangs all facades/ porch on northwest and south	$1,259.00	$53.59	$1,313.00	37.00	1.36	$2,167.48	$52.13	$216.75			
	Shutters on the windows of the addition / Trees on all facades	$1,297.00	$53.59	$1,351.00	38.00	0.36	$500.00	$14.13	$50.00			
	Shutters on the windows of the whole structure / Trees on all facades	$1,253.00	$53.59	$1,306.00	36.80	1.56	$700.00	$59.13	$70.00		√	
BEHAVIORAL SET POINTS												
worst	ASHRAE STANDARDS (RES 17 SEER/9.6 HSPF Split HP <5.5 ton)	$1,311.53	$53.59	$1,365.13	38.36							
best	Behavioral Set Points	$1,115.15	$53.59	$1,168.75	33.26	5.10	$0.00	$196.38	$0.00	√	√	
	Evaporative Cooling System	$131.15	$0.00	$131.15	-	-	$600.00	$1,233.97	$60.00			√
DHW SYSTEMS												
worst	Heat Pump	$1,311.53	$53.59	$1,365.13	38.36				$0.00	√	√	
best	Solar Thermal Water Heater	$1,311.53	$0.00	$1,311.53			$250.00	$53.59	$25.00			√
RAIN WATER CATCHMENT AND WATER COLLECTION*												
best for reuse	ceramic filter						$10-15		$1-1.5		√	√
best for catchment	5000 gallon tank						$2,476.95				√	√
* Rain water catchment and water collection strategies are not included in the total calculation. It promotes savings in water cost.						**TOTAL ANNUAL ENERGY SAVINGS**				**$1,011.24**	**$1,039.04**	**$1,969.86**
** Electricity cost per kWh is $0.11 by default.						**TOTAL COST OF THE STRATEGIES**				**$522.81**	**$488.68**	**$513.68**
*** Fuel cost per Therm is $1.05 by default.												

7.5.3 Scenario 3

This scenario is different from Scenario 2 in several ways. For shading, I picked planting trees on the west only for House 15 and 30. Instead of residential 17 SEER/9.6 HSPF Split HP <5.5 ton HVAC system, I have assumed that residents install evaporative cooling system in their homes and solar thermal water heaters instead of heat pumps.

Results indicate that for House 30 this scenario saves 94.8% more in terms of energy cost while costing only 1.75% less than scenario 1. On the other hand, residents of House 15 will save 69.36% more in terms of energy cost while paying 37.09% less when compared to scenario 1. To that extent, Scenario 3 is the best one for both cases.

7.6 Limitations and Generalizability

This study identifies best design strategies for additions to two selected homes from the sample. This study acknowledges the limitation of the results and emphasizes the process to design an addition by utilizing the toolkit, CBT. Two houses were selected to represent the existing typologies in the sample. House15 is a manufactured home built in 1974 with a wood frame self-built addition which was built in 1994. House 30, on the other hand, is a concrete block structure which was built in 1992 in two phases.

As modeling existing homes was based on several assumptions due to lack of data on R-values of the building components, air infiltration value and the type of HVAC system, accuracy of the results is not expected to be high. Selection of best strategies was based on a relative approval method of the results.

This study developed and employed modeling techniques of the suggested sustainable strategies by utilizing Autodesk Revit and GBS. GBS does not recognize some components modeled in Autodesk Revit, such as trees, shutters, and double roof. In order to overcome these challenges, I modeled trees as cross-shaped walls. Window shutters were also modeled as a wood frame wall without insulation. On the other hand, double roof was modeled as a floor on top of the existing roof. GBS was able to read them as shading elements.

Moreover, Autodesk Revit and GBS have a limited number of selections in HVAC systems. To that end, I tested the four available HVAC options in Autodesk Revit and GBS and calculated the changes in using evaporative cooling systems manually. I also changed the interior dry bulb temperature set points for cooling and heating by making adjustments on gbXML file.

7.7 Summary and Conclusions

A limited number of studies focus on identifying problems in colonias housing and propose sustainable solutions for these structures (Ward, Sullivan, et al. 2010; Sullivan and Ward 2012). These studies focus on low-income housing subdivisions in Central Texas which almost always are comprised of manufactured homes. Since my study focuses on self-help housing in Laredo, Texas, there is a gap in the literature on these homes.

This section contributes a design kit, Colonias BIM Toolkit (CBT) for best practices which enable modeling different design strategies such as 231 square feet addition to two existing homes in Laredo, Texas. This contribution was built on the previous contribution of developing CBT.

Findings demonstrate that orientation and location of the addition together with careful design of shading and mechanical systems are the main factors to reduce energy consumption. Trees, covered porch and exterior shutters on the windows were found to be the best low-cost, sustainable strategies for shading. Findings indicate that reducing the use of HVAC systems has a major impact on energy use. Extending the indoor temperature set points from ASHRAE standards, or replacing the use of HVAC systems with natural ventilation or evaporative cooling systems are suggested in this study to minimize energy consumption in the modeled homes. Furthermore, utilizing solar hot water systems instead of using fuel or electricity fired systems were also found to reduce the energy consumption.

This approach can be applicable to other colonias and informal settlements around the world.

8 SUMMARY AND CONCLUSIONS

This section summarizes the methods, limitations and results for each contribution and closes with the recommendations for further research based on this study. This study has four outcomes that lead to unique contributions to the body of knowledge and practice:

- Documentation of the existing design patterns and construction techniques of the 30 selected homes in colonias in Laredo, Texas, as a report and as BIM representations,
- Guidelines for cost effective, energy efficient design methods for low cost, self-help homes in the colonias based on expert opinions,
- A process – also applicable to other informal settlements – to create BIM models to document existing homes and apply simulations to predict energy consumption of each house and community,
- A process to design cost effective and energy efficient additions to self-help homes in the colonias.

The knowledge derived from this study is intended to influence public design and improvement strategies and policies for the colonias and other informal settlements.

8.1 Documentation of Existing Residential Architecture in Three Colonias in Laredo, Texas

8.1.1 Contribution and Significance

My contribution is to clarify and define existing architectural patterns of self-help homes through an investigation of 30 self-help homes in three colonias in Laredo, Texas. By investigating three colonias, this investigation highlights differences attributable to different communities while revealing commonalities that can support broader generalization of the results. For instance, while Green Colonia is located inside the municipal jurisdictions, Red I and Red II are two adjacent colonias located outside the city jurisdictions and have a lower density of residential development than Green Colonia.

Section 4 described the survey materials for obtaining data, which are comprised of face-to-face interviews and on-site home field inspection instruments. Data collected through interviews includes five domains: house acquisition and ownership, house massing and construction, infrastructure and services, community, and resident demographics. On-site home inspections were conducted by taking measurements and sketches, inspection of the house form and construction materials, and photographic documentation. To visualize the survey data in community scale, aerial imagery and GIS were utilized.

Results of this study provide an understanding of (a) the history and narrative of the homes, (b) the typology of homes, the quality of structures in the colonias, and the problems in these structures, and (c) the availability of the infrastructure, services, and resources. Evidence is summarized in the next section. Analysis of the results indicates a strong relationship between being located in or outside the municipal jurisdictions, and year of availability of infrastructure and basic services. However, findings show a weak correlation between the location of the colonias and the construction methods and form of the homes. Data demonstrates two major types of self-help homes across three colonias: (1) wood frame structures on either pier and beam or concrete slab, and (2) concrete block structures on a concrete slab. Almost all of the houses in the sample were built incrementally due to money availability and the changing needs of the residents, no matter where the houses were located. Age of the structures had a positive correlation with the construction quality of the house in general. Residents reported that the monthly cost of electricity fluctuates between $50 and $130 across homes. To that end, it is important to investigate and provide sustainable, low-cost design methods and construction techniques to the residents in order to lower their electricity bills.

Documentation of existing architecture in colonias may enable policy makers (a) to identify the problems in construction of the houses across three colonias, (b) to assess the quality of the structures across three colonias, and (c) to offer design improvements by considering the existing architectural patterns adopted by the residents across three colonias. My method for collecting data and documenting houses can be used to assess a community rapidly and could potentially lead to aggregated data that guides the development of better policy.

My approach to document existing self-help housing practices is applicable to other self-help homes in the colonias and also informal settlements around the world.

This contribution is a foundation for further work in my study. Findings from this part of the study have fed the process of creating BIM models of the houses in the sample. Results on acquisition and ownership, form and construction, resident demographics, and current practices helped me to comprehend cultural attitudes common in the colonias to guide recommendations for improvements in the houses. This portion of the study strengthens conclusions regarding the acceptability of the best strategies on energy efficicent, low-cost residential design for these structures that were further elaborated in other parts of my study.

8.1.2 Evidence

The study confirmed that in the three colonias the strategy to own land and a house is similar independent of when the residents first come to the colonias. Most residents (83.3%) acquired the land from previous owner and 83.3% stated that they had financed it by making payments to the seller over several years. Ownership through mortgages with banks (3%) and savings or cash (7%) play a minor role in housing finance. Residents in Green Colonia reported having paid a little bit more money for their lots than the ones in Red I and Red II. Residents in Green Colonia reported acquiring the lot earlier than the residents in Red I and Red II. Results demonstrate that residents arrived and settled in the colonias from 1970 to 2012.

The findings of this study indicate that there is no consistent relationship between the characteristics of the colonias and the house form and construction types; however, they demonstrate a similar pattern:

(1) Three *types of structures* were observed as mentioned in the literature: (1) Self-built homes, (2) manufactured/mobile homes, and (3) recreational vehicles (RVs), campers or buses. In this study, self-built homes were oversampled. Therefore, the sample includes a mixture of these generic types: self-built houses (70%), mixture of self-built and manufactured homes (20%) and self-built homes adjacent to a camper, bus or RV (10%).

