ESTABLISHING THE CONTEXT FOR SOIL USE IN PANELIZED WALL SYSTEMS FOR SUSTAINABLE BUILDINGS IN ARRIYADH

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(ABSTRACT)

In the past, soil was used as a main building component and in some cases the only building component in Saudi Arabia. Today and with the advances in building materials, concrete, glass, and steel have replaced soil as the main building components, in which the raw materials are mostly imported from other countries or derived from non-renewable resources. In Saudi Arabia, high growth in population is expected as specifics would be given to show the number of units needed to keep up with the population explosion and thus a tremendous amount of material would be consumed. Temperatures in most cities usually reach 120ºF in the summer and 30ºF in the winter, which would require high energy consumption if the proper building materials are not used to help with insulation. Therefore, this thesis focuses on establishing a context for returning to the use of soil as a main component in building materials through the use of panelized wall systems. This proposal has many key advantages. Some of the key areas that are touched on deal with offsite manufacturing where quality and quantity of panels can be closely monitored, labor requirements for handling and installation, equipment necessary to assemble the panelized wall systems and one of the largest contributions, the effect on the environment. Each of these areas is expanded on with some specific details given to more positively represent the use of soil in panelized wall systems. A clear outline of the approach was taken is detailed including such items as examining different studies and research findings, distributing questionnaires and surveys to building professionals and homeowners to understand their key concerns and obtain their suggestions, and most importantly to analyze the data findings to allow for a completed system that not only would work and work better than other systems, but that others would be willing to and want to use. The expected outcomes discussed by the use and development of the panelized wall systems using soil is a reduction in energy consumption, reduced time from start to completion of a project, significant reduction of on-site labor requirements and a substantial decrease in the amount of waste going to landfills.

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1. INTRODUCTION

1.1. Background

Construction practices continue to change in Saudi Arabia as new equipment is developed, new materials are invented, and housing requirements change. In most cities of Saudi Arabia, temperatures can reach 120ºF in the summer and 30ºF in the winter, which would require high energy consumption if the proper building materials are not used to help with insulation. In the past, most residential buildings in Saudi Arabia used soil as the main building material before mechanical systems and other modern materials were developed. In most cases, soil was the only building material. Today, residential buildings use concrete, steel, glass and other new composites as the main building materials. Concrete is the most widely used building material in homes as well as streets, sidewalks, public spaces, garden pathways, etc (Arafah et al. 1995).

As the High Commission for the Development of ArRiyadh (HCDA) plans for the future, a renewed interest has been placed on returning to the use of soil in buildings. This would be a challenge to convince the building industry professionals and stakeholders

of today that using soil in place of newer and more modern building materials is the right choice.

According to a study by The High Commission for the Development of ArRiyadh (HCDA), the population of ArRiyadh has witnessed high growth, estimated of 8.1% annually. In 2005, the population was 4.26 million and it is expected to grow to 7.2 million by 2040. The residential units needed for this population during this timeframe are estimated at 495,000 units or an average of 27,500 per year (HCDA 2006). In order to reduce the dependence on current building materials (steel, concrete and glass), the use of soil in panelized wall systems is an option that can be more cost effective and at the same time more environmentally friendly. There are a variety of products, carpet pieces, rice, straw, concrete, etc., that can be used as insulation in the panelized wall systems (Meadows and Morris 2009), but soil has many other benefits that make it the better choice. It is more readily available – natural resource, last longer, does not need advanced techniques to recycle, and fire resistant.

Saudi Arabia needs to find ways to keep the overall building costs down, reduce the dependence on non-renewable resources, and reduce time to completion while at the same time changing the perception of the people. "Saudi Arabia is a market with huge potential but affordability remains the main challenge that needs to be overcome," said John Harris, Head of KSA operations for Jones Lang LaSalle MENA. "There is currently a pricing mismatch between what the market is delivering and what most potential purchasers can afford to pay for their housing. Affordability would unlock the undoubted latent demand for additional housing, converting this into actual demand and increased sales activity." The panelized wall system can accommodate each of these objectives and at the same time make a more modern look to the residential buildings while pleasing the HCDA by using soil in the building process.

There are several factors that make using panelized wall systems with soil in today's buildings a challenge. The following aspects are some of these important factors:

- Consideration of soil as an old fashion
- Investment in new manufacturing equipment

- Reduce the use of today's common building materials that are imported or derived from non-renewable resources

This thesis establishes the context for using soil in producing panelized wall systems that can be used as the main structure for today's residential buildings in ArRiyadh, Saudi Arabia. It also gives specifics on the desired performance and constraints of the building professionals and stakeholders regarding current building materials.

Panelized wall systems take many forms and the structural insulated panels (SIPs) are the most widely used. They are becoming more popular in different parts of the world, especially in the United States and Europe, due to their excellent energy saving properties and their ease of assembly (Blanford 2009). Currently most SIPs are made with foam cores, but if using soil in SIPs proves its technical feasibility, then it would be more economical efficient due to the availability of soil in Saudi Arabia.

The proposed soil would be a mixture of gravel, sand, silt and clay as can be seen from an example in Figure 1. Not every soil is suitable for earth construction, but with some knowledge and experience, many soils can be compressed and used for construction (Maïni, 2004). Structural insulated panels (SIPs), with use of soil, are intended to be prefabricated at the manufacturer. They would be made from a single layer that would incorporate structure, insulation, and sheathing into one component.

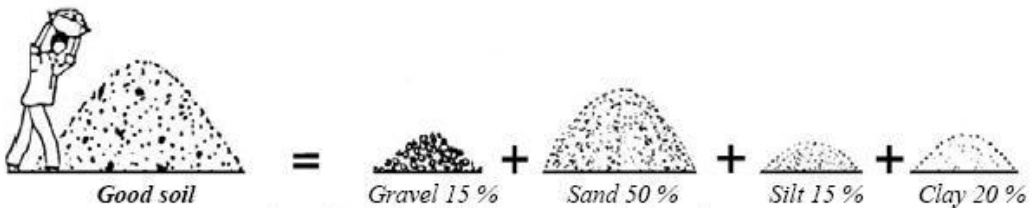

Figure 1: One example of soil composition that can be used in a SIP

The proposed SIPs not only would help reduce energy consumption and be easy to assemble, but also would offer many other aspects that can affect the overall costs. Material availability, manufacturing, labor requirements, and equipment are just a few of

the many areas that would have an effect on the overall cost of the building when using SIPs.

The availability of soil in Saudi Arabia is much more plentiful than other components used as the insulation core of SIPs. The soil would be readily available near the manufacturer and thus would save on transportation and fuel costs, time, and money for one of the key components of the SIPs. It would also allow for flexibility of the factory's location since the soil is found throughout the area.

SIPs would be manufactured offsite and delivered to the site ready to assemble. The SIPs would be shipped along with the other materials required to assemble the project/building. Materials would include the wall SIPs and all the parts for assembly including screws, joint sealant, panel seal tape, and other accessories. Installation instructions would be included, and the builder can request to receive on site advice to assist in the installation. Once all the materials have arrived and are unloaded, the wall panels would be installed like a puzzle precisely following a predesigned floor plan.

Since the SIPs would be assembled in a controlled environment, the quality can be carefully monitored and efficiencies developed to allow for maximum output with minimal people, equipment and inventories. This can have a major impact on costs since materials, etc. can be scheduled as needed and adjustments can be made easily based on the requirements. Once designs have been developed, costs to the builders can also be reduced since there would no longer be the need for a designer/architect to develop the plans up front, only new designs or modifications would need additional support.

Another key area that would be affected by the use of SIPs is the labor. Due to the ease of installation and the reduction in the number of steps to complete the project, there would be a reduction in labor time required. Also it requires a less skilled workforce to assemble compared to stick built manufacturing. Less on-site work means less labor costs. The time for specialty laborers such as electricians and plumbers can also be reduced as all the panels would have preinstalled conduits and predrilled holes to allow quick wiring and plumbing. Also, due to the reduced days required for labor, as

costs increase for labor, there would be minimal increases in cost to the builder as hours are minimized with the easy and short installation.

The use of panelized wall systems using soil does not only provide benefits to the manufacturing and assembly portions, but also has a direct impact on the environment. They can have a direct effect on the ecosystem in area such as energy consumption and landfill waste. See Figure 2

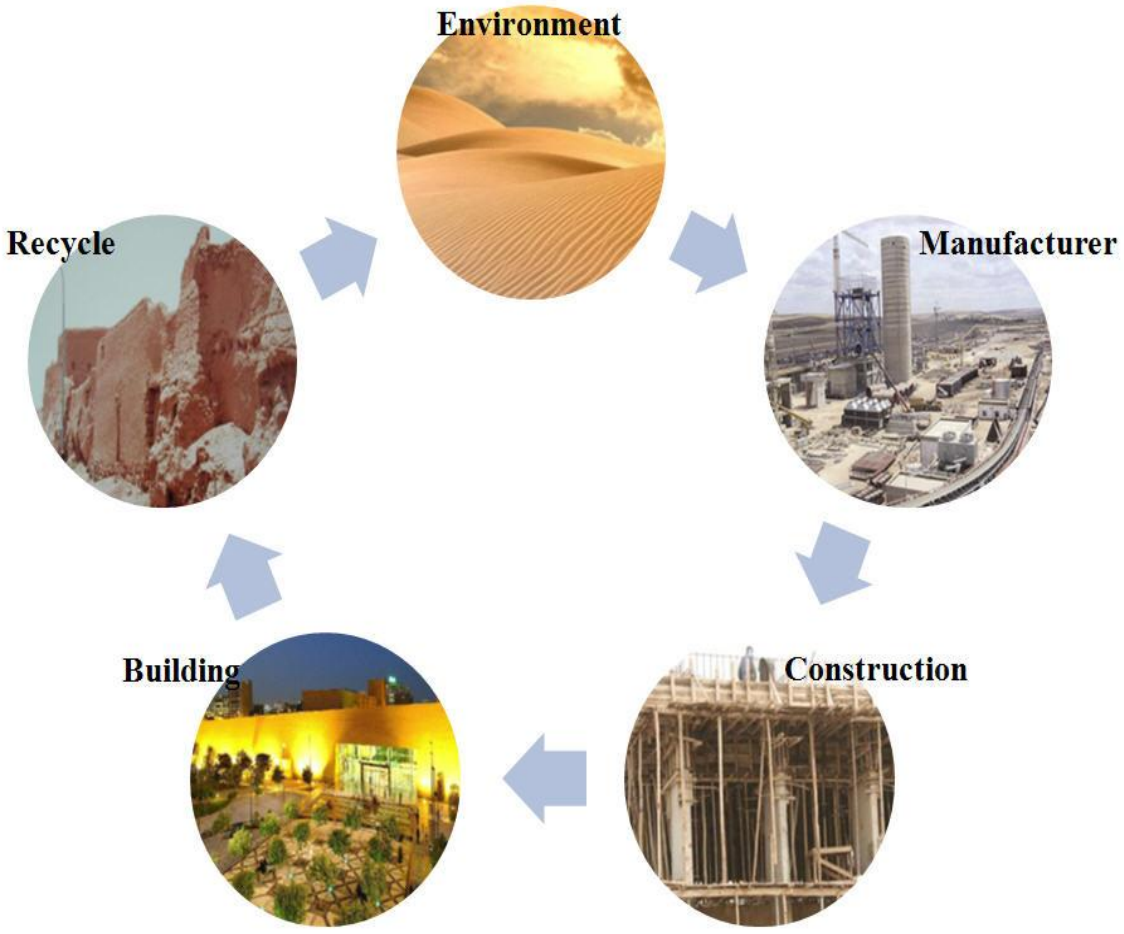

Figure 2: Life Cycle of Soil in Building Materials

Along with the positive benefits of panelized wall systems using soil, there are a number of areas of unease or areas that require more attention. A completely customized panel layout is required on the job site before any product can begin assembly. On-site modifications are also difficult and can be very costly. The initial costs of SIPs construction continues to be debated. Some companies expect project costs to parallel traditional systems, while others believe the costs would be higher. Upfront costs may be more due to the engineering and drawings required, but energy efficiency, on-site labor costs, and other savings can potentially drive the cost lower.

1.2. Problem Statement

In Saudi Arabia, most buildings use concrete, steel, glass, and other new composites as the main building materials. These materials are imported or derived from non-renewable resources, which has a significant impact on the total cost of buildings. In an extreme weather environment like ArRiyadh, these proper materials do not usually meet the desired performance of people in resisting the excessive heat, which also leads to high energy consumption experienced in today's buildings (Al-Jowair 2006). Moreover and due to the fast growth of population, more residential units are required in the future. Therefore, reduction of dependence on current building products and use of local materials that are readily available becomes a necessity of the High Commission for the Development of ArRiyadh (HCDA). In order to gratify the HCDA, the use of soil in panelized wall systems is an option that can be more cost effective and at the same time more environmentally friendly. The panelized wall system can accommodate each of these and at the same time make a more modern look to the residential buildings while pleasing the HCDA by using soil in the building process. However, finding out the desired performance and constraints of the building professionals and stakeholders regarding current building materials is required to establish the context for soil use in panelized wall systems in ArRiyadh, Saudi Arabia.

1.3. Objectives and Methodology of Research

The project comprises the creation of a framework diagramming the decision process involved in the adoption of building materials in ArRiyadh, Saudi Arabia. To create the framework for the decision-making in the selection of building materials, the factors involved in determining the desired performance and constraints of the building professionals and stakeholders regarding current building materials are identified through a literature review. Through a series of interviews and surveys with building professionals and stakeholders, the available knowledge is captured and organized to determine the desired performance and constraints of materials that are used today, which affects the adoption of a new material emerging to the market. The study begins with a mapping of the factors that determine the performance of the materials, and establishes the context for using soil in panelized wall systems for sustainable buildings in ArRiyadh, Saudi Arabia. A detailed description of the research methodology employed in this thesis is presented in Chapter 4.

A flow-chart (Figure 3) shows the parties, building professionals and stakeholders, involved in any project that may use SIPs and relationships between the parties. Table 1 describes functions of each party as stipulated in a report prepared for the U.S. Department of Housing and Urban Development Office of Policy Development and Research by NAHB Research Center, Inc. (2002), “Design, Fabrication, and Installation of Engineered Panelized Walls: Two Case Studies.”

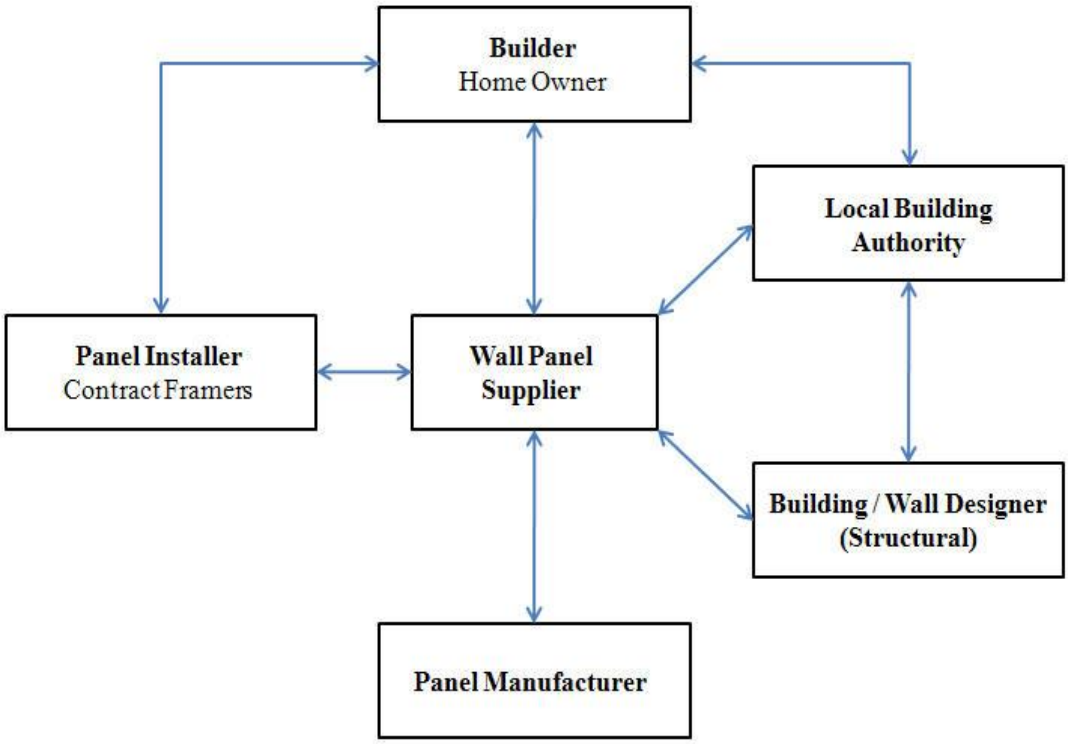

Figure 3: Flow Chart of relationships between parties involved in construction process

Table 1: Description for responsibilities of each party involved in construction process

Party	Description of Functions
Builder – Home Owner	Management of the construction process including hiring of subcontractors and obtaining building code approvals
Wall Panel Supplier	Provide complete equipment including screws, joint sealant, panel seal tape, house wrap, etc Assist in the framing process Provide panel shop drawings and customize the panel configurations to meet the building plan provided by the builder
Panel Manufacturer	Provide the structural insulated panels Provide Building Code Evaluation Reports with engineering data and construction specifications

Party	Description of Functions
Building/Wall Designer – Structural	Provide structural design of the building components and systems
Local Building Authority	Review engineering calculations, perform quality inspections, and enforce building code compliance
Panel Installer – Contract Framers	Install on-site wall construction

1.4. Technical Approach

The proposed approach for achieving the objective described in the previous section consists of two primary tasks:

1) Explore different methods and the research that has been done today in the real world, to draw lessons and avoid defects. Different studies and research have been examined, which present some techniques, strategies, and future recommendations in regards to panelized wall systems, materials used, environment where it was being applied, motivating issues behind their use, etc.

2) Survey stakeholders and building professionals to examine their constraints and their needs about walls system and materials that can be used regarding the following aspects:

   - Cost or budget to build house
   - Quality of wall and building as general: performance, reliability, durability, serviceability, features, and perceived quality
   - Appearance and aesthetics
   - Time it would take and the time desired
   - Operation and maintenance
   - Warranty and life cycle cost

1.5. Outcomes of Research

The main goal of this research is to establish the context for using soil in panelized wall systems for sustainable buildings in ArRiyadh, Saudi Arabia. This goal was approached through two primary tasks:

A. Examination of different studies and research

   This approach has provided information that leads to a better understanding of what has been done in the past in regards to the existing solutions of other products that are used in Saudi Arabia and panelized wall systems in other contexts.

B. Review and analysis of the responses received from the surveys for building professionals and stakeholders

This approach has helped to gain more knowledge and information about the needs and constraints of stakeholders and building professionals regarding current building materials to establish the context for using soil in panelized wall systems.

1.6. Chapter Summary

This chapter discusses the origin of the problem and the relevance for undertaking this study with the specific objectives behind it. It also discusses the technical approach of this study and, finally, stipulates the outcomes and benefits of the proposed building material.

2. LITERATURE REVIEW

2.1. Background

In the past, soil was used in Saudi Arabia as a main building component and in some cases the only building component, but now with the advances in building materials, concrete, glass and steel have replaced soil as the main building components today. In relation to that, this section contains a review of the recent technical literature related to the use of soil in Saudi Arabia in the past and today's building materials (red brick, compressed soil/ earth blocks, and structural insulated panels/ SIPs). Many researchers have addressed many opportunities for improving the quality of today's buildings in Saudi Arabia. The ultimate goal is to provide buildings that meet energy efficiency, reduction of pollution and waste produced to the environment, cost effectiveness, and environmentally friendliness.

This section also focuses on three alternative building materials, red brick, compressed soil (compressed earth blocks), and structural insulated panels (SIPs). Details on specific parameters are presented on each building material and a weighting given to

each of these parameters. The end result is a total score which indicates the building material that would perform best in buildings in Saudi Arabia based on the specific weights given to each parameter. This also indicates that even the highest rated building material, Structural Insulated Panels (SIPs) still has plenty of room for improvements to make it the most desired product to use.

There has been much research and studies in regards to soil and panelized wall systems, which have provided many solutions for some of the present problems in the industrial and developing worlds alike. There are problems with energy and pollution in the industrialized world, and there are problems with housing and unemployment in the developing world. There have been many articles written that discuss these areas. After reviewing a variety of literature, they fell into three main categories, which include structural insulated panels (SIPs), soil as building material, and today's building materials. A summary of each category follows.

2.2. Structural insulated panels SIPs

Structural insulated panels SIPs are composite building materials that become a widely used alternative construction material for homes and other buildings (Mosey et al. 2009). They consist of a sandwich of two layers of structural board with an insulating layer between. SIPs are most commonly made of OSB panels sandwiched around a foam core made of expanded polystyrene (EPS), extruded polystyrene (XPS) or rigid polyurethane foam, but other materials can be used. There are at least 30 types of insulating materials that can be used for the core of the SIPs (Morley 2000).
SIPs are prefabricated insulated structural elements for use in building walls, ceilings, floors, and roofs. They provide superior and uniform insulation compared to more traditional construction methods (stud or "stick frame"), offering energy savings of 30% - 50% (Mosey et al. 2009).

According to Structural Insulated Panel Association (SIPA), SIPs are very airtight and allow little infiltration, which makes SIPs contain higher R values than a similarly sized

wall in traditional system in the United States, improving thermal performance (SIPA 2006). The thermal performance of SIPs may significantly reduce costs for heating and air conditioning, one of the major expenses of home ownership. Use of SIPs in today's building industry has provided many benefits not only for the building, but also for the environment. They are easier to assemble in shorter time, which makes it possible for houses to be placed under roof within days rather than weeks. As the SIPs are prefabricated, laborers are required to have basic carpentry skills and not the skill levels of conventional framing crews, which can further reduce costs to builders (Mullens and Arif 2006). The structures of SIPs have a great resistance to wind damage and therefore, suitable for areas with stringent wind-shear or seismic codes (Lee et al. 2006).

The lumber used for manufacturing the sheathing of SIPs, OSB, is readily available. It comes from fast growing trees that can be planted and harvested in just a few years. Use of SIPs in buildings reduces the energy consumption, which also translates to the conservation of resources. As stated by many manufacturers, the foam products used for the core materials are environmentally benign (SIPA 2008).

2.3. Soil as Building Material

Soil is considered one of the oldest building materials known to mankind used in construction. This material has many potential advantages, but it is not without some flaws or obstacles, which must be taken into account and worked on to improve (Morris and Booysen 2000). Soil has been used in building construction in a variety of ways in both the past and the present based on the environmental determinants, climate, quality of soil and materials available, and the quality of skilled labor.

The articles discussing soil use were focused on the ability of soil as a building material in the past and present. They also discussed the benefits of soil use as a natural material that has a positive impact on the environment, buildings, and people as well. Aljadeed reviewed in the article "*Soil Architecture between the Past Experience and the*

Future Vision" some building construction methods that used soil, in the Arab and Western countries, ancient and recent. This study seeks to emphasize some important characteristics of soil and clarify the disadvantages that have limited the widespread use in the present time (Aljadeed 2000). There is an interest in using soil in the future for buildings in ArRiyadh, Saudi Arabia. The High Commission for the Development of ArRiyadh (HCDA) has been holding several training courses and informational sessions on the use of soil as a main building material. One of these sessions was "Earthen architecture for sustainable habitat and Compressed Stabilized Earth Block Technology" by Maïni, Satprem (2002). He presented a method of using compressed soil in construction. The aim was to redeploy the use of soil in the culture of modern buildings. In this session, a series of local and international examples of the use of soil in the building was presented with the review of the environment surrounding each of these buildings and how the effect would be, positive or negative, from the building. In both the article and the presentation, the authors provide methods to develop this material so it can be used in both present and future architecture.

2.4. Today's Building Materials

In the past sixty years, the Saudi national income has increased tremendously due to the development of the oil industry. Accordingly, Saudi Arabia has undergone vast changes in the social, economic and the physical environment. It has been transformed from a nomadic and subsistence farming economy into a modern urban/industrial society (Al-Ibrahim 1990). Building industry is one of the most sectors has experienced immense changes in the past. People has decreased their reliance on traditional building materials and started using modern building materials that are used in advanced countries such as concrete, glass, and steel. These buildings have become environmentally inefficient, hence the need for expensive artificial air-conditioning (Monawar 2001).

Concrete is the most widely used material in today's buildings in Saudi Arabia (figure 4). It represents 90% of the total buildings in the three major cities (ArRiyadh, Jeddah, and

Dammam) and 58% of the total buildings in the other cities and towns (Arafah et al. 1995). Concrete walls are considered more durable and more resistant to rain comparing to the traditional method of using soil in buildings. However, they are more heat conductive than mud walls (Al-Ibrahim 1990). The thermal load of building envelope (i.e. walls, roof and windows) is responsible for more than 70% of the total thermal load in a single-family house in Saudi Arabia (Said and Abdelrahman 1989, Abdelrahman and Ahmed 1991, Ahmed and Elhadidy 2002). Many researchers have addressed that Saudi Arabia could save up to 33 % of the annual energy consumption by using insulation products in buildings (Al-Rabghi and Al-Johani 1997 and Danny and Parker 1977). In recent years, the demand for higher standards of thermal comfort in buildings has increased by the stakeholders, which leads to the markedly increase of thermal insulation material in today's buildings (Ahmad 2002).

Figure 4: Figure 4: Concrete is most used in residential building

(http://www.aleqt.com/nwspic/12067.jpg)

The use of glass, steel, and concrete in residential dwellings normally does not include any additional materials. The homes are built and heating and cooling systems are installed to mechanically take care of the temperature. There is little attention spent integrating building materials, insulation, and HVAC systems when designing and building the homes (Aljadeed, 2000). By focusing efforts in this area and developing

strategies to reduce energy consumption or to find products to replace these that would not only offer better insulating characteristics or be more friendly with the environment, but would help reduce energy consumption, reduce landfill, and overall reduce the cost to the homeowner. It is important to consider alternatives that would enhance or improve the materials used in today's homes in Saudi Arabia. It is important to assure that the new products have long-term availability to be able to handle the increase expected in housing construction in Saudi Arabia.

According to the Ministry of Industry & Electricity in 1997, the residential sector in Saudi Arabia has the most impacts of energy conservation techniques on the overall performance (figure 5). Homeowners want to cut down the initial building cost and as a result, most basic insulation and saving measures are ignored at the residential level (Dublin and Long 1984 and Cox 1996). According to Eball Ahmad, "the average electricity consumption of an apartment in Riyadh is 20,000 kWh/yr, while the average consumption of areas of similar climates in the United States is 8000-10,000 kWh/yr" (Ahmad 2002).

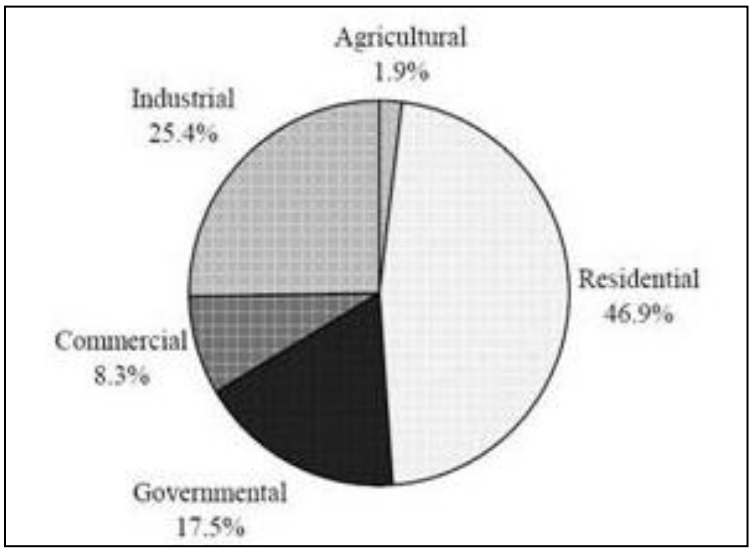

Figure 5: Energy Consumption for different sectors in Saudi Arabia

In a hot-dry climate of Madina, Saudi Arabia, there was a study done by Al-Maimani Group on several 2-story villas, one without insulation and others with different types of insulation materials. The study shows that using 5.5 cm of thermal insulation in wall assemblies can reduce the net heat flow from 64-84% depending on the type of insulation and its placement within the building envelope. It also shows that using 7.5 cm of extruded polystyrene in roof slabs can reduce the net heat flow by more than 80%. The study has demonstrated that insulation in both walls and roof can contribute to actual savings of 48-80% in annual energy consumption (Al-Maimani, 2002).

2.5. Summary of Needs for Building Product Development in Saudi Arabia

Materials play an important role in today's buildings. Architects are designing complex structures versus the plain square style houses of the past per requests of the people. Therefore, industry needs to find products that meet these complex designs. Saudi Arabia's landscape is changing as more and more homes are needed. Vast open areas are becoming residential areas to keep up with this demand. Saudi Arabia is not seeking to duplicate the buildings of the past, but is seeking to build modern looking cities. Choosing a building material when constructing residential buildings can have quite an impact not only on the building, but also on the environment. Materials such as concrete, steel, and glass are widely used, but new focus is being placed on soil. One specific area that has been a concern is the excessive consumption of energy. It is important that the materials selected meet some basic requirements such as insulating capability, availability, recyclability, structural soundness, long life cycle, long-term availability and cost.

The extreme temperatures in Saudi Arabia require increasing use of electricity or fuel to heat and cool the buildings. In order to reduce the energy consumption, it is highly recommended to use materials that have good thermal mass characteristics, high specific heat, high density, and low (but not extremely low) thermal conductivity. It is

also important to use materials that are high quality and affordable to insulate with. The most common products used in Saudi Arabia for enclosure today are concrete, steel, and glass. In most buildings, these materials are used without any additional products for insulating and thus high amounts of energy are consumed while heating and cooling the living spaces to a comfortable temperature.