(2) Residents in the colonias build their houses by themselves in stages over long periods of time. Results indicate that residents of the selected homes have built their homes in one (43.3%) to four stages (3.3%). Some of the residents came to the lot with temporary structures such as an RV, camper or school bus. First, they built a small permanent structure and then they expanded it by adding attached or detached additions. In this sample, 30% of the homes were identified as manufactured housing units or RVs enlarged with an attached or detached self-built structure.

(3) One of the main differences between three colonias observed in this study is that the ratio of self-help housing units in Red I and Red II is higher than Green Colonia. In Green Colonia, there are several hybrid dwelling units comprised of self-built structures and either manufactured housing units or campers. Residents perform improvements for their housing units incrementally as illustrated by Reimers-Arias (2009). 56.7% of the units were built in more than two stages. The most common reason for extending or making additions to the primary unit is the need for additional living and bedroom space.

(4) This study reveals a documentation on interior spatial configuration through interviews with residents although the interior space has not been investigated. Number of bedrooms fluctuates from 1 to 7 in Green Coloniawhereas in Red I and Red II, it ranges from 1 to 5. Only 13% of the homes have a half bathroom whereas most of the homes have one (46%) or two bathrooms (46%). Although 70% of residents declared one living room and 20% have two, 20% have none.

(5) The smallest home is a 350 square foot structure located in Red I whereas the largest one is a 2,896 square foot house located in Red II.

(6) Between three selected colonias, type of houses and construction techniques are found to be similar. The only difference is the lot size; residents in Red I and II have larger lots than the ones in Green Colonia. In terms of the construction materials, 30 homes are constructed with either concrete slab (50%) or pier and beam structures (13%) or both (37%). The most preferred floor finish materials are ceramic tile (64%) and wood (27%). Respondents stated that they had built their houses with concrete blocks (57%) with a stucco cover and wood frame walls with wood siding (63%). Gable roofs (77%) or hip roofs (33%) with asphalt shingles (90%) are the common roof types observed in these homes. Almost all of the structures have single glazed-double hung aluminum windows. Wood (80%) and aluminum (20%) are the most preferred materials for doors.

(7) Although the majority of the houses were built with poor construction methods and materials, there still are a few with proper construction. These houses either belong to a construction worker or have been upgraded by Habitat for Humanity or other non-profit organizations. To that extent, the general construction quality can be improved through education or field agent consultations.

When looking at the dynamics between infrastructure and services, and the characteristics of the colonias, location of colonias has an impact on the accessibility to infrastructures and services:

(1) There appears to be a minor difference between three selected colonias in terms of the year for availability of the on-site services. However, since Green Colonia is located within municipal jurisdictions, residents had access to water and electricity starting from 1970. Residents in Red I and Red II, on the other hand, recently were provided access to these services. Results indicate that 73% of residents in Green Colonia and 80% of households in Red I and Red II had electricity service on their lot when they initially arrived.

(2) Although there are multiple options available for power sources, water heater systems, and air cooling systems in colonias, electricity only (30%), and electricity and main gas together (40%) are most commonly used in the selected houses.

(3) Only 40% of the households in Green Colonia and 6.7% of the households in Red I and Red II had water supply when they initially arrived at the colonias.

(4) Only one house does not have a water heater. Respondents report that they use gas water heaters (46.6%) and electric water heaters (50%) in their homes.

(5) Central air cooling systems (53%) and partial air cooling systems (36%) are the most common. However, the improper installation of window air conditioning units and poor maintenance of the central air conditioning systems were observed. The average electricity bill among 26 respondents is 145.89$/mo which is very high. Monthly electricity payments range from $50 to $300 across homes and water usage payments are from $21 to $80 across homes.

This study confirmed that Green Colonia, a community located within the City of Laredo jurisdiction, is closer to the amenities than Red I and Red II which are neighboring communities settled 6 miles away from Green Colonia and are outside the city limits. Residents from the three colonias drive to access these amenities.

Another outcome of this investigation was the footprint of the houses and measurements of the components from outside besides the photographs.

To that end, three selected colonias share similar characteristics in terms of household composition, housing construction and materials, infrastructure and services availability, and background data. However, they show many differences in community characteristics as well as time when they first had access to services.

8.1.3 Originality

Review of the literature on related studies on documentation of colonias housing establishes that there is a lack of information on the construction and design patterns of the houses in the colonias. In that sense, this study is an original contribution to the body of knowledge. Reimers-Arias (2009) has investigated the housing diversity and the process of consolidation of the colonias houses in South Texas by focusing on changes in house form with regard to changes in household. He has performed interviews with residents in ten selected colonias on house form and household characteristics and has found that colonias share similar patterns of change over time. Therefore, Reimers-Arias's study does not cover the construction materials and design of individual homes. He has investigated only four houses by getting measurements and construction details. On the other hand, Ward, Olmeda, Rojas and Sullivan (2010) has investigated housing conditions in two informal homestead subdivisions in Central Texas. These two subdivisions are comprised of mostly manufactured homes, not self-help ones. To that end, my study is original as it addresses a gap in the literature on residential architectural patterns of self-help houses in the colonias.

In this study, I used improved survey instruments including interview and on-site inspection materials, which were previously tested in other studies (Keall et al. 2010; Meng and Hall 2006; Reimers-Arias 2009; Ward, Olmedo, et al. 2010) and adjusted for the colonias residents in Laredo, Texas. It supports the originality of the results of this study.

Utilizing three data sources enabled me to triangulate some of the data. I have used them as a primary source to make other contributions. Therefore, data obtained by these methods is stronger than the ones collected from the literature, or by using a single method. Moreover, it is more detailed than the existing data available in the literature.

8.1.4 Limitations, Validity and Reliability

This study focuses on self-help structures in the colonias. To that extent, self-help housing was oversampled. In other words, the sample of 30 homes includes only self-help homes and a combination of self-help homes with manufactured homes or RVs and campers. The structures which do not have any part built by its residents are less in number than self-help homes: 10.5% in Green Colonia, 37% in Red I and 23% in RedII. Therefore, the findings of the interviews and home inspections may provide explanations to the cases of other self-help houses in three colonias.

Sample of homes were selected from three colonias in Laredo, Texas and the data presented under coded names of these colonias: Green Colonia, Red I and Red II. As climate is one of the major factors impacting the construction of houses in the colonias, the results can be generalizable for the colonias located in similar climatic conditions. According to U.S. Climate divisions map, Laredo, Webb County is located within Texas Climate Division 9 (US Department of Commerce 2014a). Starr, Zapata, Jim Hogg, Brooks, Kennedy, Jim Wells, Duval, Live Oak, McMullen, La Salle, Dimmit, Maverick, Zavala, Frio and Atascosa are the other counties listed within the same division, and the results may be generalizable for self-help homes located in the colonias in these counties. However, they may not be generalizable to the other colonias in the U.S located in different climate divisions. Low generalizability of the results to other colonias is one of the limitations of this documentation. Generalizing the results beyond the colonias to other informal settlements could be future research.

The study lacks data on interior configuration of the homes because I did not have permission to inspect the interiors of the homes. To overcome this limitation, during the interviews, residents were asked to identify the number of rooms and their functions. The data on construction materials is limited to the observations from exterior of the structures which result in a lack of data on insulation materials and construction material layers in the building components.

The interview questions and home inspection surveys were derived from similar studies that have been performed in colonias and informal settlements (Keall et al. 2010; Meng and Hall 2006; Reimers-Arias 2009; Ward, Olmedo, et al. 2010). This study uses data from both on-site home inspections and face-to-face-interviews with residents with the questions that have been already tested by other researchers. It proves that the instruments and operations represent the object of the study and measure the housing conditions and quality of construction (Groat and Wang 2002). To that extent, this part of my study has an internal validity.

I do not claim that the results of this part are externally valid. There are several reasons behind it: (1) sample size is limited to 30 homes which is very small, (2) samples were selected from only three colonias in Laredo, Texas which makes the results not applicable to other colonias in the U.S., and (3) self-help structures were oversampled which provide findings on self-help homes, not another type of structures. However, it is clearly stated that this study focuses on 30 homes selected from three colonias and the results were generalizable to the other colonias self-help houses located in the same climate division with Laredo.

The findings, however, are reliable. If a researcher applies the same instruments on a set of self-help homes, the results should be the similar.

8.2 Documentation of Guidelines for Cost Effective Energy Efficient Design Methods

8.2.1 Contribution and Significance

The research has contributed guidelines and rules for sustainable residential design and construction appropriate to the region and social context of the colonias in Laredo, Texas. A focus group with six experts was conducted with open-ended questions. Each expert has a different background and is focused on different aspects of sustainability. All of the participants have expertise in affordable, residential design in Texas.

Section 5 described the focus group discussion and its three domains: Climatic Determinant Domain, Building Design/Passive Design Domain, and Mechanical Systems-Sustainable Technologies and Techniques Domain. The discussion was video and audio recorded and transcribed. The findings were corroborated by reviewing the literature. I used the results of the focus group as a primary source for the next phase: BIM technology implementation to improve housing quality in the colonias.

Results of this study provide an understanding on (1) how to guide residents to build more sustainable structures by considering the cost, and (2) how to reduce the increasing energy usage of the houses in the colonias. Evidence is summarized in the next section.