ArRiyadh building industry is expanding at a rapid pace (Figures 6, 7, 8, and 9). Availability of materials is critical in order to keep up with this demand. Most of the materials used in today's buildings are being imported from other countries. Although the foreign suppliers are able to keep up with the requirements, it is having a negative effect on the economy. If materials can be developed from within the borders of Saudi Arabia, it would reduce lead times, reduce transportation costs, and help with the overall economy.

Figure 6: view of ArRiyadh in the past (www.50005000.com/Riyadh)

Figure 7: Riyadh in the past (http://www.2s2s.com/vb/t53448/)

Figure 8a: Riyadh today (www.arriyadh.com)

Figure 9: Riyadh today (www.arriyadh.com)

It is important, as environmental awareness grows, to find ways of reducing landfill waste caused by building materials. Decisions that are made with building materials today can have a profound effect on the waste stream in the future. Focus needs to be placed on finding materials that can be recycled to reduce or eliminate the amount of waste sent to landfills for disposal. It would be important, as new environmental products are developed to educate the architects, builders, and consumers so they incorporate them into the designs. Thus, there would be a benefit by reducing landfill waste and costs by recycling.

Builders must have materials that are structurally sound in order to meet stakeholder's demands. Today's advanced building materials allow for modern designs and complex structural concepts. The materials must also be able to withstand extreme environmental conditions such as high wind and torrential rains while providing aesthetically pleasing appearance to the building and providing sound structure and insulating properties.

It is important to the owner of a building to have materials that would not degrade quickly and would require minimal maintenance. Although longer life cycle materials may cost more initially, the benefits would well outweigh the disadvantages.

Saudi Arabia's expanding population is requiring a tremendous number of new building constructions. This growth can place a strain on the raw materials needed to manufacture the building components. As new materials are developed, it only makes sense, that focus be placed on materials that are renewable or have vast quantities available, and would be around for many years to come.

The economic situation in Saudi Arabia is under continuous change as it is throughout the world. The prices of materials continue to rise and fall depending on the economy in both Saudi Arabia as well as the countries where the products are coming from. Unfortunately, in today's economy, prices continue to go up. Finding a material that is not influenced by the world's economy would have a positive impact on the economy of Saudi Arabia. It is also beneficial to develop products that are easy to handle, less labor intensive and multifunctional to keep the costs down.

Characteristics needed in main building materials in Saudi Arabia

- Positive impact on the building and the environment
- Good thermal mass or insulation characteristics
- Readily available within the boarder of Saudi Arabia
- Reduction of landfill waste
- Structurally sound that able to withstand for extreme weather conditions
- Durable and require minimum maintenance
- Cost efficient and not affected by the world's economy
- Reduction of construction time

2.6. Opportunities for Building Product Development in Saudi Arabia

With the high interest in sustainability around the world, reducing energy consumption, integration between the building and the environment, renewable resource, recycling, total cost, and landfill reduction, use of soil in ArRiyadh, Saudi Arabia can help in each of these areas if the proper building material is developed. Using soil does not only provide benefits to the manufacturing and assembly portions, but also has a direct impact on the environment. They can have a direct effect on the ecosystem in areas such as energy consumption and landfill waste. ArRiyadh needs to find ways to keep the overall building costs down, reduce the dependence on non-renewable resources, and reduce time to completion while at the same time changing the perception of the people. The panelized wall system can accommodate each of these and at the same time make a more modern look to the residential buildings while pleasing the HCDA by using soil in the building process.

2.7. Chapter Summary

The literature review in this chapter focuses on three main categories, which include structural insulated panels (SIPs), soil as building material, and today's building materials. Based on this literature review, needs and opportunities for building product development in Saudi Arabia have been stipulated. The next chapter discusses how others have tried to meet these opportunities for other products in Saudi Arabia and SIPs in other contexts.

3. REVIEW OF EXISTING SOLUTIONS

3.1. Introduction

Today's residential buildings in Saudi Arabia are built using concrete, steel, glass and other new composites as they have been since 1973 when the people became more prosperous due to the production of oil. In the past, most residential buildings in Saudi Arabia used soil as the major building material since this was the main material available. These homes were more energy efficient because of the properties of the soil (Maïni 2002 and Al-Jowair 2006); however other products with world changes, new developments, and emerging materials and the desire for buildings to look more modern have replaced soil. Now as the population continues to grow and more residential buildings are required in Saudi Arabia, focus is being placed on building materials that can support the rapid growth while at the same time help reduce the consumption of energy (HCDA 2006). It is also important to have the materials readily available for use. The use of concrete, steel and glass, although popular, do not offer the insulating

properties that soil does and must be imported from areas outside of Saudi Arabia or derived from non0renewable resources.

Building materials have been changing as new products have been developed, but these new product are harder to come by and not as effective as soil that was used many years in the past. As direction from the government of ArRiyadh has changed, the building materials being used must change to conform to the requirements. It is important to select the right materials that are economical, safe for the environment, and positively affect the social and cultural impacts while at the same time offer good insulation, availability, structure, long life-cycle and are recyclable. Red brick, compressed soil and SIPs are three alternatives that offer some solutions to the recommendations of the government. Each would be discussed in more details with specific emphasis on how well each solution meets the objectives specified above.

3.2. Products used soil in Saudi Arabia

3.2.1. Red Brick

Red brick is a product that was developed in 1980 and put in use by 1982, especially in western Saudi Arabia. The red brick has made it easier to build arches and domes, especially in mosques, while significantly reducing the time of construction and the overall cost. After the success of the red brick in mosques, it was migrated to residential units for use.

The red brick (Figure 10 & 11) uses a red soil available in the western portion of Saudi Arabia. It is mixed with other components and resembles the cinder blocks used in the US. These bricks are fired before use to yield a stronger material. They also have good load resistance, 200 kg/cm^2, which allow them to be used for load bearing walls due to their high compression resistance. Hasan Sardar, Om Alqura University in Saudi Arabia, made one of these studies. Hasan designed a five-story building using the red brick instead of concrete as the load bearing walls. He found that using this material in

the construction of load bearing walls reduced the overall cost of construction by 24% (Sardar 1985). Red bricks also reduce the overall cost by minimizing the use of reinforcing concrete to around 30%, the use of reinforcing steel to around 50%, and the use of columns, thus minimizing the need for formwork (Algabli 2000). The red bricks also offer the strength and durability while at the same time provide a higher heat insulation characteristic (Al-Maimani 2002).

However, these products are not available throughout Saudi Arabia as they are produced primarily in the western province and shipped to other areas by trucks, thus increasing their cost. In addition, red bricks are produced by a highly-mechanized industrial process, which also drives the cost up and affect the total cost of buildings. The result, unfortunately, is large-scale monotony (Al-Ibrahim 1990).

Figure 10: house was built with red brick in Saudi Arabia (http://www.maimani.com)

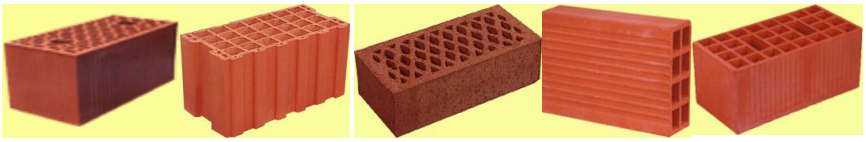

Figure 11: Different sizes of red brick (http://www.maimani.com/Brick/Brick_Index.html)

3.2.2. Compressed Earth Blocks

Satprem Maini, from India, developed compressed soil bricks in the early 1980s. It was not until 2005 when this technology arrived in Saudi Arabia. The compressed soil bricks offer many good traits. They are resistant to rain, snow, and freezing and thawing and therefore do not require much maintenance (Maïni 2002). In addition, they use soil from the surrounding area, which along with the other benefits help reduce overall costs. They do not require any firing as the red bricks do, and any unused bricks or bricks from a demolition, are crushed and reused in new bricks or recycled back into the earth with no harmful effects.

A key material that is readily available that has drawn attention again is soil. Soil has many characteristics that make it an ideal building material in Saudi Arabia. It is more readily available, a natural resource, lasts longer, does not need advanced techniques to recycle, is fire resistant, and reduces economic strain. However, even with all the advantages and good qualities of soil as a building material in Saudi Arabia today, it is still looked at negatively. The perception among people is soil brings to mind a backward society, it is related to poverty, and it is inferior to other building materials used today (Aljadeed 2000).

The building material in the past was made by placing soil (a mixture of gravel, sand, silt, and clay) and water in a cloth mold. These molds would allow the water to evaporate while in the sun and the end product would be a brick (Figure 12). In addition, a soil mixture would be mixed with a smaller quantity of water and placed on the ground. It would then be shaped and cut by hand into small sections or bricks and allowed to dry in the sun. Although these methods were the key ways to use soil in the past, today the emphasis has been compressed soil. This process uses the same components found in soil mixtures before, but with the addition of 10% cement. These bricks are produced using machinery that would yield uniform and stronger bricks than the past (Figure 13) (Maïni 2002).

Figure 12: Building with soil, old method (www.gulflobby.com/lobby/t80822/)

Figure 13: Building with soil, compressed soil (www.alriyadh.com/2005/01/02/img/021273/jpg)

There is attention by The High Commission for the Development of ArRiyadh (HCDA) to use compressed soil, but only for heritage buildings such as museums and mosques. These buildings are specifically built to look like buildings from the past including the use of soil versus modern building materials. The main reason compressed soil is not used for residential buildings is the negative perception people have towards soil. The older style bricks are not used because they have many other issues that affect their use. Such things as high maintenance, structural weakness, and short life span due to the environmental effects of rain and high winds, and labor requirements discourage their use.

3.3. SIPs in other context

Structural Insulated Panels (SIPs) have become a widely used alternative construction material for homes and other buildings in different parts of the world. SIPs usually are made from a thick layer of foam (polystyrene or polyurethane) sandwiched between two layers of oriented strand board (OSB), plywood, or fiber-cement. As an alternative to the foam core, SIPs are available with a core of agriculture fibers such as wheat, straw, rice, etc. The outcome is an engineered panel that provides structural framing, insulation, and exterior sheathing in a solid, one-piece component. Different types of SIPs can be specified according to the type of two categories, sheathing material and insulation components.

3.3.1. SIPs sheathing materials

There are a number of sheathing materials that can be used in today's panels system. Below is a brief description of the common three types of sheathing materials.

3.3.1.1. Oriented Strand Board (OSB)

OSB is engineered wood that made from sustainable fast-growing trees, and is the most common type of sheathing material for SIPs.

3.3.1.2. Metal

Stainless steel and G90 galvanized are the most common metal sheathing used for SIPs. Long-term it's probably best to go with stainless.
http://www.sipsupply.com/metal_skinned_sips.html

3.3.1.3. Fiber-cement SIPs

The exterior SIPs layers can also be made from fiber-cement and cellulose, making a less common but important type of SIPs, called cementitious or fiber-cement SIPs.

3.3.2. The SIPs core

The SIPs panel core is usually a layer of polystyrene or polyurethane foam. Wheat straw and other agriculture fibers can be used instead of the polystyrene or polyurethane, ensuring a similar structural and thermal performance, but it is a less common alternative.

3.3.2.1. Expanded Polystyrene Insulated Panels

Most of SIPs are produced with expanded polystyrene (EPS) foam board. This type of SIP has a nominal R-value of about 4 per inch (2.5 cm) to 5 per inch of thickness (PATH 2006).

3.3.2.2. Polyisocyanurate and Polyurethane Insulated Panels

Some manufacturers choose to use polyisocyanurate or polyurethane as the insulating material. Foam board or liquid foam can be used to manufacture an SIP. Liquid foam can be injected between two wood skins under considerable pressure. When hardened, the foam produces a strong bond between the foam and the skins. Polyurethane and polyisocyanurate SIPs have a nominal R-value of around R-6 to R-7 per inch (2.5 cm) of thickness. Liquid foams contain a blowing agent, some of which escapes over time, reducing the initial R-value of the SIP from about R-9 to R-7 (PATH 2006).

3.3.2.3. Other compressed organic core insulated panels

Some organic materials e.g. straw can be used as insulation core in the SIPs. They are more environmentally friendly than the other types because they're made from renewable resources. However, most of these SIPs offer less insulation per inch of thickness, and they are considerably heavier (Reference).

The SIPs are building materials that have not been innovated in the Saudi market. Different types of SIPs that are adopted today all over the world mainly use materials and techniques that are not readily available in Saudi Arabia. Thus, adopting SIPs in the Saudi market using the same products that are used outside the country would increase their cost. In addition, the common SIPs are produced by a highly-mechanized industrial process, which also drives the cost up and affect the total cost of buildings.

3.4. Chapter Summary

This chapter includes a review of products that are used in the Saudi building industry to meet the needs of building professionals and stakeholders. Red bricks and compressed soil are the two main building products that have emerged to the market in the past three decades. This chapter presents the good traits and limitation of better adoption of the red bricks and compressed soil in Saudi Arabia. It also discusses the different contexts of SIPs that are used in different parts of the world. The next chapter establishes the context for using soil in the SIPs system to be used in ArRiyadh, Saudi Arabia in order to meet the needs of building professionals and stakeholders.

4. THE PROPOSED SOLUTIONS

4.1. Introduction

There are a number of systems and methods that have been addressed to improve today's buildings and environments. One of these systems is structural insulated panels or panelized wall systems. A key point in these systems is to incorporate the insulation with the wall or roof materials. It can have a positive effect on the building and the environment. In addition, it is a suitable material that can be used in today's changing world. The U.S. Department of Housing and Urban Development (HUD) has established a guideline for the design, manufacture and installation of panelized wall system construction. More importantly, it provides a starting point for the development of industry standards which, through a reference in future building codes, could advance panelized wall construction as a safe and affordable housing technology. The U.S. Department of Housing and Urban Development (HUD) also has done some case studies in regards to different materials that can be used in the panelized wall systems. Although the scope of these case studies covers all types of panelized walls including

load bearing and nonbearing walls, shear walls are the focus of the engineering evaluation of panelized wall construction. An effort is made to scrutinize the engineering methods and substantiation procedures used by the demonstration participants for structural design of lateral force resisting systems. Shear walls of both buildings are analyzed using innovative engineering methods and recommendations for improvements or novel design solutions are provided.

4.2. Use of Soil in structural insulated panels (SIPs) in Saudi Arabia

Structural insulated Panels, SIPs for construction began in the 1930s. The SIPs used today, foam cores, gained attention in the 1970s and continue to be used in areas outside of Saudi Arabia. A home built with SIPs can reduce the time of construction, offer higher insulating values, and thus offer decreased energy consumption. The development in ArRiyadh, Saudi Arabia would be focused on using soil as the insulating layer. This would take both time and money to fully develop a strategy to encourage their use over other products. Once SIPs with soil are implemented, further reduction in costs would be seen, as the soil is readily available in and around ArRiyadh.

Use of soil in SIPs can have a positive impact on the people, the environment, and the economy. It would minimize waste materials and the negative impact on the surrounding environment. From an economic perspective, it can reduce the cost of using virgin products to produce the panels. Thus, using this strategy can have a positive effect on the people's health and comfort. In addition, developing a better understanding of the materials available and helping in the selection of the right materials to meet the needs would not only benefit just the building, but also the whole environment.

Building professionals and stakeholders are interested in adopting building products that would their needs in the building industry. Table 2 summarizes the hypothesis

responsibilities and interests of the building professionals and stakeholders as would be observed during the building construction process.

Table 2: Responsibilities and interests of each stakeholder involved in construction process

Stakeholder	Description of Functions	Interests
Homeowner	Select the house and pay the bills	Structurally sound Appearance Reducing energy consumption Reducing environmental waste Affordable
Building/Wall Designer - Structural	Provide structural design of the building components and systems	No design limitation of the size and shape (Creativity) Energy efficient Structurally sound Appearance
Panel Manufacturer	Provide the structural insulated panels Provide Building Code Evaluation Reports with engineering data and construction specifications	Good investment Decreasing imports Using renewable and Recyclable products Easy to assemble
Project Manager	Management of the construction process including hiring of subcontractors and obtaining building code approvals	Cost Complexity

Wall Panel Supplier	Provide complete equipment including screws, joint sealant, panel seal tape, house wrap, etc Assist in the framing process Provide panel shop drawings and customize the panel configurations to meet the building plan provided by the builder	Easy to transport Availability of equipment Easy to follow instructions
Panel Installer – Contract Framers	Install on-site wall construction Weight of Panels Cohesiveness	Easy to follow instructions How many people needed for installation Reducing waste on the job-site
Local Building Authority	Review engineering calculations, perform quality inspections, and enforce building code compliance	Meets the code requirements Decreasing imports Using renewable and Recyclable products Reducing energy consumption

Red bricks and compressed soil bricks are the only two developments that have considered soil as the main material, in ArRiyadh, Saudi Arabia. The SIPs, although currently not in use, would also focus on soil, as the insulating layer versus the more commonly used foam products. Each of these methods offer better insulating qualities than glass, steel, or concrete by themselves and each would reduce the dependency on imports as well as reduce overall costs.

4.3. Expectation of Using Soil in SIPs

Many researchers and experimentation on building products have focused on materials that would satisfy the key demands or requirements from the building professionals and stakeholders. The interests vary widely as can be seen in Table 2, depending on who the stakeholders are, but ultimately satisfying all players would make the new product more acceptable for use by everyone. There are many parameters that have a significant effect on the interest of the building professionals and stakeholders. The following is the hypothesis performance of SIPs using soil as a building product in order to meet these parameters.

4.3.1. Availability of raw materials

Large reserves of soil are readily available throughout the country of Saudi Arabia, which would make it easy to adopt the SIPs in all the area, while the raw materials of red brick are only found in the western region of the country

4.3.2. Structural Soundness

The strength of SIPs using soil has not been determined, but table 3 below shows the strength properties of red brick and compressed soil. Therefore, developing a product that would have equal properties if not better is essential to satisfy the building professionals and stakeholders.

Table 3: The parameters of structurally soundness of red brick and compressed soil

Structural Parameters	Red Brick	Compressed Soil
Tensile Strength	Very low unless reinforced (Bryan and Mervyn 2004)	13.5 – 19.5 lbs/sf. (Maïni 2008).
Lateral Strength (Flexural)	Very low unless reinforced (Bryan and Mervyn 2004)	13.5 – 19.5 lbs/sf. (Maïni 2008).

Structural Parameters	Red Brick	Compressed Soil
Compressive Strength	47.18 lbs/sf.	67.4 – 134.8 lbs/sf. (Maïni 2008).
Torsion Strength (Shear)	Very low unless reinforced (Bryan and Mervyn 2004)	13.5 – 19.5 lbs/sf. (Maïni 2008).

4.3.3. Stabilization and Durability

Red brick is usually fired in a kiln and as a result, it is very good stabilized and can last at least 100 years, but the mortar breaks down sooner and would affect the overall durability (Al-Gabli 2000). Compressed soil is added to 5% of cement to improve the stabilization properties (Maïni 2008) and it would stand for centuries (Morony n.d.). Therefore, it is important to consider some techniques in developing the SIPs to improve the stabilization and durability of the product.

4.3.4. Water absorption

According to Maïni (2008), the water absorption of red brick can be between 10 to 14% whereas it is 9 to 12% in compressed soil (Maïni 2008). SIPs are extremely airtight and water absorption in SIPs using polystyrene as an insulator is 4%. The water absorption when using soil would significantly depend on the all components of the product and it is essential to consider this in developing the product.

4.3.5. Energy Efficient

Building with red brick can reduce the energy used to heat and cool the building by 25% - 30% (Ahmad 2004). R-values are 0.2 per inch with red brick (Al-Sebaiee 2008). In most cases, insulation is needed to provide additional protection from heat and cold (e.g. polystyrene), which would increase the cost (Al-Gabli 2000).

In compressed soil, the mass of compressed earth blocks makes the walls an energy efficient system. The physical attributes and ability of soil to regulate moisture and temperature, allows for heating/energy reductions of up to 30% and in some cases even

up to 80% (Cebtex 2006). The thermal resistance of soil is dependent on soil type and density. Thermal qualities of adobe and other earthen materials cannot be accurately expressed or understood using only the R-values of conventional building materials. For adobe, it is the latent heat flux promoted by a moisture differential that lowers and raises the temperature of the adobe. The concept of insulation, as it is applied to conventional building materials, is of doubtful use or significance (Morony n.d.).

SIPs are extremely airtight and when using compressed soil, the energy efficiency would be better in SIPs than other building materials that exist in the market. SIPs using polystyrene as an insulator can cut energy consumption by up to 50% when heating or cooling a home (SIPA 2008). Using soil in SIPs is also expected to cut energy consumption as well.

4.3.6. Cost

Building with SIPs, builders can save money through decreased construction time and labor costs. They significantly reduce job-site waste disposal and temporary heat during construction (SIPA 2008).

4.3.7. Eco Friendly

SIPs using polystyrene as an insulator emit around 1.76 kg/m3 of pollution to the air (SIPA 2008). Production of compressed earth blocks emits 16 kg/ m3 (Maïni 2008). Therefore, SIPs using soil are expected to emit more than 16 kg/m3 due to the use of other components and high mechanism that would be used.

4.3.8. Disposal or Demolition

Soil in SIPs can be 100% recycled or returned to the soil without any negative impact on environment.

SIPs are pre-fabricated panels that would substitute soil in the current panelized wall system. This strategy can have a positive impact on the people, the environment, and the economy. SIPs have good thermal mass characteristics, high specific heat, high density, and low (but not extremely low) thermal conductivity, which helps reduce the energy consumption. From an economic perspective, it can reduce the cost of using

virgin products to produce the panels. SIPs are also environmentally friendly since the soil can be recycled back into the earth with no harmful effects, the sheathing materials & adhesives would need to be addressed as they are developed. They also minimize waste materials and the negative impact on the surrounding environment. Thus, using this strategy can have a positive effect on the people's health and comfort.

4.4. Conclusion

In conclusion, understanding the requirements of stakeholders and following the directions of the HCDA can impact the end results or where additional research needs to be spent. Residential building materials have changed little for many years, mainly built from concrete. In the 1980's such materials as red brick and compressed soil were introduced as potential products to replace concrete. Each of these products has better insulation properties and thus helps to reduce the consumption of energy for both heating and cooling. The majority of residential buildings today are still built with concrete with only little interest in either red brick or compressed soil. The HCDA has an initiative to use soil as a building material and this continues to drive research and development in this area in Saudi Arabia. SIPs, an emerging product with many positive characteristics, can potentially help to meet the HCDA initiative. With some modifications to use products available in Saudi Arabia, and more pressure to find ways to reduce energy consumption, returning to the use of soil in SIPs can help to meet the requirements as well as offer other benefits, i.e. faster assembly, reduce space at work site, and reduce total cost. The interior and exterior finishes of the SIPs would have to be closely evaluated and decisions on what products to use for sheathing to produce these finishes would need to be addressed so additional problems are avoided (i.e. imports used for sheathing). Thus, spending some time upfront to understand the requirements of stakeholders and what drives their decisions and knowing the initiatives of such organizations as the HCDA would help in the development of a useful end product that would be beneficial to the environment and meet the building requirements of all the stakeholders

4.5. Chapter Summary

This chapter establishes the context for using soil in the structural insulated panels SIPs in ArRiyadh, Saudi Arabia. It presents the interests of the building professionals and stakeholders about building materials in the Saudi Market as discussed in the literature review chapter. Based on that, it discusses the expectation of the proposed solution, using soil in SIPs, in the Saudi building industry. However, understanding the requirements of building professionals and stakeholders and what drive them to adopt a specific material is essential to establish the context for using soil in SIPs in ArRiyadh, Saudi Arabia. The next chapter discusses the methodology of this research to gather such information needed from the building professionals and stakeholders.

5. Research METHODOLOGY

5.1. Introduction

This study relies on a qualitative method of research wherein the most important potential limitation is that the researcher is the instrument of evaluation, solely dependent on self reporting. The data for the research is reliant on the views of the participants, which are then interpreted as understood by the researcher. This retrospective collection of data is another important limitation of this study.

This section explains the qualitative research methodology adopted for exploring people's concerns and desired performance of building materials used in today's buildings in ArRiyadh, Saudi Arabia. The research data came directly from the participants in the form of words, not numbers. Each data set was unique as it captured information from the perspective of different individuals. The participants were the independent variable in this research.

The nature of this research suggested a qualitative methodology, which aims to gather an in-depth understanding of the stakeholders' behavior and the reasons that drive their

decisions. The data gathered came from the participants in the form of words and numbers and captured information from the perspective of different stakeholders.

5.2. Selection of Participants

Participant selection criteria were exercised so that only people from the building industry involved in residential projects and were invited to participate in this research. The research investigated multiple realities for a phenomenon as no one person's experience building with SIPs. Only a qualitative method has the scope for exploring a multi-faceted problem such as this. The research includes four surveys that were addressed to stakeholders who deal with building materials in the residential industry in Saudi Arabia and can give their reflections about the performance of these buildings. The target population includes homeowners, architects, builders, and manufacturers.

5.2.1. Homeowners

The participated homeowners in this case study were randomly selected in ArRiyadh. Diversity in demographic characteristics was considered in this study and therefore, an equal number of 25 homeowners in each of the north, south, east, and west of the ArRiyadh area were selected. The new housing developments are taking place toward the north direction and thus, residential units in the north is newer and more expensive than the once in the south. The eastern and western buildings fall in between with some variation according to the location of central commercial points, public and private services, and governmental offices. This minimizes bias and simplifies analysis of results. In particular, the variance between individual results within the sample is a good indicator of variance in the overall population, which makes it relatively easy to estimate the accuracy of results.

In the summer, people usually meet very often for gathering, socializing, or special events such as weddings or parties. There are also other places where people usually go during the summer more often such as malls, summer auctions, tourism sites, etc.

Moreover and as a Muslims society, people always go to mosques five times a day. That made it easy to recruit some homeowners, who were randomly selected, in groups of 4-5 people in such locations or during such events. In these specific events and places, the researcher approached people who were in groups asking for their participation in the survey. Fortunately, most people were willing to participate in the questionnaires and helped in sharing thoughts and ideas between the researcher and the other participants. In some cases, the researcher helped people challenged with writing in completing the surveys and recording their comments on some questions.

5.2.2. Building Professionals

The other stakeholders, architects, builders, and manufacturers were also randomly selected with respect to the differences in class and size of the offices that these professionals represent. The researcher met first with ten of his colleagues, architects who graduated from Architecture College, King Saud University in 2005, and are working now in both sectors, public and private. Throughout their experience, they have established formed relationships with some building professionals who were contacted first via phone calls or emails before meeting with them personally. There were 60 building professionals who participated in these questionnaires, 20of each group (architects, builders, and manufacturers). The questionnaires involve different levels of employees who represent their companies, ranging from top management to the workers.

5.3. Design and Development of the Questionnaires

Homeowners are ones who most experience with building materials and building professionals, architects, builders/ contractors, and manufacturers also deal with these materials. Therefore, it is important to know their evaluation regarding materials they have chosen for their buildings. All the questionnaires were prepared to gather the stakeholders' concerns and desired performance of these materials regarding cost, time

of construction, appearance, building structural soundness, insulation capability, energy efficiency, and environmental friendliness.

All the questionnaires were intended to be done in ArRiyadh during the summer, 2008. Therefore, the time limitation was an important factor in choosing standardized open-ended and close-ended questions to be an easy to complete in less time. However, there were some comments regarding some questions from the participants and they were documented separately. This approach helped in understanding subjects' impressions and the desired performance of the proposed building material of SIPs using soil.

The following represents the process developed by Patton (1990) that was used in this research as a guide to gather information of people's needs regarding the building materials in ArRiyadh.

5.3.1. Thematizing

The purpose of the study was clearly stated to the interviewees and a diagram of the proposed building material in this research was also presented.

5.3.2. Designing

The overall design for the study, including the later stages of analyzing and reporting, was planned before the interviewing began. The standardized open-ended and close-ended questions approach was a good technique that made the data easier to gather, code, and analyze later. Although a draft of the questionnaire was made, the option to modify the questions during the completion of the questionnaire to suit the participant was never ruled out. Even additional questions could be asked if it seemed necessary during the course of the interview. The order of addressing the questions was kept flexible, but within the limit of logical sequence. The ultimate aim of this approach was to get the required data from the participants.

The questionnaire started with a presupposed statement to encourage the participants to relax and come out of their shell. This was followed by an optional space for personal information for further communication purpose. The first question in the four questionnaires was one that helped participants to have a very good concept of the

remaining questions related to each stakeholder's interests and concerns. All the questions were categorized in a logical order. They did not directly ask for comments on any particular point, but they were generic to the category. They also were framed to seek the suggestions and opinions of the participants. The concluding question asked for their comments and opinions regarding use of SIPs in their future buildings if they have the chance to build again for themselves or any of their relatives. A copy of the four questionnaires, original English and a translation to Arabic, is included in Appendix A.

5.3.3. Development of the questionnaires

There was not a pilot test of the study due to the time limitation. However, there were three meetings that took place in the United States with the researcher committee and two others, one with a group of architecture colleagues and one with a group of professionals previously known to the researcher in Saudi Arabia. The goal of these meetings was to develop effective questionnaires that can collect information about the needs and concerns of building professionals and stakeholders regarding the current building materials in the market and from then, establish the context for using soil in SIPs in Saudi Arabia. Therefore, questions had to be easy to understand and relevant to the study.

The first meeting was a committee meeting with Prof. Annie Pearce, Prof. Christen Fiori, and Prof. James Jones, who are faculty members at Virginia Tech. This meeting was mainly to discuss the face validity of the questionnaires. Based on that, some adjustments had been applied to all the questionnaires including adding or deleting some questions, reformulating others, and adding statements and figures that can make sense to building professionals as well as lay people.