The focus group suggests that a simple rectangular one story structure with a gabled or hipped roof and reduced window aperture on South, East and West is a good solution in terms of energy efficiency and affordability. Advanced framing is suggested as the best practice if it is a wood frame structure. Concrete block structure was also proposed as it has a high thermal mass and is aligned with attitudes of residents about construction. There was a consensus that a careful design of mechanical systems has a major impact on energy consumption. The experts suggested reducing or eliminating the HVAC use through careful passive design strategies, such as natural ventilation, careful orientation, and low-cost shading of windows. Other low-cost, energy efficicent cooling systems such as ERVs, mini split air conditioning systems, and evaporative cooling systems by substituting conventional HVAC systems may also be appropriate. Several other sustainable strategies such as water reclamation and reuse, cost effective lighting and plumbing strategies were also revealed during focus group as good strategies for colonias residents in Laredo.

All respondents agreed that the reason for these challenges in self-help housing in colonias is due to residents' lack of knowledge in construction and sustainability which brings up the need for education and training.

The outcome of this study could be useful for policy makers to set up regulations on improving colonias houses in Laredo, Texas and other colonias located in similar climates. Moreover, these strategies can be used by help centers when advising residents during construction. A similar focus group can be utilized to collect data for other informal settlements to identify the guidelines for low-cost energy efficient best practices and to provide expert consultation to residents.

This contribution serves as a basis to create another contribution: a toolkit to model homes in the colonias, to predict the energy consumption of individual homes and the community, and design additions to existing homes.

8.2.2 Evidence

The focus group was conducted in one day via a face-to-face meeting in College Station. First, challenges related to current housing practices were discussed. Evidence to support the conclusions is derived from the transcripts of video and audio recordings. The discussion confirmed that:

(1) The biggest challenge in colonias regarding housing is the wrong choice of materials and improper installation.

(2) Another significant challenge is the lack of knowledge of residents in construction and the notion of sustainability as it was confirmed by Ward, Sullivan, and others (2010).

(3) The third one is the cultural mind-set of the residents which play a major role in the selection of materials, form of structures, and the desire for installing air conditioner.

Table 67: Summary of the suggested low-cost and sustainable design and construction techniques and technologies

HOUSING ENVELOPE AND MATERIALS

FOUNDATION		FLOOR FINISH		ROOF			ATTIC
Types	Insulation	Materials	Insulation (Sub-flooring)	Type	Materials	Sustainable	Insulation
Concrete Slab	*No Insulation*	Stained Concrete	*No Insulation*	Gable Roof Hipped Roof	Metal Licence Plate Roofs	Water reclaim-Gutters	cellulose foil
Pier and Beams	Fiberglass Cellulose Recycled paper Open cell Spray foam	Wood Tile	fiber glass batt insulation Open cell Spray Foam		Shingles		

FRAMING		WALL			DOORS	WINDOWS	PAINT
Materials	Type	Materials	Exterior Cladding	Insulation	Type-Material	Type-Material	Type
		Concrete Blocks		Cellulose Batts	Single Metal Doors w/o glazing	Vinyl-Double Pane	Zero VOC No Paint
Wood	Advanced Framing	Wood	Hardy Plank Wood Siding Brick	Recycled Paper Tight Houses			

MECHANICAL SYSTEMS - SUSTAINABLE TECHNOLOGIES & TECHNIQUES

HEATING AND COOLING SYSTEMS	WATER HEATERS	LIGHTING	APPLIANCES	PLUMBING
ERV or house dehumidifier Heat Pump central air systems Multi speed Air Conditioners/Mini Splits	heat pump for hot water heaters manifold hot water design	Can Lights Cost Effective CFLs Solar Tubes (daylighting)	energy star	low flow fixtures

BUILDING DESIGN / PASSIVE DESIGN STRATEGIES

HOUSING SHAPE				HOUSING FENESTRATION / APERTURE			
Form	No. of Storey	Roof Shape	Relationship with the ground	Strategies for Placing Windows and Doors		Controlling solar gain	Ventilation-air infiltration
simple rectangle	Single	Gable	elevating the building with pier and beam structure	using least amount of windows	Small on South, East and West	shutters	Cross Ventilation
		Hipped	slab connected to the ground	choosing the size of the windows depending on the orientation	Solar Tubes	overhangs	Chimney Stack Effect
				alternative strategies and techniques for daylighting		baffles	Elevated Floor Ventilation
						covered porch	Fans-Ventilators : window box fan, pasive attic

Table 67 provides a summary of the proposed low-cost and sustainable design and construction techniques and technologies for colonias houses. During the course of this study, below are the confirmed strategies for colonias residents in Laredo, Texas:

(1) During the discussion, almost all of the participants suggested a simple single storey rectangle structure with either a gable or hipped roof. Some participants asserted that elevating the building with pier and beam structure is more cost effective and energy efficient than slab which is connected to the ground.

(2) The consensus on fenestrations was to use the least amount of windows with careful consideration on the orientation such as having smaller windows on South, East and West. Solar tubes were also brought to the table as an alternative strategy and technique for daylighting.

(3) In order to control solar heat gain, findings reveal that installing shutters, extending roof overhangs or constructing a covered porch on South, West and East facades would be helpful to reduce energy consumption.

(4) Participants stated that if residents prefer concrete slab as the foundation type, they do not need to insulate it in Texas. Regarding the floor finish, one participant supported the idea of staining the concrete. However, if pier and beams were selected as the foundation, insulation materials such as fiberglass, cellulose, recycled paper and open cell spray foam were suggested to be a better fit. Wood or tile is the recommended floor finish materials.

(5) If residents prefer to build a wood frame structure, all participants claimed that advanced framing is better than conventional framing. Participants suggested residents install Hardy plank, brick or wood siding when they build a wood frame structure. On the other hand, in order to acquire a structure with higher thermal mass, they agreed that concrete block structure with stucco cover is a better strategy. Cellulose, batts, and recycled paper are the insulation materials suggested during the focus group.

(6) Gabled roof is the most preferred roof type by four experts as it has the potential to work as a solar roof. Two participants suggested designing hipped roofs with higher pitches to make it more wind resistant. Consequently, there was a consensus on having larger overhangs on the south facade to reduce heat.

(7) Although metal roof is not a cost effective material for these residents, two participants suggested metal roof was, in fact, a sustainable option. One participant brought up the idea of using recycled license plates as roof material which is a cost effective alternative. Others stated that they preferred shingles.

(8) Almost all participants emphasized the importance of adding insulation in the attic. Cellulose, recycled cloth and foil were recommended. However, if the residents were to prefer using recycled cloth, they should make it fire resistant by exposing the cloth to boric acid.

(9) To avoid any air leakage through attic, almost all participants asserted that residents should not make any holes on the ceiling. Therefore, recess lighting is not suggested.

(10) As a better alternative to recess lighting, the experts suggested can lights, cost effective CFLS and solar tubes.

(11) As a sustainable strategy, water reclaimation was suggested by all participants.

(12) A single metal door with and without glazing was the type of door that was brought up by experts. If the residents prefer to have glazing on the exterior door, then experts suggested going with a smaller one.

(13) In terms of windows, double vinyl was recommended.

(14) ERVs, house dehumidifiers, heat pumps and mini split air conditioning systems were highly suggested as better alternatives to conventional central air conditioning systems.

(15) Energy Star appliances were suggested by experts.

(16) For plumbing, the best strategy was stated as low flow fixtures.

8.2.3 Originality

Literature on low-cost,energy effective strategies for existing low-income houses focuses on houses for middle-income and high-income residents, rehabilitation of existing houses for low-income settlements, and infrastructure systems of informal settlements. UN-Habitat (2011) states that there are several proven passive, low-cost and low-energy strategies and techniques, but they are required to be adjusted according to the climate and human comfort requirements. The presented study is original by proposing strategies tailored for colonias residents in Laredo, Texas. It incorporates evolving technologies and innovations in design and construction, thus differing from older studies. The results are in alignment with common recommendations for energy efficient, affordable design.

Questions for the focus group were derived from the literature (Ward, Sullivan, et al. 2010; Choguill 2007; Global Green USA 2007; Waters 2003; Thomas and LLP 2006) and adjusted to colonias houses in Laredo, Texas considering the climate conditions.

8.2.4 Limitations, Validity and Reliability

This contribution has limited generalizability. Six experts have participated in the focus group discussion. The low number of participants reduces the level of external validity of the findings, as other experts might have made different suggestions. In addition to that, the nature of focus group study creates a subjectivity. These limitations make the reliability of the results questionable. However, from the fact that each participant was selected with different backgrounds increases the level of reliability of the focus group results. Each expert has a different background in terms of the organizations and companies at which they work, whether they are a non-profit or for-profit organization and the target client for their work. Moreover, their understanding of the concept of sustainability and affordability show variations which enrich the results.

The focus group discussion explicitly considered design for colonias residents in Laredo. Therefore, the findings should be narrowly interpreted. However, one of the major considerations of participants is the housing types observed in the colonias and the climate. Thus, the findings from focus group can be stated as externally valid in the colonias having the same hot and dry climate as Laredo.

The findings of this part of my study are internally valid as the focus group instruments were derived from the literature. The questions address three domains: (1) Climatic Determinant Domain, (2) Building Design/Passive Design Domain and (3) Mechanical Systems-Sustainable Technologies and Techniques Domain (Ward, Sullivan, et al. 2010; Choguill 2007; Global Green USA 2007; Waters 2003; Thomas and LLP 2006). The results were also corroborated with the literature.