The other two meetings, with a group of architecture colleagues and other professionals previously known to the researcher, took a place in Saudi Arabia. These two meeting had helped in developing the surveys in the chosen Arabic words and the layout of the questions due to the similar background and culture. For example, in the architects'

questionnaire, there were two questions related to the insulation location. One asked about the percentage of total designed buildings that have insulation in the roofs and the other one asked about the total designed buildings that have insulation in the walls. In the final questionnaire was handed out to the participants, these two questions were emerged into only one question asking about the percentage of the total designed buildings that consider insulation in the designed process.

5.3.4. Questioning

5.3.4.1. Homeowners

Understanding people's customs and traditions had helped in communicating with people in ArRiyadh and particularly homeowners. The questionnaires were done in the evenings of the summer, when most people are free and spending more time with their families going to some of the public places and social events, e.g. malls, coffee shops, social clubs, and wedding parties. In shopping malls, many people go to cafeteria areas or coffee shops while waiting for their families to finish shopping. This was a good opportunity to interview some homeowners in groups of 4-5 people. The researcher handed out a questionnaire for each participant. The participants can ask the researcher any question, provide more suggestions, and share thought and ideas between the researcher and the other participants of the group, which helped in generating more information related to the study. Coffee shops and social clubs, in which people come and spend some free time with their friends, were two other places for interviewing people. People were willing to answer the questionnaires and provide any information related to the subject. Moreover, customs of wedding parties in Saudi Arabia vary from trip to trip. In general, there are lots of people, 200 or more, who come to that night and this was another way of meeting people in groups to get their responses regarding building materials. Table 4 shows the breakdown of the selection of homeowners in different events and places in ArRiyadh.

Table 4: Breakdown of the selection of homeowners in different events and places in ArRiyadh

Event or Place where questionnaire took place	Day	Location	Time	# of sessions	# of people	Average time
Shopping mall	1	South	6-9 pm	1	2	40-45 mins
Shopping mall	2	South	6-9 pm	3	5	40-45 mins
Real estate auction	3	South East	4-8 pm	4	15	40-45 mins
Real estate auction	4	South East	4-8 pm	6	22	40-45 mins
Wedding	5	North	8-10 pm	3	9	40-45 mins
Wedding	6	West	8-10 pm	3	10	40-45 mins
Prince Salman Club (Social Club)	7	Center	8-10 pm	3	13	40-45 mins
General invitation	8	East	8-10 pm	1	5	40-45 mins
Coffee Shop	9	Center	9-11 pm	2	8	40-45 mins
Coffee Shop	10	North	9-11 pm	2	8	40-45 mins
Shopping mall	11	West	6-9 pm	3	6	40-45 mins
Shopping mall	12	West	6-9 pm	3	7	40-45 mins
Shopping mall	13	Center	6-9 pm	2	5	40-45 mins
General invitation	14	East	8-10 pm	1	4	40-45 mins
Coffee Shop	15	North	9-11 pm	2	6	40-45 mins

5.3.4.2. Building professionals

For architects, builders/ contractors, and manufacturers, there was a different approach for reaching individuals. They were mostly contacted first via email and phone calls to schedule appointments for interviews and surveys. These interviews were done

individually with all participants of this section. There were some arrangements to have information sessions regarding production of building materials with three of the manufacturers who participated in this study. This helped in gathering valuable information that supports this research as well as other areas of study. Architects and builders/ contractors had also help in collecting data in regards to preferable building materials and pros and cons of different building materials based on specific needs for different projects.

5.3.5. Analyzing

As the data was gathered, it was entered into the Microsoft Excel program for analysis. After the complete data was entered, frequencies were run for the generation of descriptive statistics. For each question or variable in the four questionnaires, the overall percentages, averages, modes and ranges (where applicable) are presented in text and/or chart form.

Appendix B contains the complete list of categorized responses to open-ended questions. Each response to an open-ended question was grouped into a category with similar responses, counted and then the categories were prioritized based upon frequency of mention. In general, open-ended questions elicit the strongest and most important responses of visitors. They also lead to a relatively wide range of detailed responses and give the respondents an opportunity to express their opinion on important issues in their own words.

5.3.6. Verifying

The purpose of this step is to determine reliability (how consistent the findings were) and validity (whether the study really investigated what is needed). One way used for verifying the analyzed results was going back to some individual stakeholders and asking them if the answer is really what they meant. Some questionnaires were excluded due to contradictions found in the data. There were 100 out of 110 homeowners' questionnaires were considered in this study. The other ten were excluded for unreality or incongruity information or numbers mostly related to cost. For example, in some questionnaires, homeowners stated that their housings are rented

from the government and they answered other questions related to construction issues such as time, cost, site concerns, etc. where homeowners did not experience such issues.

5.3.7. Reporting

The results and findings of the study are intended to be usable and used. For a study to be usable, the researcher believes in full disclosure, describing the methods completely. Detailed technical reports cover the sampling, fielding, and data collection procedures. To be used, results must be presented to meet the needs, style, and convenience of all audiences.

5.4. Ethics in Research

Human subjects are the source of data for this research. The guidelines followed for this research are listed below.

- The purpose of this study was clearly stated.
- Participants were not exposed to any risk, so the gains from this study clearly outweigh any potential risks.
- The identities of the participants shall always be protected in all written or electronically published work.
- The findings from the collected data are truthfully reported.

An approval for the study was obtained from the Institutional Review Board (IRB) of Virginia Polytechnic Institute and State University. The collection of data was approved for May 2008, to August 2008. The application package submitted to the IRB included a protocol for the research, investigators' resumes, and the questionnaires. Appendix C includes the IRB application package documents.

5.5. Chapter Summary

This chapter describes the method of applying qualitative design to this research which includes the selection criteria for participants. It also explains the process of designing and developing the stakeholders' questionnaires including the themes, designing and development of the questionnaires as well as interviewing, analyzing, verifying, and reporting data. A description of the method adopted for analyzing the data and the ethics follows.

6. RESEARCH FINDINGS AND ANALYSIS

In this study, four questionnaires were presented to four different stakeholders that deal with building materials in ArRiyadh: homeowners, architects, manufacturers, and builders. The questionnaires were developed to find out the building material needs of the people in the area. The ultimate goal of this case study is to create a product that offers better insulating properties, is more energy efficient, is environmentally friendly, and reduces the time of construction. SIPs (Structural Insulated Panels), an emerging product with many positive characteristics, can potentially help to meet the HCDA initiative. With some modifications to use products available in the ArRiyadh area, and more pressure to find ways to reduce energy consumption, returning to the use of soil in SIPs can help to meet the requirements as well as offer other benefits, i.e. faster assembly, reduce space at the work site, and reduce the total cost of construction. On the other hand, other key aspects that do not have enough information would need further investigation. This would help in finding specific results or numbers that can be enhanced if needed to meet people's desired performance and eliminate their constraints. The results can be presented to the defined stakeholders at some point in this study.

6.1. Introduction

For the past five decades, the people in ArRiyadh lived in homes built with soil. These buildings had good thermal mass characteristics, high specific heat, high density, and low (but not extremely low) thermal conductivity. However, the walls of these buildings had to be very thick due to their weakness in carrying loads. In the current buildings, most people use concrete, glass, and steel to construct their homes. These materials require more insulation treatments. Therefore, new technologies and materials have been developed in the past twelve years to improve the insulation properties and reduce the energy consumption in today's buildings. Red brick, which has been used in other areas of Saudi Arabia, has limited use today in ArRiyadh due to their availability limited to the western region of Saudi Arabia, which is about 600 miles from ArRiyadh. Each of these products and technologies has both positive and negative aspects that would be captured by developing some surveys for homeowners and building professionals, which include manufacturers, architects, and builders in ArRiyadh. The primary goal of the questionnaires is to find out the desired performance and constraints of building materials that have been used in the area. The recruitment of homeowners was evenly split to include north, south, east, west, and center regions. Most were done in groups of 4-5 people where their thoughts and ideas were shared between all the participants. The homeowners have basic information on current performance of building materials used in their homes and also the requirements they want from the building materials. In addition, the recruitment includes manufacturers that are located near ArRiyadh and other regions of Saudi Arabia based on where current production occurs. The manufacturers have the knowledge of the market needs and understanding of the requirements to manufacture the different building materials. The recruitment also includes builders/contractors in ArRiyadh (mainly to include those that build residential homes). The builders understand the requirements required at a job site based on the material chosen for construction. Architects/designers were also included in this study with a focus on those located in ArRiyadh. They have the ability to integrate and suggest a variety of building materials in the designs to meet the homeowner's needs. The ultimate goal of this case study is to create a product that reduces energy

consumption, reduces time from start to completion of a project, significantly reduces on-site labor requirements, and substantially decreases the amount of waste going to landfills.

The data published by the Saudi Ministry of Industry and Electricity shows that buildings consume the largest portion (about 73%) of the total electric energy sold in the country. The residential buildings alone consume about 46.9% of the total energy consumption in these buildings (figure 14) (Ministry of Industry & Electricity, Saudi Arabia, 1998)[1]. An analysis of the data collected at the Research Institute of King Fahd University of Petroleum and Minerals shows that air conditioning accounts for about 73% of total electricity consumed in the residential sector (Elhadidy, Ul-Haq, and Ahmad, 2001) [2]. The excessive demand for air-conditioning has created a need for building materials that offer better insulation properties, are more energy efficient, environmentally friendly, and reduce the time for construction.

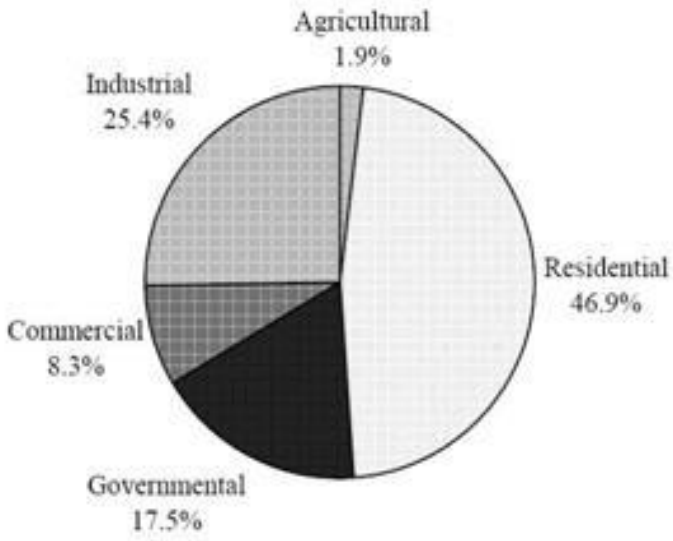

Figure 14: Energy Consumption for different sectors in Saudi Arabia

6.2. Homeowners

The homeowners were evenly recruited in five regions of ArRiyadh, north, south, east, west, and central. This gave a general picture of the residential buildings in ArRiyadh with differences between people and their income. There were 100 questionnaires evenly divided in the five regions. The recruitments were done in groups of 4-5 people to share thoughts and ideas between all the participants. They were also done in public places where people usually go such as coffee shops, mosques, real estate auctions, weddings, and general invitations. The study included different types of housing units that were divided into 11 traditional houses, 41 villas, 21 single floor villas, 25 apartments, and two others that were unspecified (figure 15). The tenure of these units was 56 owned, 37 rented, six provided by employer, and one that was unspecified (figure 16). These units have different heights that range from 1 floor to 3 floors or more (figure 17).

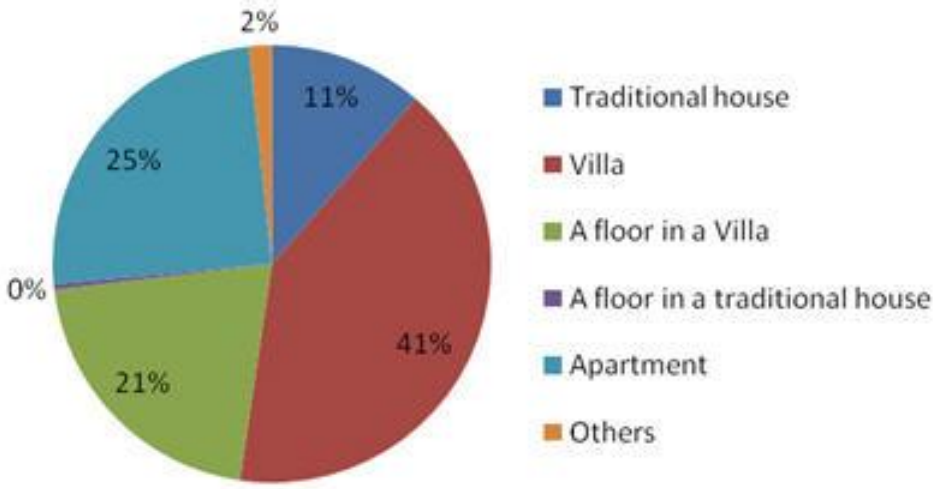

Figure 15: Important aspects for homeowners regarding building homes

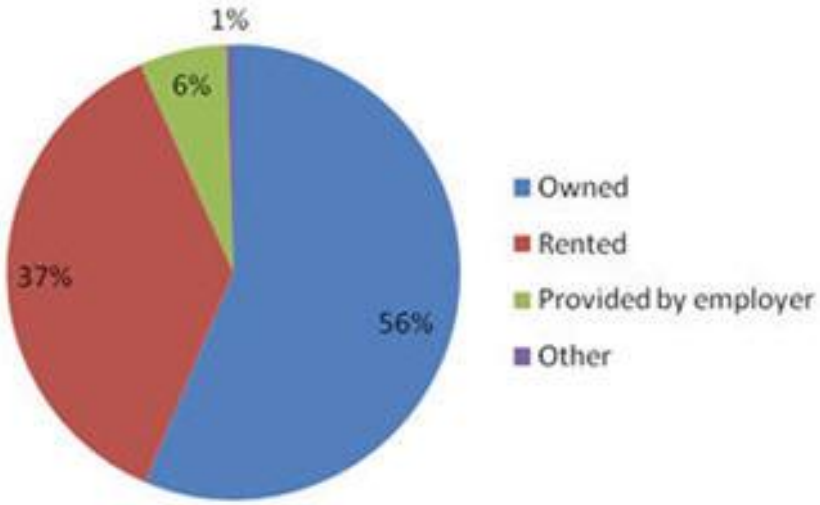

Figure 16: Tenure of housing units in Riyadh, Saudi Arabia

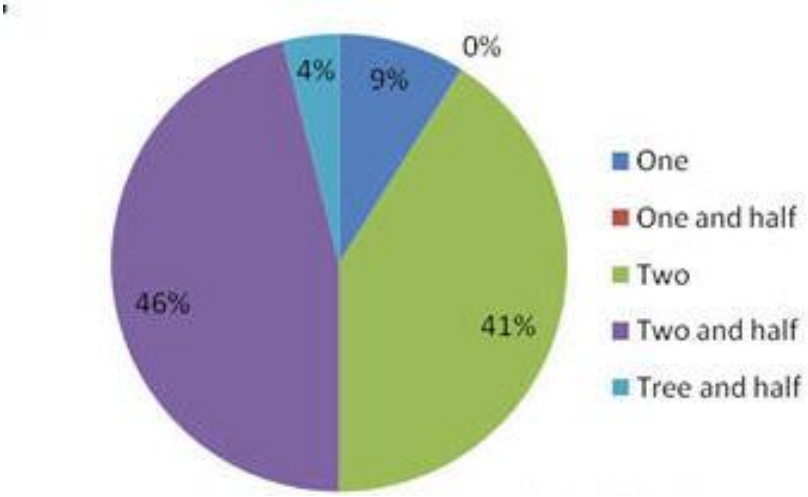

Figure 17: Total floors in Riyadh's buildings

It is always important to know the constraints and the desired performance the people want in their housing units. After analyzing the data collected, building structural soundness was the most important consideration for most of the population at 22%. Most people want to have houses that are structurally sound and can carry possible

loads. Total cost of construction was the second most important key for people at 21%. After that, appearance was 11%. Buildings that are environmentally friendly and reduction of energy consumption tied for the fourth important aspect for most people at 10%. The two key aspects of building materials that have insulation properties and the total time of construction were sixth at 9%. Finally, ease of constructing the building was the last consideration homeowners thought of at 8%. The following figure shows the most important aspects for homeowners in ArRiyadh (figure 18).

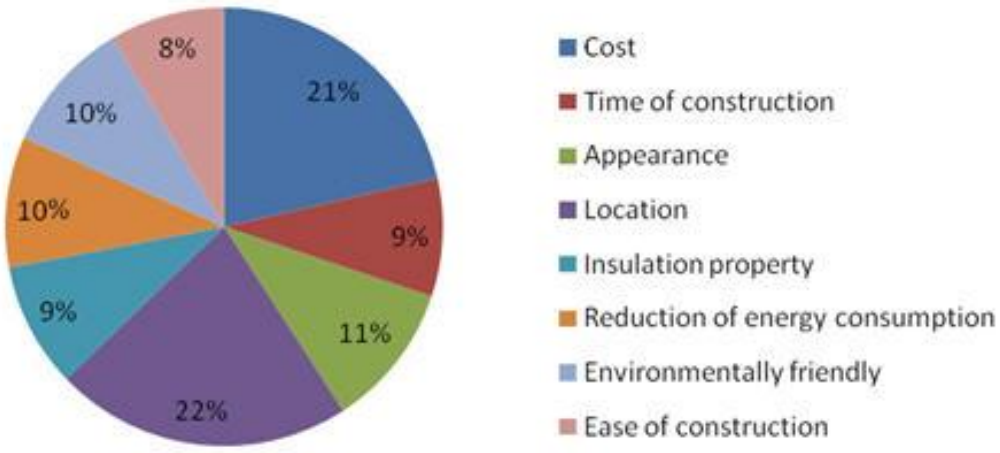

Figure 18: Important aspects for homeowners regarding building homes

People used to use soil in the past before concrete began to take over in the 1950s. For the next 20 years soil use declined and concrete use increased to the point where soil use is almost nonexistent. Based on the data that has been analyzed, the average time of construction was about 18.5 months for building homes that have 723 m^2, the average build area for a family in ArRiyadh. Here are some factors that can have an effect on the time of construction: schedule, weather, vehicle and people circulation, sediment control, and disposal materials management. The figure below shows the percentage each one of these factors has on the construction process (figure 19). Most homes are usually two and a half floors with 46% of the total buildings in ArRiyadh in this category. For this average area, the average cost is about 872,000 SR ($235,533).

On the other hand, people who rent their housing units, 37% of the total population, live in homes or apartments that have an average area of 161 m^2 and cost about 18,000 SR ($4800) yearly.

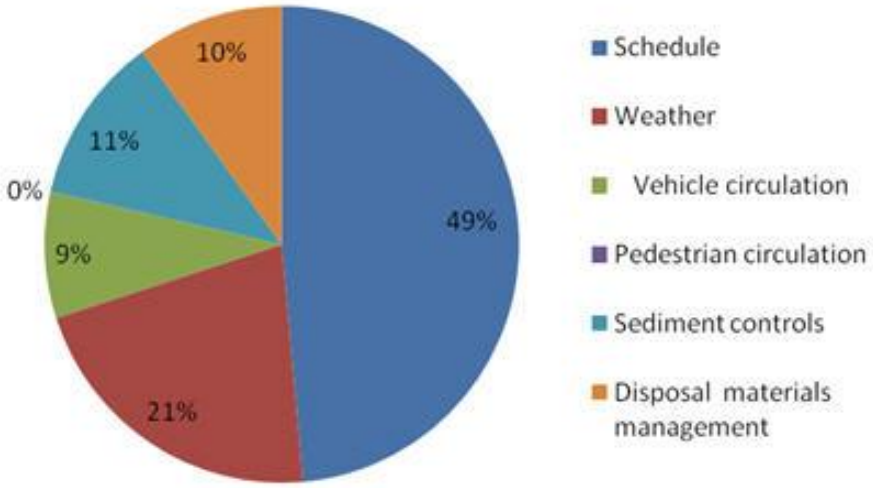

Figure 19: Constraints on the job site during the construction process

Temperatures in Saudi Arabia can reach in excess of 120 ºF in the summer and 30 ºF in the winter. These extreme temperatures require increasing use of electricity or fuel to heat and cool the buildings. Based on the homeowners' questionnaires, the average monthly electric bill for average home size in ArRiyadh - 723 m^2 - is 720 SR ($192) in the summer, 363 SR ($96.8) in the winter, and 267 SR ($71.2) during temperate weather (figure 20). The average consumption for every person in ArRiyadh, Saudi Arabia is considered very high (6192 kW/hr.) compared to the average personal consumption in the United States, England, and Australia (5750, 4625, 3250 kW/hr) respectively (Szokolay, 1980) (figure 21)

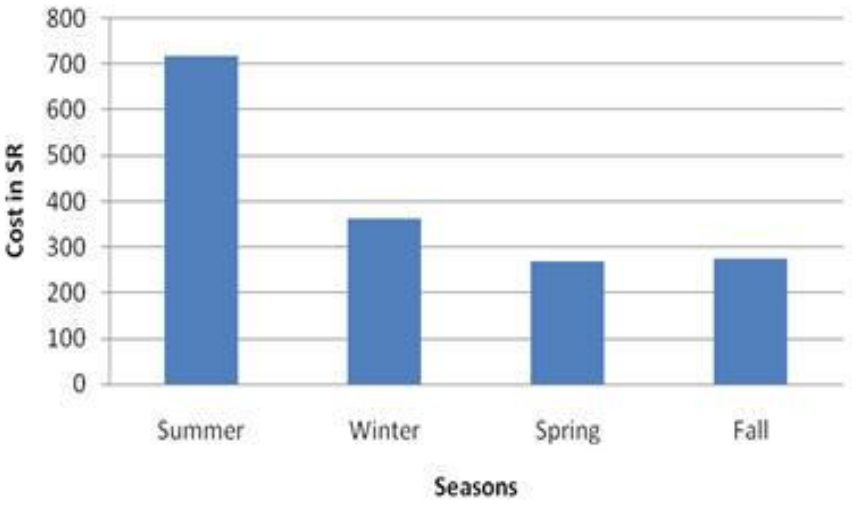

Figure 20: Monthly electric bill for residential buildings

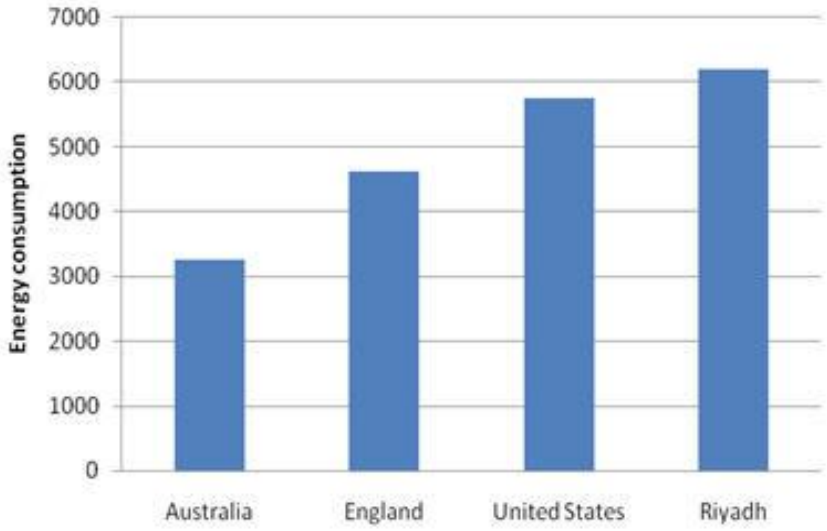

Figure 21: Total energy consumption for every person in Riyadh, Australia, England, and the United States

In order to reduce the energy consumption, it is highly recommended to use materials that have good thermal mass characteristics, high specific heat, high density, and low (but not extremely low) thermal conductivity. It is also important to use materials that are high quality and affordable to insulate with. The most common products used in

Saudi Arabia for enclosures today are concrete, 92% of the total residential buildings (figure 22). In most residential buildings, 52%, these materials are used without any additional products for insulating and thus high amounts of energy are consumed while heating and cooling the living spaces to a comfortable temperature. The other 48% of population uses the red brick or the concrete masonry units that have insulation in the core (figure 23).

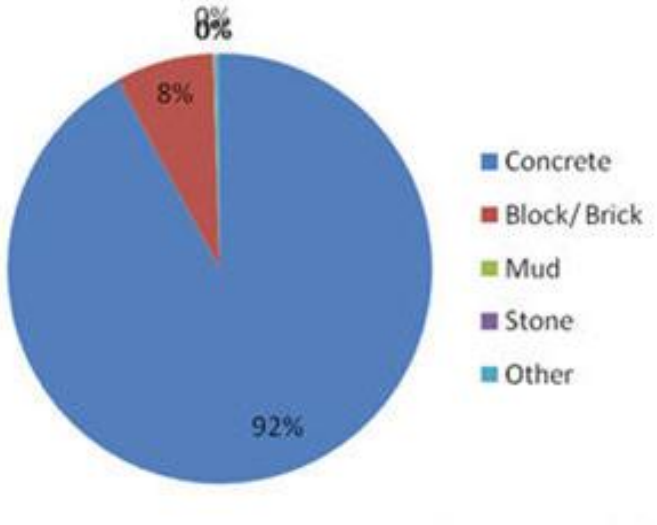

Figure 22: Building materials of residential buildings

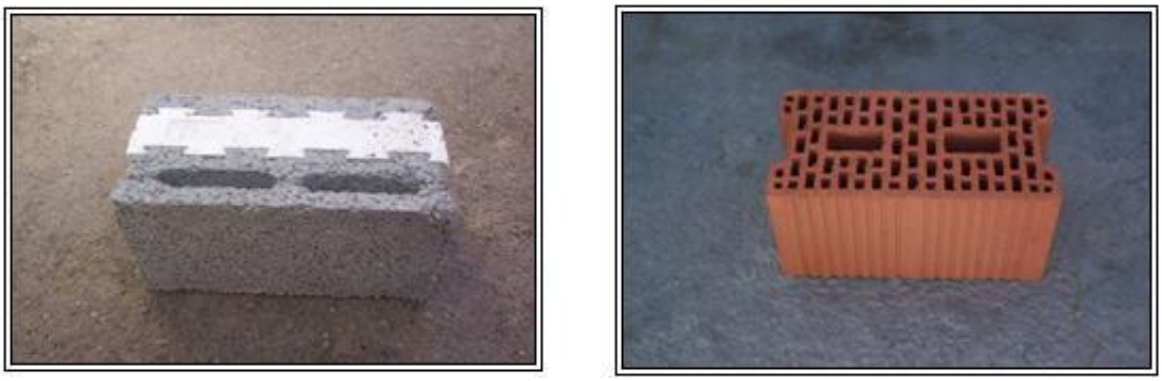

Figure 23: Common methods of insulating residential buildings in Riyadh

The common sheathing materials in Saudi Arabia includes paints, rag paintings, and plaster for internal sheathing and paints, stone, and marble for external sheathing. The

figures below show the internal and external sheathing materials used for residential buildings in ArRiyadh (figure 24).

Figure 24: Common internal and external finishes for residential buildings in Riyadh

Most homeowners do not have the knowledge of insulation because there are few specialists in ArRiyadh. Most of the buildings that are not insulated were built over 12 years ago, before the Ministry of Municipalities and Rural Affairs obligated homeowners and building professional to consider insulation in buildings. Several insulation materials are commonly used in ArRiyadh's buildings. Expanded and extruded insulation materials are the most common materials used in ArRiyadh's industry. The average cost for these materials in the market is about 30 SR ($8) for each horizontal square meter and 22.5 SR ($6) for each vertical square meter. The insulation materials

can increase the cost of a building by up to 5%. Some of the homeowners who currently live in insulated homes mentioned that the temperature has been reduced by up to about 10° - 15°C in the summer compared to their homes or buildings they have experience with in the past. The following are some benefits people have mentioned regarding integration of insulation materials in the buildings:

- Accomplished comfort in the buildings
- Reduced the energy consumption and the electricity bill
- Reduced the pressure on the power plants in ArRiyadh, especially since more than half of the energy consumption is used to run heating and cooling systems
- Increased the lifetime of the heating and cooling systems, which also helps keep the costs down

There is a high interest in sustainability around the world today; reducing energy consumption, integration between the building and the environment, renewable resources, recycling, total costs, and landfill reduction. Saudi Arabia can help in each of these areas if the proper building material is developed. Using soil does not only provide benefits to the manufacturing and assembly portions, but also has a direct impact on the environment. They can have a direct effect on the ecosystem in areas such as energy consumption and landfill waste. ArRiyadh needs to find ways to keep the overall building costs down, reduce the dependence on non-renewable resources, and reduce time to completion while at the same time changing the perception of the people. The panelized wall system can accommodate each of these and make a more modern look to the residential buildings while pleasing the HCDA by using soil in the building process.

Only 35% of the Saudi homeowners have heard of “Structural Insulated Panels”. Seventy percent of people in Saudi Arabia are willing to use materials that offer better insulation properties, are more energy efficient, are environmentally friendly, and reduce building time even if it costs more. Based on people’s opinions, 67% of people do not think they are going to use soil in the future if they have the chance to build again. They built their opinions based on the traditional image of soil usage along with the fact that soil is not in use today. It is not offered in the market and only limited information is available on how people used to build with soil. Some people have mentioned that soil

is a target for bugs and insects and does not have the ability to withstand rain and therefore, it requires lots of maintenance. Other people are very concerned with the soil's appearance and have a negative perception of using it in today's buildings. While still others are concerned with the thickness needed for the walls built with soil; especially with the available materials in the market which have eliminated some of these problems and offer other advantages over soil. However, some people have indicated they would choose to build with soil if they had the chance in the future to build again. Those people have confidence in soil and its insulation ability compared to today's buildings. In addition, soil is a local material that is environmentally friendly, which reduces the cost of the imported insulation materials in the current buildings.