8.3 A Design Kit for the Colonias, Colonias BIM Toolkit (CBT), to Create BIM Models of Colonias Homes and to Predict Their Energy Consumption

8.3.1 Contribution and Significance

The research contributed a design kit for the colonias, Colonias BIM Toolkit (CBT) that supports rapid modeling and simulation of existing homes and design of possible additions to the homes. This contribution was built upon (a) the findings of on-site data collection of 30 different homes in Green Colonia, Red I and Red II (Section 4) and (b) the findings of focus group discussion on best energy efficient, low-cost strategies (Section 5). Section 6 described (a) a new procedure for creating BIM models of colonias homes that led to analyses on cost and energy use, and (b) an example of a CBT design kit created for the selected 30 homes. Section 7, on the other hand, discussed (a) process for designing low-cost energy efficient residential home additions to existing colonias homes, and (b) an example of a CBT design kit for best practices suggested by experts.

Rapid Modeling and Simulation of Existing Homes

Although BIM technology is widely used for design and modeling of formal structures, creating BIM models of informal houses is a new application. Having a model that includes extensive building information enables users to calculate the cost of the construction, conduct building performance analyses, or conduct life cycle analysis. I have utilized Autodesk Revit 2014 to develop CBT and create BIM models, and Autodesk GBS web based open analysis tool which runs DOE-2 in the background as a building performance analysis tool. BIM models were exported as gbXML files through space export category in Autodesk Revit. gbXML files were uploaded to GBS to run the analysis.

CBT is a Revit template file which encompasses colonias building components library. The library includes material definitions, wall types, roof types, floor types, window types, door types, trees, views and sheets. BIM models of each house were created with conceptual mass objects. Dividing the homes into spaces according to the incremental construction process enabled me to specify different parameters for each space. To illustrate, if a house was built in three phases, the recently built one and the one built before 1970 have different construction standards and infiltration values. To that end, I was able to assign different construction systems and infiltration values to the different portions of the house.

Challenge in modeling existing informal structures is that the construction is not standardized, and some details are unknown. My goal in Section 6 was to develop a BIM-based process to estimate the energy consumption of colonias homes from the data that a researcher would be able to collect through face-to-face interviews and on-site home inspections from outside the houses. Other data, such as R-values of the building components, air infiltration values and HVAC systems are unknown. My strategy is to determine the probability of building performance given a range of values for unknown data. I have developed 20 scenarios for each house to compensate for the unknown data.

Results may provide an understanding on (1) the benefits of a unique BIM-library including the construction materials of the colonias houses on quick modeling of the community, and (2) on the energy consumption of each house, and communities across three colonias,

CBT could be beneficial for federal or local programs that provide assistance to colonias residents to improve construction or modification of homes and to reduce their energy consumption. The toolkit may enable stakeholders to rapidly model houses in the three communities that were included in this study. These projected and estimated numbers for energy consumption may be beneficial for policy implications. Data from utility companies could be used to further calibrate the model of houses and the communities to enable more accurate forecasting of energy consumption. BIM representation of the homes may allow Housing and Urban Development (HUD) or Texas Department of Housing and Community Affairs (TDHCA) to monitor the existing energy use and the change in energy use after the additions or improvements to the house, and to monitor the cost of the additions or improvements to homes. Having the 3–dimensional models of their homes could be beneficial for residents to participate in the decision-making process of designing upgrading implementations.

Design of Additions to the Homes

Section 7 proposed a new process of modeling and simulating sustainable low-cost strategies by utilizing BIM technology. The design process using CBT was developed according to the focus group suggestions to incoprate best practices.

I proposed a new process of modeling and simulating energy efficient, low-cost strategies by utilizing BIM technology. The investigation was based on two test cases selected from the sample of 30 different homes located in the three selected colonias: (1) House 15, a manufactured home and wood frame pier on beams self-help addition, and (2) House 30, concrete block structure on a concrete slab built in two stages. The addition was proscribed to be a one bedroom and one bathroom structure. The square footage of the addition was determined to be 231 by referring to International Residential Code (IRC), Americans with Disabilities Act requirements for Accessible Design (ADA), Habitat for Humanity affiliates designs, focus group discussion, and existing residential architectural pattern in the sample. The proposed strategies on location and orientation, shading, construction materials, and mechanical systems were not only tested on the one bedroom and one bathroom addition (231 square feet) but also on the existing structure itself as well. The outcomes are the cost and energy savings of the suggested strategies.

This research also provides an understanding of (1) capabilities and modeling techniques of Autodesk Revit BIM tool and GBS simulation tool in modeling and simulating the strategies of low-cost sustainable design suggestions, and (2) capabilities and limitations of existing BIM library of components to model colonias houses.

This study enables regional and local governments, and policy makers to advise residents on low-cost strategies such as (a) planting trees, installing exterior shutters, constructing covered porches, (b) reducing reliance on the use of HVAC systems by using passive design strategies, ventilation, evaporative cooling strategies, solar hot water heaters, and (c) encouraging use of water catchment and reuse strategies. It demonstrates a method that could be applied to other colonias or informal settlements.

This dissertation foresees a model of delivering expert opinions and ideas on design to residents by field agents in local help centers to provide assistance in house improvements and new construction. A BIM toolkit enables field agents to rapidly model a home in the colonias for purposes of community analysis and design of additions. It may also allow field agents to estimate energy use and cost of the structure, and to guide residents on designing additions to their homes and improvements to the existing structure. Although this investigation has not explored the issue of how to train a field agent, the informal assessment is that a field agent would require little training beyond an architectural education.

The approach may be applicable to other colonias and also informal settlements after a similar data collection process.

8.3.2 Evidence

Rapid Modeling and Simulation of Existing Homes

By utilizing the CBT developed according to the data collected from 30 different homes, I was able to model the houses in 90 hours. In that sense, a community with 120 homes can be modeled within 25 to 30 days by one user which is very efficient and quick.

After the performance simulation, the CBT was able to generate results as shown below which would prove that the process would enable users to extract valuable information during the design and construction phases of building improvement.

The potential EUI of each house was calculated to be in a range from 40 to 60 (kBtu/ft²/year) according to 20 scenarios. The relationship between age of the structure and its energy use was found to be strong. The impact of increasing R-values on energy use was found to be significant in wood frame structures, and not to be very significant in concrete block ones. Moreover, aggregated annual electricity usage of each colonias were estimated: 3,500,000 (kWh) for Green Colonia, 1,800,000 for Red I and 2,000,000 (kWh) for Red II.

The contribution on energy use unfolds two scales: (1) housing scale, and (2) community scale. In term of individual housing scale, my research contributes that:

(1) Regarding the findings on 20 scenarios for each house, House 6 (between 42 to 138 kBtu/ft²/year), 10 (between 46 to 138 kBtu/ft²/year), 12 (EUI between 45 and 167 kBtu/ft²/year) and 15 (between 48 and 128 kBtu/ft²/year) potentially have the highest EUIs. This confirms the negative impact of age of the structure on its construction quality and energy consumption level.
(2) The range for minimum total annual EUI values changes between 36 and 47 kBtu/ft²/year. The minimum and maximum values are around 60 to 166 kBtu/ft²/year.
(3) Findings indicate that the difference between two R-values scenarios (A and B or B and C) is very low in concrete block structures whereas it is higher in wood frame structures.
(4) Since houses 5, 13 and 16 were reported not to have an AC system, their EUIs are the lowest.
(5) Results demonstrate that having an adjacent manufactured home or a self-help structure both of which were constructed over 30 years ago, have a strong negative impact on the

energy usage. However, utilizing low-cost strategies such as shading, helps to take control of energy consumption as it was observed in House1. House1 has a very large covered porch on west and north facades.

(6) Results indicate that having EUIs between 40 and 60 (kBtu/ft²/year) is very likely for each home, according to the distribution of 600 runs which include 20 runs for each 30 homes.

(7) Data shows that the maximum value of aggregated total energy cost can be $84,078 kBtu/ft²/year if each house has (a) the worst R-values which are A, no insulation, and B, moderate insulation depending on the age of the structure, (b) worst infiltration values by referring to the LBNL database, and (c) Residential 14 SEER/8.3 HSPF Split/Packaged HVAC system. However, data indicates that the minimum value of aggregated total energy cost could be $39,522 if each house were built with Option 2; (a) having moderate or high insulation and R-values, (b) having the lowest infiltration value 0.17 ACH, and (c) Residential 17 SEER/9.6 HSPF Split HP<5.5 ton HVAC system.

(8) Findings indicate a strong association between age of the structure and the energy consumption.

Regarding the community scale:

(1) Green Colonia has 126 occupied lots, and their aggregated total annual EUI is around 9,000 (kBtu/ft²/year). Red I with 80 occupied lots has an estimated EUI of 5,000 (kBtu/ft²/year), whereas the total annual EUI of Red II community is 5,500 (kBtu/ft²/year).

(2) The aggregated total annual electricity usage of Green Coloniaas a community is estimated to be 3,500,000 (kWh) while, for Red I and Red II, the electricity usage may be 1,800,000 and 2,000,000 (kWh).

Design of Possible Additions to the Homes

The simulation through CBT provided valuable information in assessing the different strategy proposals while making the single room addition to the two modeled homes.

Orientation and location of the addition were found to be very crucial for House 15 since it has more and larger windows on all facades than House 30. Another reason behind it was being built by wood frame structure on the pier and beams whereas House 30 has a higher thermal mass by being constructed with concrete blocks on a concrete slab. For House 15, east-c option was found to be more energy efficient (51.22 EUI) among 11 alternatives. For House 30, on the other hand, although the difference between 11 alternative scenarios was not significant, West-B option (38.36 EUI) provided the best results.

In terms of shading, for most of the strategies, making changes or replacements in the existing structure was found to be very expensive. As experts suggested, it is better to "go lean on windows" or shade them properly. They proposed not only adding a covered porch or extending the overhangs but also shading the windows with shutters or trees.