6.3. Architects

Twenty-five architects participated in this case study. They worked in both sectors, government and private, and have a different variety of experience ranging from 4-20 years. Most architects realize the importance of insulation for buildings and integrating it into the design, but the problems are in the persuasion of homeowners and wrong appliance selection by the builders and contractors. Based on the questionnaires and data collected, the common way of insulation applied for buildings in ArRiyadh is using the insulated concrete masonry units, which have an insulation layer in the core, and red brick, unless something else is required by the homeowners. There are some aspects that architects consider in choosing insulation materials such as quality, age, ease of integration, cost, thickness, maintenance, availability in the market, weight, and if it is environmentally friendly. Some participants mentioned that most homeowners do not need their buildings to be fully insulated and few people are choosing to have it insulated. Therefore, the design cost is different for the two cases. In addition, some architects do not believe that homeowners who need to install insulation would do it the right way to prevent heating or cooling from penetrating through the buildings.
There are some key aspects that architects/designers in ArRiyadh have to consider in their homes' designs such as, cost, time of construction, appearance, building structural soundness, insulation property, energy efficiency, and if it is environmentally friendly. The total cost of building plays an important role in driving designers' decisions by 20%

of the total aspects. The designers are usually limited with a specific amount of money that homeowners are willing to pay. This specified cost helps decide what systems and materials would be used in the building. Appearance is also a very important factor for most architects in ArRiyadh at 19%. The work of the architect, the lay people, and other external factors help shape the appearance of the building. The following figure shows the key aspects for architects and the total value for each one of them (figure 25).

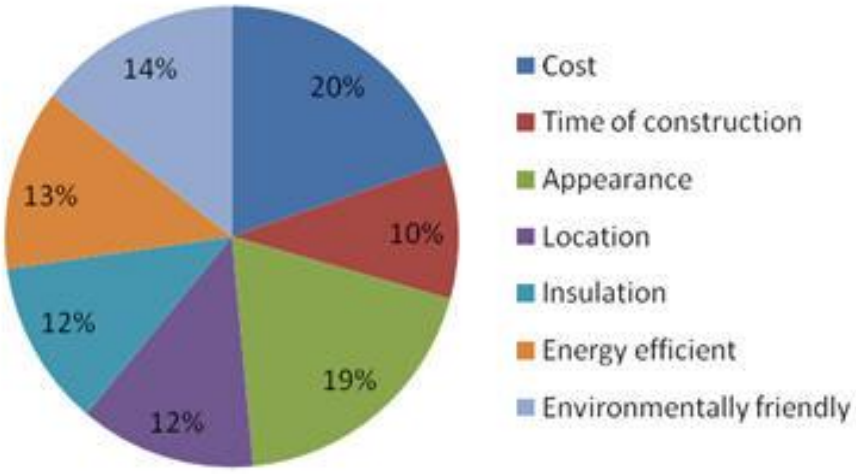

Figure 25: Important aspects for architects regarding building homes

Architects share with homeowners the preferred building materials that are available in the Saudi market. Seventeen out of twenty-five architects chose concrete as the preferred building material. However, there are some architects, three out of 25, for which soil is still the preferred building material. Those three favor soil for its thermal mass and availability in the surrounding area. They also request if there is a technique that can eliminate some soil problems regarding maintenance difficulty, negative perception, thickness, etc. they would like to know more about it. The residential projects have the largest share of the architecture market in ArRiyadh. Fifty-two percent of the total projects designed by the architects in ArRiyadh are residential buildings. The other projects, commercial, educational, hospitals, industrial, governmental, and others, have 22%, 9%, 4%, 2%, 8%, and 3%, respectively (figure 26). The total

percentage of the insulated buildings designed by the architects is only 49%. Several factors led to this number. The most important one is the total cost that the owner is willing to pay. Another reason is that people are accustomed to the old traditional system of constructing buildings, without insulation, before the government recommended homeowners and building professionals to consider insulation in the buildings about 12 years ago.

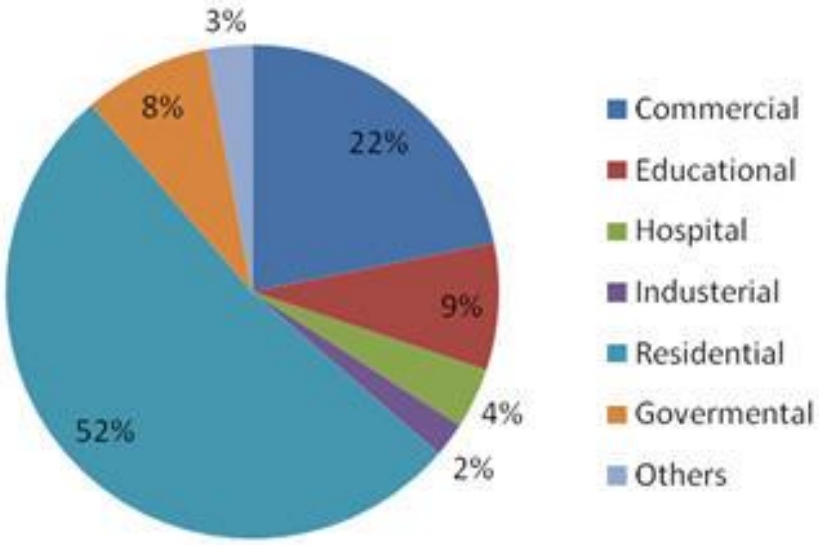

Figure 26: Total projects designed by architects in Riyadh

In regards to using soil in panelized wall systems, 76% of the architects in the study heard of structural insulated panels using common insulation materials such as polystyrene and polyurethane in the core between two layers of concrete. They also think using soil is going to be a good step in the right direction because of the thermal mass properties soil has. However, their advice is to consider some critical points such as the strength and limitations in design. Fifty-six percent of the architects in ArRiyadh have a key role in the selection of the building materials chosen. Most homeowners have confidence in the architects and are interested in what they suggest for building materials. Therefore, it is always important to find materials that would also meet the architects' needs.

6.4. Manufacturers

The initial intention was to survey 15 manufacturers in ArRiyadh, but due to the prevailing method of using concrete in at least 92% of the residential buildings, there was not a need to find additional manufacturers. Concrete factories, including ready mix, precast, and masonry units (regular and insulated), have the highest share of the building materials in the market. This case study includes twelve manufacturers, five of ready mix concrete, four of masonry concrete units, one of precast concrete, one of cement, and one of aerated concrete. The age of these manufacturers ranges from three to 52 years. The main reason for their existence is to meet the market requirements. There is a high demand for these building materials, especially concrete. Residential buildings have the highest demand of materials in the market at 39% of the total buildings in ArRiyadh. Commercial buildings have the second demand at 36%. Other projects industrial, governmental, educational, and others that unspecified have percentages of 10%, 7%, 7%, and 1%, respectively (figure 27).

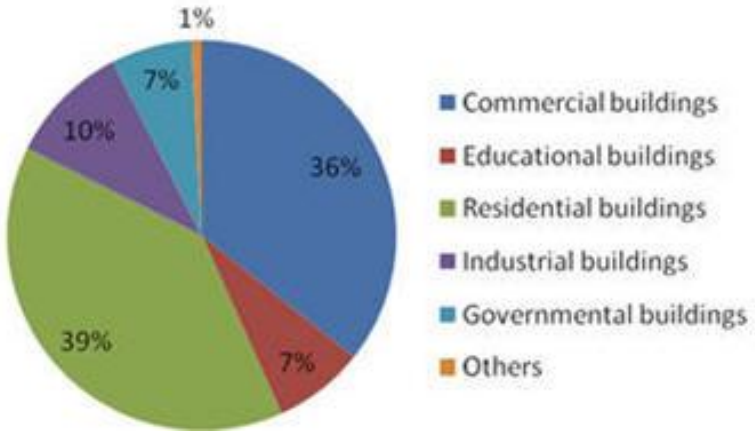

Figure 27: Demand of building materials for different projects in Riyadh

Manufacturers consider some key aspects in regards to production of building materials. These include automated production versus manual, material appearance, transportation requirement, reduction of energy consumption during production, ability to recycle, and its friendliness to the environment. Efficient production is the most important value to manufacturers and the method of production, automated production versus manual, is the aspect that manufacturers consider first in production. It represents 25% of the importance between all the aspects mentioned above. The other

factors: environmentally friendly, insulation, reduction of consumed energy during production process, appearance, transportation requirements, and ability of recycling represent 17%, 14%, 13%, 11%, 11%, and 9%, respectively. The figure below shows each of these aspects and their representative percentage (figure 28).

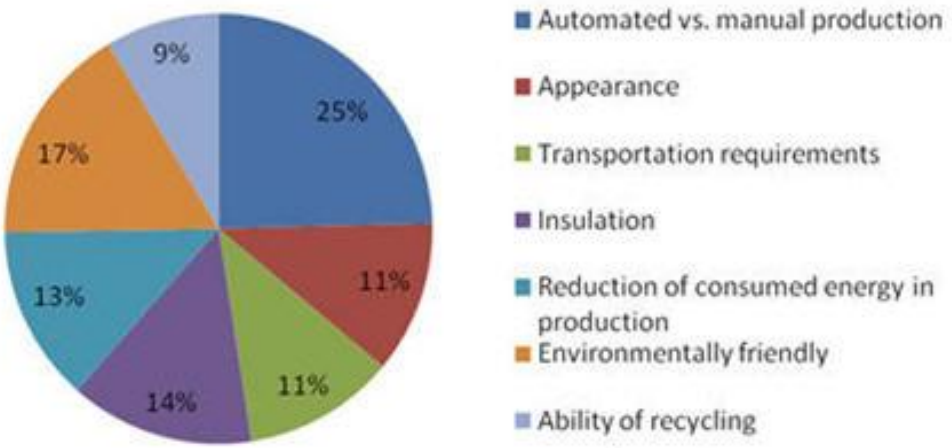

Figure 28: Important aspects for manufacturers regarding building materials

The pressing need of the market and availability of the raw materials are the two most important reasons that most manufacturers choose to invest in concrete products, ready mix, masonry units, precast concrete, aerated concrete, etc. Raw materials needed to manufacture concrete products are currently available in the market, but at least 58% of the manufacturers expect shortages in the availability in the future due to the extreme demand.

6.5. Builders/Contractors

The case study included 15 builders who were selected through projects that were under construction. They also shared the previous stakeholders, homeowners, architects, and manufacturers' preference for a building material, concrete. Eighty percent of builders in ArRiyadh favor using concrete masonry units to construct buildings. There are some reasons that led to this method. People are accustomed to this system and are confident in the concrete properties, strength, durability, availability

in the market, appearance, longevity, weight, cost, etc. In addition, concrete is easier to deal with than emerging materials since the work crews are not trained to use them. General contractors usually deal with this issue by sending individuals away for training, hiring a subcontractor, or only using products that permanent work crews are trained to use.

There are some key aspects that builders/ contractors usually consider in regards to construction of residential buildings such as cost, time of construction, building materials used, location, insulation properties, weather, and ease of construction. Cost is the most important value contractors usually consider when constructing homes at 23% of the total factors. Cost can be impacted by many factors such as disregarding the payment agreement, which builders usually use to pay for materials or workers needed on the jobsite. Changes in pricing today also have a significant impact on the project progress. Cost along with other factors can have an effect on the time of construction, which builders are concerned about at 22% of the total factors. Other factors, building material used, location, insulation properties, weather, and ease of construction have values of 9%, 13%, 7%, 12%, and 14%, respectively (figure 29).

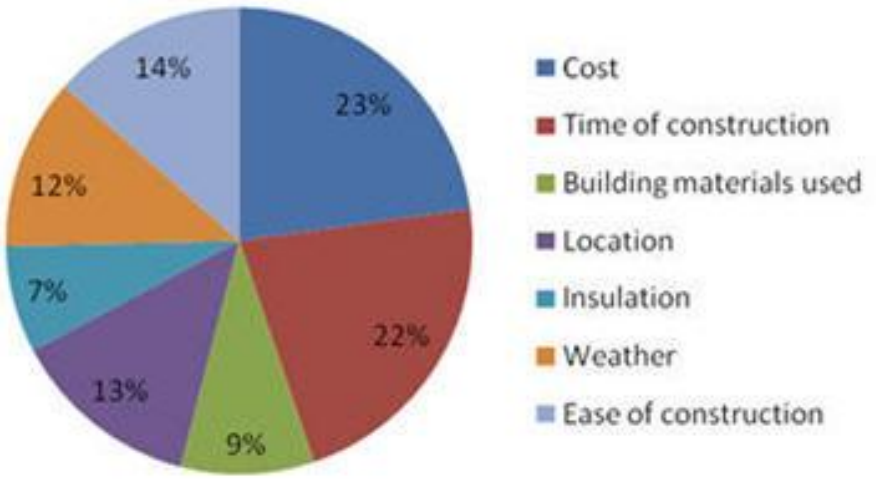

Figure 29: Important aspects for builders regarding building homes

Residential buildings represent the highest percentage of projects that builders usually have yearly at 63% (figure 30). These buildings have an average of two and half floors.

However, some builders mentioned that they have dealt with residential buildings and apartments that can reach up to eight floors. Contractors emphasize that the average time for constructing an average size residential building in ArRiyadh, 723 $m^{2,}$ is 18 months. This period can be affected by several factors such as cost, weather, arrival of building materials, labor, quality of the building material, storage space available on the jobsite, and equipment used during construction process. However, these constraints do not occur frequently on the jobsites of residential buildings. In this case study, there are 15% - 20% of the homeowners who have some of these issues that can occur on the jobsites. Out of this percentage, cost has the most value that stakeholders complained about, 29%. The other factors, weather, arrival of building materials, labor, quality of the building material, storage space available on the jobsite, and equipment used during construction process, can be seen in (figure 31).

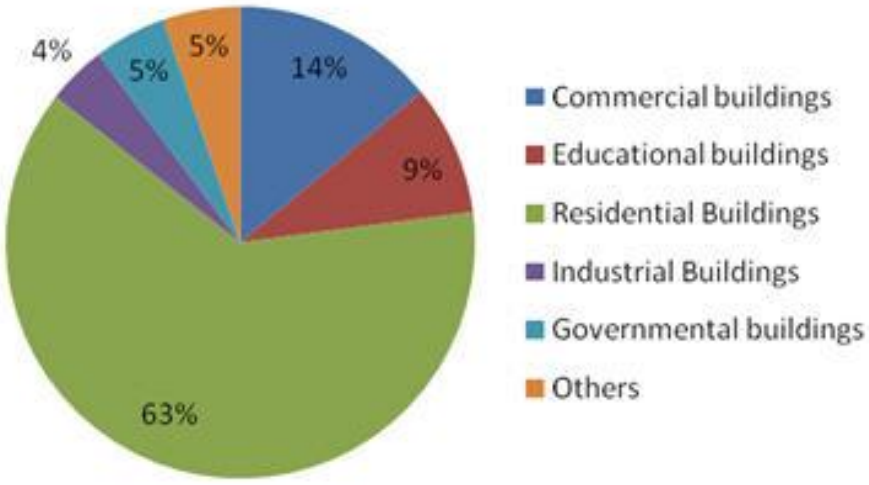

Figure 30: Total projects built by builders in Riyadh

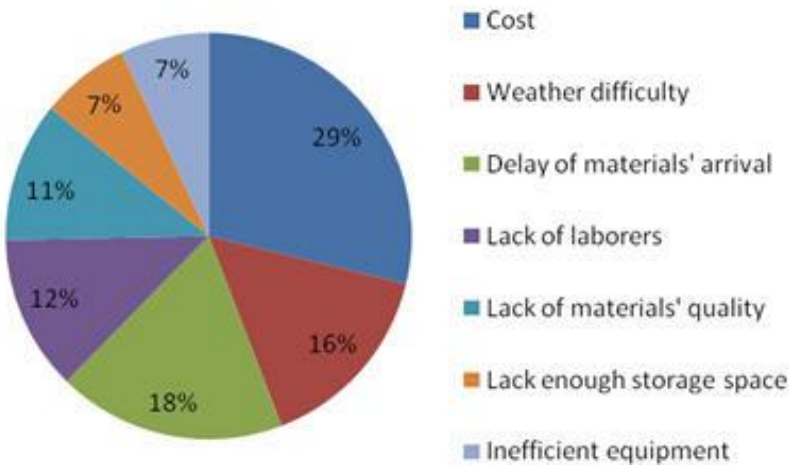

Figure 31: Factors can have an effect on the project progress

6.6. Chapter Summary

This chapter presentes the findings of the building professioanls and stakeholders who participated in the questionnaires in regards to their desired performance ans concerns about the current building materials in Saudi Arabia. Diversity of the participants was considered and thus, several criteria were communicated with both, the building professionals and stakeholders, in regards to their interests in buikding materials.