(1) First, I have tested *shading the windows on the addition*. However, as the additional structures were designed with minimum required size of fenestrations, the change in the EUIs was very low for both cases (0.05% for House 15 and 1.13% for House 30). Therefore, I have expanded this strategy to the whole house. By installing *exterior window shutters* to the whole structure, the EUI could be reduced by 6.36% with a $45 annual payment for House 15 while the annual savings could be as high as $99.39. EUI of House. 30 can be 1.98% less with a $30 annual cost. This practice was found to be a good strategy for colonias homes.

(2) *Extending roof overhangs* of the whole structure was found to reduce EUI of House 15 by 2.29% but with a significant cost of $934.15. It lowers the EUI of House 30 by 1.56%. This strategy was found to be very expensive compared to other strategies. Therefore, it is not recommended as the best practice.

(3) *Building a covered porch* on the Northeast could reduce the EUI by 1.15% with an additional cost of $264.50 for House 15. For House 30, on the other hand, EUI can be 2.2% less by building a covered porch on Northwest side of the house. However, the cost is also high: $462.09. Although the price of building a covered porch is considerably high, it provides residents an outdoor space to spend their time. Moreover, covered porches have an aesthetic and social value. As it was observed in the existing structures, residents enjoy spending their time in these areas. Therefore, it is found to be a successful practice for colonias homes.

(4) *Planting trees* on the west side of House 15 could reduce EUI 1% with a $50 cost. It was found to be affordable and sustainable strategy for both homes. However, careful

consideration on the orientation of the trees is required in order not to increase the energy consumption. Moreover, trees add an aesthetic value to the structure.

To sum up, for both cases, the combination of planting trees and shading windows were found to be the most successful low-cost energy efficient strategy. If residents can afford it, results demonstrate that in addition to shading the windows and planting trees, building covered porches or expanding overhangs reduces the energy consumption by 7% in House15 and by 4.3% in House 30.

The construction materials play an important role in energy efficiency. Since changing the R-value of the existing structure would be expensive and not be a good solution for these residents, this study only considers the improvements on the addition. However, the impact of it was not significant for both cases as the addition is only 231 square feet. The difference between having no insulation, and a moderate one was found to be significant. In house 15, upgrading from R-13 to R-19 or R-24 lowers annual electricity cost by $20 and $40 respectively. Improving the walls from R-4 to R-6 in House 30 saves $1 in annual electricity cost. However, the price for upgrading is very high. To that extent, experts suggested other low- to no-cost insulation materials such as old cloths, and recycled papers for colonias residents.

Results demonstrate that the design of mechanical systems has the most impact on energy use.

(1) Selection of *HVAC system* may reduce the EUI by 52% for House 15 whereas by 79%, for House 30. Multi-zone mini split air conditioning systems, which costs around $2,600 are the one suggested by experts in focus group.
(2) *Evaporative cooling system*, which uses “recovered” or “free energy” (Chengqin, Nianping, and Guangfa 2002), is another best practice for colonias residents. These systems consume 90% less electricity than refrigerated units (Breezair 2014). The price of these systems ranges between $600 and $700. Therefore, this strategy is a good one for colonias residents.
(3) If residents extend the set points for indoor temperature from ASHRAE standards (70˚for heating and 74˚ for cooling) to 60˚ for heating and 80˚ for cooling, their savings in EUI would be 55.7% for House 15 and 44.2% for House 30. The savings are very significant.

(4) If residents *combine best shading strategies and behavioral set points*, for House 15, they can save 68% in heating loads and 62% in cooling loads while for House 30, 95% electricity for heating loads and 37% for cooling loads.

(5) If residents install solar hot water systems for *domestic hot water (DHW)s*, they will have savings in fuel consumption (by assuming that they are currently using a fuel based DHW system). Residents in House 15 can save 3% and residents in House 30 can save 4% in their total annual energy cost with a price ranging from $250 to $1,500.

To sum up, this study suggests residents can achieve significant savings by applying passive design strategies such as natural ventilation, shading the house with carefully placed trees, extending the indoor dry bulb temperature set points to 60˚F and 80˚F, installing evaporative cooling systems that consume less energy than the conventional HVAC systems, and solar hot water systems. CBT proved to be a useful tool and process while evaluating and comparing the different strategies.

8.3.3 Originality

In informal settlements context, Geographic Information Systems (GIS) software is the tool that has been widely used. GIS is a software that combines spatial and non-spatial data to manage geo-spatial data and solve spatial problems by visualizing the data (Lo and Yeung 2007). According to the literature, it has been used to manage, monitor and predict health of residents, growth of colonias and resources (Davidhizar and Bechtel 1999; Mier et al. 2008; Parcher and Humberson 2009; USDA-RD 2011; Reimers-Arias 2009). However, this tool is less useful for modeling in building scale. BIM, on the other hand, is a recent advancement in the Architecture, Engineering and Construction Industry (AEC) that is an object-based parametric modeling technology that enables designers to define objects with parameters and rules (Eastman et al. 2008). This technology represents building components as objects with geometric and integrated information.

Although BIM technology has not been utilized in informal settlements context, it has several capabilities that can be beneficial in studying these settlements.

As self-help housing approach is a better alternative to the non-affordable, non-sustainable method of constructing apartment blocks after forced eviction and common in informal settlements other parts of the world (Bredenoord and Verkoren 2010; Goethert and Hamdi 1988; Joshi and Sohail Khan 2010; Kowaltowski et al. 2006; Sengupta 2010; Turner 1972; 1977; UN-Habitat 2003; Yap and De Wandeler 2010), having a 3-dimensional model of homes could be beneficial for residents to be able to participate during the decision-making process of implementations. There is not such a visualization of the homes in the selected colonias for this study. This study focuses on identifying best practices for self-help colonias homes in Laredo, Texas, which has not been discussed in the literature.

8.3.4 Limitations, Validity and Reliability

Rapid Modeling and Simulation of Existing Homes

Although BIM technology is capable of representing substandard housing in terms of their incremental building process with mostly an improper way of construction, I came across several limitations and made several assumptions to overcome these challenges. Data arose from on-site, face-to-face interviews, and home inspections lacked some information.

First, since it was not possible to investigate the layers of construction materials on building components, R-values, and the tightness of the building envelope (air infiltration values) were unknown. In order to overcome this challenge, I developed scenarios on R-values for each building component with reference to the literature and building codes. I have identified scenarios for R-values of the building components which were mentioned in the previous section: Scenario A which means structures with no insulation at all, Scenario B, which refers to having moderate insulation still not meeting the minimum requirements by codes and Scenario C which has insulation meeting the minimum requirements of the code. Different rules were established for different structures including concrete block self-help structures, wood frame self-help structures and manufactured homes. Age of the structures was collected through face-to-face interviews with residents, and I have referred to it when determining the R-values of the components.

Building envelope leakage value, on the other hand, was a major challenge in my study. Blower door test is a method to measure the leakage through the envelope of the building. However, it was not feasible, and affordable for me to employ it. Therefore, I referred to an extensive database on housing called the U.S. called Residential Diagnostic Database developed by Lawrence Berkeley National Laboratory (LBNL) (2011) to make an educated guess for these structures. The gbXML files exported from Autodesk Revit did not include any information on infiltration value. I scripted the infiltration value in the gbXML file prior to running it on Autodesk GBS tool and entered different values to different spaces in one home as needed. Four scenarios were tested for each house: worst and most likely values from LBNL database and very low (0.27ACH) and high values (3.5 ACH) from GBS as a default.

The available data on HVAC systems was for determining whether it is a central system or partial system. Therefore, the type of HVAC system used in each house is unknown. I selected the available four residential options in Autodesk Revit and GBS to overcome this challenge which provided reasonable ranges in electricity usage. Since these structures are residential, I applied seven days a week and 24 hours per day as the schedule for each structure.

To that extent, 20 scenarios were tested for each house to estimate their potential energy consumption. Section 6 presented these predetermined rules and scenarios in detail. This may be accepted as a limitation. Increasing the number of scenarios and making them parametric can be identified as future work.

In the community scale, in order to estimate the aggregated total annual EUI and energy cost, I extrapolated the median EUIs of the sample. The results are only estimates and not claimed to be accurate.

Second limitation arose due to the available libraries of materials in Autodesk Revit, which are sufficient for modeling formal structures. I found the existing libraries insufficient to model these structures. To that extent, as Revit enables users to create their own materials and libraries, I have created my own for colonias. I have used the thermal property values from DOE-2 Basics (Simulation Research Group 1991).

This study does not claim the accuracy of the models in terms of materials and construction techniques whereas it claims the accuracy in footprint and measurements. However, with more accurate and sufficient data, this method leads researchers to develop more accurate toolkits, models and results on building performance. The toolkit was tested on modeling 30 different homes, and it was found to be successful despite the unknown data. Therefore, this study demonstrates that the process is both externally and internally valid and reliable. Additionally results are based on several assumptions and scenarios. However, instead of claiming a pinpoint number for building performance, CBT provides a range for each house. If one has access to more accurate data, the results may be more accurate. Comparison of the numbers is the key to arrive in conclusions.

This process can also be applicable to other colonias and other informal settlements around the world.

Design of Possible Additions to the Homes

Findings are limited with only two homes selected in the sample of 30 houses. The selection of two test cases was based on their representativeness of the typology of structures in the sample of 30 homes in the three selected colonias. House15 is a manufactured home built in 1974 with a wood frame self-built addition built in 1994. House 30, on the other hand, is a concrete block structure which was built in 1992 in two phases. Although these test cases represent the self-built structures (70%) and the combination of them with manufactured ones (20%), they do not cover the ones with RVs, campers or school buses (10%). However, the findings were generalizable to the sample of 30 houses and consequently to the colonias that they were located in, but they may not be valid for other colonias.

As it was mentioned above, existing homes in the sample were modeled based on several assumptions and scenarios. However, a comparison between options was used as a method to identify the best practices for colonias homes. Cost analysis was based on a total cost of the improvements and the payments of residents over 10 year period of time. The cost of the strategies was derived from RS Means Residential Data 2011 or Home Depot's webpage. Total cost of existing homes was not calculated since it is impossible to calculate due to various unknown data.

BIM tool has some limitations on modeling some of the strategies such as trees, shutters, and double roof. GBS does not recognize tree components during building performance analysis. To overcome this challenge, I have modeled trees as cross shape walls and elevated them form ground to express the shading profile. These are passed to Green Building Studio as shading elements. Additionally, modeling exterior window shutters was another challenge as BIM does not have them as an option. I modeled them as wood frame walls with no insulation and placed them on the window openings. They act like protecting the windows from sun. Lastly, GBS does not recognize the second roof modeled in BIM. I overcame this challenge by placing a floor component as a second roof.

BIM tool has limitations on designing HVAC systems. Autodesk Revit and GBS have a limited number of options as HVAC systems. Mini-split, window AC units, and evaporative cooling systems were not included in the software. Therefore, I was able to use only four options which were available in the Autodesk GBS and Revit and calculated the changes in using evaporative cooling systems manually. Changing interior dry bulb temperature set points for cooling and heating also presents a limitation. Autodesk Revit does not allow users to make adjustments to set points. However, I was able to change them in the gbXML file after being exported from Autodesk Revit and then ran them on GBS.

8.4 Extension of Research

Integrating BIM technology into informal settlements context was proposed as a new process for introducing sustainable, low-cost strategies to colonias residents to reduce their energy consumption. While BIM provides enhanced process for modeling these homes and calculating their energy use, the need for further research and implications is highlighted. Future implications and research include two processes: (1) process for creating CBT and (2) process for use of CBT.

The possible extensions of research unfold five sections according to the group of audiences: (1) academia, (2) policymakers, (3) builders, and (4) residents.

8.4.1 Recommendation on Future Research: Academia

Academic research projects could create additional BIM design toolkits and improve the process of creating them.

Parametric Building Performance Analysis

This study employs a hierarchy of parameters and values to generate 20 scenarios for building performance analysis. However, by enhancing the parametric modeling capability of BIM by application programming interface (API), one can increase the number of scenarios and energy analysis runs per house. Exploration of more parameters, values, and combinations will enhance the reliability and validity of the results.

Probabilistic BIM can be studied in order to increase the number of scenarios for unknown variables.

Data Collection of Unknown Parameters

In this study, there are four unknown parameters that are required for energy analysis. It is reasonable to make assumptions on construction materials layered in the building components. Even though I have asked it as a question to the residents, almost all of them did not answer the thickness or all the layers in the components. They were able to report finishes such as hardwood floor, or concrete floor. The exterior finishes of the walls were observed during the on-site interviews. Since this study does not have permission from IRB to inspect the homes from interior, they remain unknown. It affects the accuracy of the results; reliability and validity of the findings. However, as a suggestion for future work, one can get approval for interior inspection of the houses and collect data on these unknown variables. Moreover, for infiltration values, one can perform a blower door test.

Applicability of the Process to Other Colonias

This study is limited to three colonias in Laredo, Texas, and 30 homes selected from these colonias. Although I asserted that the results of the sample can be generalizable to the communities that they are located in and the communities sharing the same climate, they are not for other colonias in the U.S. However, the process is applicable to other colonias. As a future work, one can repeat the process for other colonias.

In this study, I have focused on residential structures. However, many colonias have houses with small stores. By using the same process, this study can be extended to these micro economic structures.

Applicability of the Process to Other Informal Settlements

This study focuses on colonias that differ from other informal settlements in several ways. The most significant ones are the availability of air conditioning systems in the colonias and the availability of land compared to the lack of land in other parts of the world. While some of the houses in the colonias have air conditioning systems, almost always informal settlements in other parts of the world do not have an AC system. However, as passive design techniques were discussed in this process, the process can be applied for any informal settlements around the world.

Research may adjust the interview questions and home inspection sheet to the context of the informal settlement that they focus. However, they can develop Informal Settlement BIM Toolkit (ISBT) by following the same process described in this study.

Development of BIM Design Toolkit for Other Types of Sustainability

BIM technology allows architects to design sustainable buildings considering other sustainability features such as water harvesting, daylighting, ventilation and renewable energy (Krygiel and Nies 2008). This study has the potential to extend the process developed in this study of sustainability from an energy efficiency point of view to other scopes.

8.4.2 Recommendation on Implications

Recommendations on implications are introduced according to four groups of audiences: (1) policymakers, (2) utility companies, (3) builders, and (4) residents.

Policymakers

The process of creating CBT has been introduced in this study. The use of this design toolkit would be beneficial for policymakers in terms of enabling them to identify the problems in construction of the houses across three colonias, to assess the quality of the structures across three colonias, to offer design improvements by considering the existing architectural patterns adopted by the residents across three colonias.

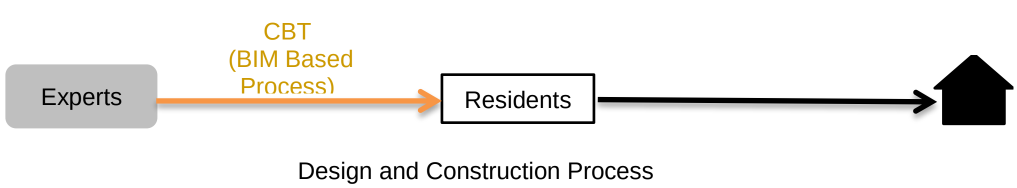


Figure 53: Conceptual map of the “field agents/spatial agents” idea

After having the proper CBT for the colonias, state organizations (HUD, SOS, or TXDHCA) can provide support of (1) training field agents who are either from residents of colonias or freshman students from Department of Architecture, (2) technical equipment which are BIM software and laptop computers or tablets, and (3) cost of modeling and data collection which include equipments for measuring the structures and performing inspections on construction materials on-site. By utilizing BIM toolkit stakeholders in the county organisations can provide assistance to residents for rehabilitation of their homes. They can follow the process proposed in this study which can empower the residents by making them participate to design process.

In colonias, community organization is a way of achieving the collaboration between residents and experts to overcome challenges in housing (Choguill, 2007; Tolba, 1987). Texas Department of Housing and Community Affairs (TDHCA) has developed the *Colonias* Self-Help Center (SHC) program according to the 74th Legislature in 1995 and has established centers in several counties of Texas such as Cameron/Willacy, Hidalgo, Starr, Webb and El Paso (Vargas 2012). These programs target providing technical assistance to residents in housing improvements, new housing design and constructions, access to basic services, and access to capital for mortgages (McKenzie 2002; SECO 2011; TDHCA 2012; Vargas 2012). These centers are run by nonprofit organizations, local community action agencies, or local housing authorities. In sustainable design and construction, introducing expert knowledge can be very useful to colonias residents. My research foresees employing 'spatial agency' in architecture by extending the concept of the self-help centers to share knowledge of experts with residents (Figure 53). A field agent could employ BIM and energy simulation to design an addition, and advise residents on how to improve their homes.

By referring the results on cost and energy consumption of colonias homes, policymakers can set up regulations and guidelines on low-cost energy efficient strategies for colonias residents and improve the building code.

Utility Companies

Utility companies can provide actual energy use of the homes which would help researchers to calibrate the results on energy consumption that are generated by BIM technology. With more precise and calibrated results, utilities can utilize this information to come up with better forecasts in terms of energy consumption of communities and load growth. This would allow them to create better strategies for infrastructure development.

Builders

This study foresees the knowledge of experts in best sustainable design and construction practices for informal settlements can be shared with residents using *Colonias* Self-Help Centers (SHC) as ‘field agents’. The model is similar to the widespread practice of using state-employed field agents to encourage adoption of best practices in agriculture. As an extension of my research, this study can be useful for builders such as Housing and Urban Development (HUD) or Texas Department of Housing and Community Affairs (TDHCA). CBT can be used by these builders as a road map to improve the housing quality. Help-centers, on the other hand, can use this toolkit when advising residents during construction. Builders, furthermore, can use CBT to model new colonias.

BIM can be used to as a road map to improve construction or modification of homes and to reduce their energy consumption. Builders can monitor the existing energy use and the change in energy use after the additions or improvements to the house, and to monitor the cost of the additions or improvements to homes.

Builders can use the findings of this study about the construction materials, techniques and design of colonias homes to provide assistance to the residents in their design process.

Residents

By utilizing CBT, residents can have a 3-dimensional models of their homes and possible extensions. Visualization of their homes enables them to better participate in decision-making process for upgrading implementations. With the help of field agents, they would have information on the reflection of a possible future improvements or extension to their existing homes in cost and energy use. This information would allow them to identify the best strategies specific to their home.

The findings of this study demonstrate that residents should consider the placement of the additional structure with respect to climate conditions. Placing the addition attached to the oldest part of the existing structure would be a good strategy to reduce the air leakage through building envelope. Planting trees on west and east sides of the homes, installing window shutters, extending roof overhangs and building covered porches on the west, and east side of the homes are the highlighted strategies that residents should consider in order to reduce their energy consumption. Residents should take natural ventilation in consideration while building their homes. Instead of conventional air cooling systems, they may use evaporative cooling systems. Together with other passive design strategies such as solar water heater systems and rain water catchment strategies, they can reduce a significant amount of their energy bills.

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APPENDIX

- Focus group questionnaire
- Colonias Residents Interview Questions
- Home Inspection Sheet

FOCUS GROUP QUESTIONNAIRE

Topics	Question
Climatic Determinants/Orientation	
	What are the major problems/factors about climate that have the biggest impact on home design in Laredo, Texas?
	What features have you considered for placement of housing in the site?
	In terms of orientation of housing, what have you found successful in terms of sustainable cost effective housing design?
Building Design/Passive Design	
Housing Shape	
	In terms of orientation of housing, what have you found successful in terms of sustainable cost effective housing design?
Housing Fenestration/Aperture	
	What are your strategies for placing windows and doors that seem to contribute best to achieving energy efficiency and other aspects of sustainability?
	What techniques and methods have you found to be successful in terms of controlling solar gain for sustainable and cost effective housing?
	What techniques and methods have you found to be successful in terms of ventilation for sustainable and cost effective housing?
Housing Envelope/Materials	
	What construction methods have you found to be successful?
Mechanical Systems - Sustainable Technologies & Techniques	
	What heating and cooling systems have you found to be successful for sustainable and cost effective housing? Why were they successful?
	What type of water heaters have you found to be successful for sustainable and cost effective housing? Why were they successful?
	What lighting systems have you found to be successful for sustainable and cost effective housing? Why were they successful?
	What type of appliances have you found to be successful for sustainable and cost effective housing? Why were they successful?
	What type of appliances have you found to be successful for sustainable and cost effective housing? Why were they successful?
	What type of plumbing have you found to be successful for sustainable and cost effective housing? Why were they successful?
	What features for water resources utilization seems to be successful?

COLONIAS RESIDENTS INTERVIEW QUESTIONS

ARCHITECTURE AND CONSTRUCTION OF HOMES IN THE COLONIAS

Texas A&M University
College of Architecture
Department of Architecture
January 2013

Dear Sir/Madam,

A research team at Texas A&M University is conducting a study to devise ways to assist in design of self-help housing in colonias in Laredo, Texas. The purpose of this study is to define house construction patterns and layout changes over time in Larga Vista, San Carlos I and II in Laredo, Texas. Your house was selected as part of a sample of 30-40 houses. We would like to include your house in our study.

The study is comprised of two parts: a questionnaire and a physical survey of your home. In part one, we will ask questions about the construction of your house, and how you have changed the house through time. These questions will take about 15 minutes to answer. Second, we will measure and inspect your home to determine construction materials. The survey will take 20 minutes. The information that you provide is very important to complete successfully this study.

If you agree to participate, your participation in this study will be confidential. Your name and your particular address will be concealed and safeguarded. Identifying information will not be shared or included in any reports or publications of this study. You can choose not to answer a question at any time. You may withdraw from the study at any time. You will receive a $20 gift card or a small gift of equivalent value as our expression of appreciation for your participation. You will receive the gift whether we complete the questionnaire and physical survey or not.

If you have any additional questions or concerns now or at any time after you participate in this study, please contact us. You may contact either faculty supervisor Dr. Mark J. Clayton at the Department of Architecture, TAMU 3137, College Station, TX 77843-3137, phone (979) 777-0672, in English. This study has been reviewed by the Institutional Research Board-Human Subjects in Research, Texas A&M University. For any questions or issues related with subject's rights, you can contact the Office of Research Compliance, Institutional Research Board at (979) 458-4067.

Sincerely,

Dr. Mark J. Clayton
Principal Investigator
Department of Architecture, Texas A&M University
Pavilion Bdg, College Station, Texas 77843-3137

IRB NUMBER: IRB2013-0119
IRB APPROVAL DATE: 03/20/2013

A. HOUSE BACKGROUND DATA:

a. When did you come to this colonia? *(Year)*__________

b. What sort of title to your land do you have? *(Deed/Contract for Deed/Other:________)*

If you have a deed (warranty, quitclaim or other), whose names are listed on the title?

(Mine -The householder/My Spouse/Both of us jointly/Previous Owner/Other:_______)

c. If you are still paying for the land, do you have a written agreement, oral agreement, or no agreement? (Delete what does not apply)

d. How long have you been living on this land/lot? *(Years)* _________

e. Do you know:

i. Lot Size? *Y/N*
ii. Lot Size? (*Square Feet)* ________
iii. Lot Size? (*Acres*) _________

f. From whom did you purchase the land?

i. Inherited from a family member
ii. A company or land seller
iii. Previous Homeowner
iv. Other: __________

g. How did you purchase the land?

i. Mortgage with Bank
ii. Payments to seller over several years
iii. Savings /cash
iv. Other: __________

h. Do you remember how much did you pay for the initial land? *($)*__________

i. How much do you think you have invested into your house in total? *($)* ____________

j. How much do you think your current house is worth? *($)* ______________

B. HOUSE FORM CHANGE DATA

B.1 Original Structure/First House

a. What was your first house/structure on this lot?

i. Manufactured Home-single wide (trailer)
ii. Manufactured Home-double wide (trailer)
iii. Modular Manufactured Homes (not on wheel base/chassis) assembled on site
iv. Custom home – self built on site
v. Camper (RV – recreational vehicle)
vi. Other_____________

b. What were the onsite services at arrival?

i. Water ii. Electricity iii. Sewer iv. Garbage

c. When was the first house/structure built? (Year) ____________

d. How long did it take to build? (Months, years)_________

e. Approximately how big was the first house/structure? (Square foot)________

f. What materials were used for this first house/structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

g. How many rooms did the first house/structure have and how were they used?

____

h. Why did you build this first house/structure?

____

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B.2 Stage #2: Additions/Changes/Improvements

a. What were the first changes or additions you made to the first house/structure?

i. Manufactured Home-single wide (trailer)
ii. Manufactured Home-double wide (trailer)
iii. Modular Manufactured Homes (not on wheel base/chassis) assembled on site
iv. Custom home – self built on site
v. Camper (RV – recreational vehicle)
vi. Other____________

b. When was it built/ made? (Year)___________

c. If addition, approximately how big was it? (Square foot) _______

d. What materials were used for the new structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

e. How many rooms were added and how were they used?

____

f. Why did you build/ made this addition/change/improvement?

____

B.3 Stage #3: Additions/Changes/Improvements

a. What were the next changes or additions you made to the house/structure?

i. Manufactured Home-single wide (trailer)
ii. Manufactured Home-double wide (trailer home)
iii. Modular Manufactured Homes (not on wheel base/chassis) assembled on site
iv. Custom home – self built on site
v. Camper (RV – recreational vehicle)
vi. Other____________

b. When was it built/ made? (Year)___________

c. If addition, approximately how big was it? (Square foot)_______

d. What materials were used for the new structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

e. How many rooms were added and how were they used?

____

f. Why did you build/ made this addition/change/improvement?

____

B.4 Stage #4: Additions/Changes/Improvements

a. What were the next changes or additions you made to the house/structure?

i. Manufactured Home-single wide (trailer)
ii. Manufactured Home-double wide (trailer home)
iii. Modular Manufactured Homes (not on wheel base/chassis) assembled on site
iv. Custom home – self built on site
v. Camper (RV – recreational vehicle)
vi. Other____________

b. When was it built/ made? (Year)___________

c. If addition, approximately how big was it? (Square foot)_______

d. What materials were used for the new structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

e. How many rooms were added and how were they used?

____

f. Why did you build/ made this addition/change/improvement?

____

B.5 Stage #5: Additions/Changes/Improvements

a. What were the next changes or additions you made to the house/structure?

i. Manufactured Home-single wide (trailer)
ii. Manufactured Home-double wide (trailer home)
iii. Modular Manufactured Homes (not on wheel base/chassis) assembled on site
iv. Custom home – self built on site
v. Camper (RV – recreational vehicle)
vi. Other____________

b. When was it built/ made? (Year) ___________

c. If addition, approximately how big was it? (Square foot)_______

d. What materials were used for the new structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

e. How many rooms were added and how were they used?

____

f. Why did you build/ made this addition/change/improvement?

____

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B.6 Final Stage: Additions/Changes/Improvements

a. What are the most recent improvements made to your house?

____

b. When were they built/ made? (Year)___________

c. If addition, approximately how big was it? (Square foot)________

d. What materials were used for the new structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

e. How many rooms were added and how were they used?

____

f. Why did you build/ made this addition/change/improvement?

____

B.7 Future Stages: Additions/Changes/Improvements

a. What are your plans for future improvements to your house?

____

b. When do you plan to build or make them? (Year)___________

c. If you are planning an addition, approximately how big will it be? (Square foot)________

d. What materials will be used on the new structure?

	Type	Materials	Insulation	Age	Other Information
Foundation					
Floor					
Walls					
Roof					
Attic					
Doors					
Windows					

e. How many rooms will be added and how will be used?

____

f. Why have you planned to make this addition/change/improvement?

____

C. INFRASTRUCTURE AND SERVICE DATA

Present on-site services	electricity	water	sewer	garbage
Year the service provided				
Monthly cost				

C.1 Power

a. What is the principal source(s) of power in the main house?

i. Electricity (metered supply)
ii. Propane small tank
iii. Propane large tank
iv. Mains gas
v. Truck delivered gas
vi. Other: ____________

b. What secondary source(s) of power are provided in the main house? ______________________

c. Describe any serious problems with the principal source(s) of power:

____

C.2 System of Heating

a. How do you heat your water in the main house?

i. No water heating in the house, cold water supply only
ii. Electric water heater
iii. Gas water heater
iv. Other:____________

C.3 System of Air Cooling

a. What type of system of air cooling in the main house?

i. Partial AC
ii. Full AC
iii. Ceiling fans
iv. Stand-alone fans
v. Breezeway
vi. Other:____________

b. What type of (other) system of air cooling is used in the main house? ______________________

c. How many AC units such as window units? ___________

d. How many ceiling fans? _________

e. How many stand alone or floor fans? ________

f. Describe any serious problems with the system of air cooling:

____

C.4 Garbage Disposal System

a. How do you dispose of garbage and solid wastes?

i. Contract with formal company service
ii. Semi-formal arrangement for collection with individual collectors
iii. None, we drop off our garbage at the dump or other sites
iv. Drop off & Burn
v. Other:______________

b. How do you (other) dispose of garbage and solid wastes? ___________________

c. How often is the garbage and solid waste collected? __________

d. What is the monthly cost for garbage / solid waste disposal? __________

e. Describe any serious problems with the garbage / solid waste disposal:

____

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D. COMMUNITY DATA

D.1 Grocery Stores

a. How many grocery stores do you have close to your house? ___________
b. Where do you get your groceries? _______________
c. How do you access the grocery store, such as walk, drive, ride a bus, ride with someone, or cycle? _______________
d. How far is the nearest grocery store from your house? _______________
e. Describe any serious problems with the access to grocery:_______________

D.2 Gas Stations

a. How many gas stations do you have close to your house? _______________
b. Where do you get gas? _______________
c. How far is the most convenient gas station from your house? _______________
d. Describe any serious problems with the access to gas stations:_______________

D.3 Bank

a. How many banks do you have close to your house? _______________
b. Which one is convenient for you? _______________
c. How do you access the bank, such as walk, drive, ride a bus, ride with someone, or cycle? _______________
d. How far is the most convenient bank from your house? _______________
e. Describe any serious problems with the access to bank:_______________

D.4 Work

a. Where are you working? _______________
b. How do you travel to work, such as walk, drive, ride a bus, ride with someone, or cycle? _______________
c. How far is the work from your house? _______________
d. Describe any serious problems with access to work:_______________

D.5 Schools

a. How many schools do you have close to your house? _______________
b. Which schools do your children attend? _______________
c. How do they access the school, such as walk, drive, ride a bus, ride with someone, or cycle? _______________
d. How far is the school from your house? _______________
e. Describe any serious problems with the access to school:_______________

E. HOUSEHOLD DATA

E.1 Tenancy:

a. Do you own or rent your home? (Y/N)________
b. How much do you pay per month? (*Mortgage or rent $ amount*)_________
c. Who is the owner of your home? ____________
If you are not, what is the relationship with the owner? ____________
d. How many separate households are there on this lot? (*Single Household Unit/ Two Household Units/Three Household Units*)
*(For 2 household units on lot), are they related to you? (Y/N)*___
*(For 3 household units on lot), are they related to you? (Y/N)*___
e. Does any household member have experience & skills in construction? (Y/N)_____
In construction, what are their skills?

E.2 Main Household Data

a. Household Head

Tenancy		
Age/Gender/Ethnicity		
Relationship		
Year of Arrival		
Education Background		
Occupation		
Present Employment/Years		

b. Other Member(s)

Tenancy		
Age/Gender/Ethnicity		
Relationship		
Year of Arrival		
Education Background		
Occupation		
Present Employment/Years		

E.3 Other Household(s) Data

a. Head Representative

Tenancy		
Age/Gender/Ethnicity		
Relationship		
Year of Arrival		
Education Background		
Occupation		
Present Employment/Years		

b. Other Member(s)

Tenancy		
Age/Gender/Ethnicity		
Relationship		
Year of Arrival		
Education Background		
Occupation		
Present Employment/Years		

HOME INSPECTION SHEET

HOME INSPECTION

HOUSE CONSTRUCTION DATA

A. CONSTRUCTION TYPE & MATERIALS

a. Structure type of the units:

- Manufactured Home-single wide (trailer home)
- Manufactured Home-double wide (trailer home)
- Custom home – self built on site
- Camper (RV – recreational vehicle)
- Other____________

b. Foundation

Foundation Types	*Insulation Types*
▪ Piers or cinder blocks	▪ Dampproofing
▪ Slab	▪ Sheet Waterproofing
▪ Piers or cinder blocks on slab	▪ Fluid-Applied Waterproofing
▪ Other______________	▪ Cementitious Waterproofing
	▪ Bentonite Waterproofing
	▪ Other______________

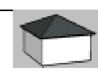
c. Floor

- Hardwood
- Cork & Bamboo
- Laminate
- Carpet
- Vinyl
- Tile or stone
- Brick
- Other______________

d. Roof

- Gable Roof

- Mansard Roof



- Pyramid Hip Roof

- Bonnet Roof

- Hip Roof

- Flat Roof

- Gambrel Roof

- Saltbox Roof
- Other: _________

Materials	*Insulation*
▪ Asphalt shingles	▪ Slab insulation
▪ Wood shakes and wood shingles	▪ Rigid insulation
▪ Clay tile and concrete tile	▪ Foam insulation
▪ Metal roof systems for steep-slope applications	▪ Wood sheathing (R-0.6)
▪ Slate roofing tiles	▪ Asphalt-impregnated sheathing
▪ Synthetic, PVC for flat roofs	▪ Expanded polystyrene (R-2),
▪ Tar & Gravel, Bitumen and Roll Roofing for flat roofs	▪ Extruded polystyrene (R-2.5 to 3),
▪ Foam Roofing for flat roofs	▪ Polyisocyanurate (R-3.4 to 3.6) foam insulated sheathing
▪ Other:_______________	▪ Other:_______________

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e. Walls

Exterior Walls	*Interior Walls*
▪ Brick walls	▪ Brick walls
▪ Stone Walls	▪ Stone Walls
▪ Concrete Walls	▪ Concrete Walls
▪ Wood siding walls	▪ Wood walls
▪ Insulated Vinyl Siding	▪ Insulated Vinyl Siding
▪ Aluminum sheets	▪ Aluminum sheets
▪ Insulated Wall Panels	▪ Insulated Wall Panels
▪ Straw Bale	▪ Straw Bale
▪ Gypsum Board	▪ Gypsum Board
▪ Other:____________	▪ Other:____________

f. Insulation

Foundation	*Floor*	*Walls*	*Attic*
▪ Cellulose	▪ Cellulose	▪ Cellulose	▪ Cellulose
▪ Fiberglass	▪ Fiberglass	▪ Fiberglass	▪ Fiberglass
▪ Spray-in-place foams	▪ Spray-in-place foams	▪ Spray-in-place foams	▪ Spray-in-place foams
▪ Cotton	▪ Cotton	▪ Cotton	▪ Cotton
▪ Slab insulation	▪ Slab insulation	▪ Slab insulation	▪ Slab insulation
▪ Rigid insulation	▪ Rigid insulation	▪ Rigid insulation	▪ Rigid insulation
▪ Foam insulation	▪ Foam insulation	▪ Foam insulation	▪ Foam insulation
▪ Sheating	▪ Sheating	▪ Sheating	▪ Sheating
▪ Other: _____	▪ Other:______	▪ Asphalt-coated paper backing on insulation 0.40	▪ Loose fill
		▪ Polyethylene plastic (6 mil) 0.06	▪ Batt insulation
		▪ Plywood with exterior glue 0.70	▪ Other:_____
		▪ Plastic-coated insulated foam sheathing 0.4 to 1.2	
		▪ Aluminum foil (.35 mil) 0.05	
		▪ Vapor barrier paint or primer 0.45	
		▪ Other:______	

g.Doors

Style	*Material*
▪ Single flush door (w/o glazing)	▪ Aluminum
▪ Double flush door (w/o glazing)	▪ Wood
▪ Sliding (w/o glazing)	▪ Vinyl
▪ Garage Door (w/o glazing)	▪ Fiberglass
▪ Storm Door (w/o glazing)	▪ Fibrex
▪ Other:_____	▪ Other:_____

h. Windows

Window Style	Style	Material
▪ Single-glazed	▪ Awning	▪ Aluminum
▪ Double-glazed	▪ Casement	▪ Wood
▪ Shutters	▪ Double-Hung	▪ Vinyl
▪ Blinds	▪ Sliding	▪ Fiberglass
▪ Other:__________	▪ Fixed	▪ Fibrex
	▪ Bay windows	▪ Other:______
	▪ Shutters	
	▪ Storm	
	▪ Other:__________	

B. NUMBER OF ROOMS

a. Number of bedrooms in primary unit:__________
b. Number of living rooms in primary unit:_________
c. Number of dining rooms in primary unit:_________
d. Number of kitchens in primary unit:_____________
e. Number of full bathrooms in primary unit:___________
f. Number of half bathrooms in primary unit:_________
g. Number of (other) rooms in primary unit:__________
h. Types of (other) rooms:_______________

C. EXTERIOR FEATURES

	Location (room)	Material
▪ Porch (covered/uncovered) ▪ Overhangs ▪ Decking ▪ Shadings ▪ On Walls ▪ rainwater collection ▪ Other:______________________		

D. GARDEN

a. Is there a garden in the lot? Y/N
b. How many trees are in the lot? *(number)*___________
c. How many plants are in the lot? *(number)*___________
d. Describe any serious problems with the garden:____________________

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E. PLAN, ELEVATION, SKETCH OF THE HOUSE

Sketch