7. CONCLUSION AND RECOMMENDATIONS

7.1. Introduction

The defined stakeholders, homeowners, architects, manufacturers, and builders have some constraints and desired performance about materials used for residential buildings today in ArRiyadh. The goal of this study is to find out these constraints and desired performance and then use this information to develop a building material that is suitable not only for people but also for the environment and the economy. Panelized wall systems that would use soil in the core, as an insulation layer, were the proposed solution to meet the desired performance and eliminate the constraints of these defined stakeholders in ArRiyadh. There are some points in which soil use in structural insulated panels can be very effective such as availability, thermal mass properties, environmentally friendly, etc. On the other hand, there are points that lack enough information and would need to be researched in depth to eliminate a negative image. These points may include weight of this system, height, strength, ability of integration with other building systems or structural elements, etc. Defining both points and working on them to develop a prototype that can be presented to the defined

stakeholders in ArRiyadh to get feedback on their impressions and any suggestions or comments. The inputs from all would be used to develop a final product. At this time, it is expected to be a SIP using soil as the insulation layer that would then be used to convince people to use in place of current building materials as the main building component.

7.2. Summarizing the Research Findings

7.2.1. Homeowners

The average size of residential buildings in ArRiyadh is 723 m2 divided into two or two and a half floors. The average consumed time to construct such a building is about 18 months with a total cost of 872,000 SR ($235,533). Therefore, it is important to find building materials that have the ability to construct such a size with less money if possible. Homeowners consider building structural soundness the most at 22% and cost at 21%. Building structural soundness is going to differ from building to building based on many factors that properties of the main building materials play an important role in determining it. Cost can vary according to building materials used. Therefore, it is important to provide a building material that people can afford and are willing to pay for. Other aspects that homeowners are concern about when building homes are: the appearance, how energy efficient the building is, how environmentally friendly would it be, and what are the insulation properties. The expected results of these aspects are positive compared to the current materials on the market, but it is important to test a prototype and find specific numbers that can be shown to people. Time and ease of construction are two other positive points compared to the traditional method of construction, which uses small units and can take about 18 months to construct a typical two-story building of 723 m^2. Moreover, using structural insulated panels can eliminate some problems that can affect the project progress such as schedule, weather, and multiple storage spaces required on the jobsite.

7.2.2. Architects

Most architects in ArRiyadh have a significant impact on the building materials that are chosen. Most homeowners have confidence in the architects and the building materials they suggest. Therefore, it is always important to find materials that also meet the architects' needs. There are some aspects that architects consider when choosing insulation materials. These include: quality, age, ease of integration, cost, thickness, maintenance, availability in the market, weight, and environmental effects. Research is needed to determine specific details that can be shown to the stakeholders and help direct their decisions.

Cost and appearance are the two most important aspects architects usually consider when designing residential buildings in ArRiyadh. Designers need to present different choices for materials that are affordable for the homeowners' budget and have good appearance. The intent is to compute the approximate cost of the SIPs using soil at some point in this study after developing the prototype and then contacting some manufacturers who produce building materials. The appearance of buildings usually depends on the internal and external sheathing materials used. People use different materials such as paint, rag paint, gypsum, and plaster for internal sheathing and paint, stone, and marble for external sheathings. The ability to use these materials over the SIPs using soil would also be determined while developing the prototype.

7.2.3. Manufacturers

There is major construction in ArRiyadh due to the budget increments in Saudi Arabia and therefore, current manufacturers are not able to supply enough materials for these projects. Currently, there are only three cement factories that supply cement. The concrete is supplied to the concrete product manufacturers as well as sending it directly to the jobsites. All the manufacturers included in this case study expect shortages in the future of the raw materials, especially cement. Soil is readily available in ArRiyadh and therefore, soil use in panelized wall systems would be a good choice for

manufacturers to invest in. The most important point that would lead manufacturers to invest in the structural insulated panels (SIP) is the people's desire for this product.

There are some key aspects that manufacturers look for when producing a building material. Effective production has the highest consideration of manufacturers at 25% of the total factors. Production process of the SIP using soil would be similar to the production of any SIP using any other material. It would be an automated process, which meets the manufacturers' needs regarding type of production process. In addition, it is also important for manufacturers to produce a building material that has good quality insulating properties, is energy efficient, and environmentally friendly. The ability of recycling soil is also one big advantage that soil has over other building products that are currently on the market.

7.2.4. Builders/ contractors

Most builders in ArRiyadh favor using concrete masonry units to construct buildings over any other building material. There are some reasons that led to this method. People are accustomed to this system and are confident in the properties of concrete, its strength, durability, and availability in the market, its appearance, longevity, weight, cost, etc. Therefore, it is important to deal with the expected weight of the SIPs using soil, as it is important to consider other factors e.g. strength, durability, appearance, longevity cost, etc. Time and ease of construction are two important aspects for builders when constructing residential buildings. In regards to the building construction process, the SIPs are similar to the precast concrete that is used in Saudi Arabia, but for big projects such as residential compounds, commercial and governmental projects. The SIPs would cut the accustomed time of construction, but builders/contractors would have to deal with that untrained work crews. Sending individuals away for training, hiring a trained subcontractor, or only using products that permanent work crews are trained to use, can address this problem.

7.3. Conclusion

In conclusion, it is important to find building materials that help to eliminate people constraints and meet their desired performance of residential buildings in ArRiyadh. Understanding the requirements of stakeholders and following the directions of The High Commission for the Development of ArRiyadh (HCDA) can impact the end results or where additional research needs would be spent. The majority of residential buildings today are built using concrete with only little interest in other materials. The HCDA has an initiative to use soil as a building material and this continues to drive research and development in this area in ArRiyadh. SIPs, is an emerging product to the industry of other countries (e.g. the United States) with many positive characteristics, can potentially help to meet the HCDA initiative. With some modifications to use products available in the ArRiyadh area, and more pressure to find ways to reduce energy consumption, returning to the use of soil in SIPs can help to meet the requirements as well as offer other benefits, i.e. faster assembly, reduce space at work site, and reduce total cost of construction. However, there are some key aspects that different stakeholders are concerned about in the residential buildings. Further research is needed in these areas to find suitable or measurable information, which can be presented to the defined stakeholders at some point in this study. Thus, spending some time upfront to examine and find precise information of the SIPs' properties would help to develop a product that can meet the people needs and eliminate their constraints and also be beneficial to the environment and meet the building requirements of all the stakeholders. Table 6 shows the key aspects of the stakeholders' interests regarding the use of the SIPs using soil as a main building material in today's buildings in ArRiyadh. The table also presents the areas where precise information and further research are needed such as, cost, ability of adding finishing materials, insulation properties, energy efficient, environmentally friendly, weight of the product, transportation requirements, strengths properties, and ability to make curves in the plans or elevation of the buildings.

Table 5: Important aspects for the stakeholders regarding use of the SIPs and concrete in residential buildings in ArRiyadh

Important aspects for the stakeholders	SIPs compared to concrete
Cost	Costs of raw materials, production process, construction process, laborers, etc. have to be determined.
Time of construction	Faster
Appearance	Ability of adding the desired sheathing materials has to be determined
Insulation properties	Have to be determined
Energy efficient	Has to be determined
Environmentally friendly	Pollution emissions have to be determined
Ease of construction	Not enough knowledge on their use
Automated vs. manual production	Automated, same as the concrete products in the market
Transportation requirements	Depending on the size of the panels and it has to be determined
Ability of recycling	Better
Structurally sound	Tensile strength, lateral strength (flexural), compressive strength, and torsion strength (Shear) are values that have to be determined
No design limitation of the size and shape (Creativity)	No ability to make curves in the plans or elevation of the buildings

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9. APPENDIX

9.1. APPENDIX A: Questionnaires

Homeowners' Questionnaire

Reason for Survey: This survey is being given to help gather information for my Thesis Paper at Virginia Tech. Your responses are needed and would be greatly appreciated. The data provided would be summarized with all other respondents and analyzed to potentially develop a new building material that could provide changes in the building industry to benefit homeowners and building professionals in the future. Please feel free to answer any and all questions. If you do not know an answer, you can skip it. There are no ramifications if you do not fill out the questionnaire in its entirety.

Homeowner's Name:
Phone:
Fax:
E-Mail:

Please answer each of the following questions to the best of your ability.

1. Please rank the following aspects from most (1) important to least important (7) in regards to building your home:
   - __ Total cost of construction
   - __ Time from start to finish
   - __ Exterior appearance
   - __ Building structural soundness
   - __ Insulation capability
   - __ Energy efficiency
   - __ Environmentally friendly
   - __ Other ……

2. What kind of home do you live in?
   - ☐ Single dwelling house
   - ☐ Apartment/Condo Complex
   - ☐ Townhouse
   - ☐ Duplex
   - ☐ Other: ……

3. Do you own or rent your home?
   - ☐ Own
   - ☐ Rent

4. How old is your home? (or approximate age):
   ……years

5. How many years have you lived in your home?
   ..... years .....

6. How long did it take to construct your home?
   .....

7. During the construction process, were there any constraints on the job site? (*Check all that apply*)
   - ☐ Schedule
   - ☐ Weather
   - ☐ Vehicle circulation
   - ☐ Pedestrian circulation
   - ☐ Sediment controls
   - ☐ Storm drain inlet protection
   - ☐ Disposal materials management
   - ☐ Discharging and dewatering control

8. What were the overall construction costs of your home?
   ..... SR .....

9. How much is your monthly electric bill?
   - Summer ..... SR .....
   - Winter ..... SR .....
   - Spring ..... SR .....
   - Fall ..... SR .....

10. Which part of ArRiyadh do you live in?
    - ☐ North
    - ☐ South
    - ☐ East
    - ☐ West
    - ☐ Center

11. What is the main building material on the outside of your home? (*Check all that apply*)
    - ☐ Concrete
    - ☐ Soil
    - ☐ Stone
    - ☐ Brick

- ☐ Other: ……

12. Why did you select this particular building material?

……

……

13. What are the square meters of your home not counting garages and unconditioned areas?
……m^2

14. How many <u>stories</u> does your home have?
    - ☐ 1
    - ☐ 1.5
    - ☐ 2
    - ☐ 2.5
    - ☐ 3
    - ☐ Other: ……

15. A. Does your home have insulation?
    - ☐ Yes
    - ☐ No *(Go to Q.16)*
    - ☐ Don't know (*Go to Q.16)*

    B. What kind of insulation was used?
    - ☐ Loose-fill Insulation
    - ☐ Batt and Blanket Insulation
    - ☐ Rigid Board Insulation
    - ☐ Spray Foam Insulation
    - ☐ Other: ……
    - ☐ Don't know

    C. Where is the insulation located in your home? (*Check all that apply*)
    - ☐ Walls
    - ☐ Roofs

    D. How thick is the insulation?
    - ☐ 5 cm
    - ☐ 10 cm
    - ☐ 15 cm
    - ☐ More than 15 cm
    - ☐ Don't know

16. What is your preferred building material? (*Assume no constraints, i.e. cost)*

.....

.....

17. What is the main reason you prefer this building material?

.....

.....

18. If you were to rebuild your current home, what improvements would you make?

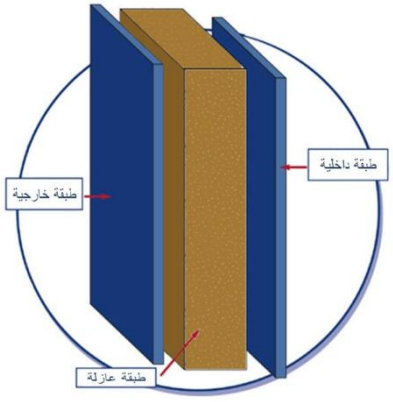
.....

.....

19. Have you heard of Structural Insulated Panels (SIPs) as a building material?
    - ☐ Yes
    - ☐ No

20. If there was a material that offered better insulation properties, was more energy efficient, was environmentally friendly, and reduced building time would you choose it to build with even if it cost more?
    - ☐ Yes
    - ☐ No
    - ☐ Maybe
    - ☐ Need additional information

Thank you



استبانة المالك

الهدف من الاستبانة: صممت هذه الاستبانة لجمع معلومات متعلقة برسالتي للماجستير "استخدام الطين في الجدران الإنشائية العازلة لمباني مستدامة بالرياض". يهدف هذا البحث إلى استخدام الطين المضغوط في عمل ألواح مكونة من ثلاث طبقات، طبقة عازلة في الوسط، و قشرتين داخلية و خارجية تهدف إلى حماية المادة العازلة والعمل على توزيع الأحمال و توفير قشرتين للتكسيات الخارجية.

إجابتكم على الأسئلة التالية سوف تُحلل مع بقية إجابات أفراد العينة للتوصل إلى تطوير مادة بناء مستدامة و ملائمة لبيئة المملكة العربية السعودية. الرجاء الإجابة على الأسئلة التالية قدر الإمكان، شاكرين لكم حسن اهتمامكم و تعاونكم.

الاسم:
رقم التلفون:
رقم الفاكس:
الايميل:

من فضلك أجب على الأسئلة فدر الاستطاعة علماً أنه يمكن تخطي السؤال الذي لا تريد إجابته

1) من فضلك رتب المعايير التالية من الأكثر أهمية إلى الأقل أهمية بالنسبة لبناء منزلك، *(1 أكثر أهمية، 9 أقل أهمية)*

—— القيمة الأجمالية للبناء
—— الوقت الأجمالي للبناء
—— المظهر الخارجي
—— موقع المبنى
—— نوع العزل الحراري
—— تخفيض استهلاك الطاقة
—— ملائم للبيئة
—— سهولة البناء
—— أخرى :.....

2) ما نوع المبنى الذي تسكن فيه؟

☐ فيلا
☐ شقة سكنية
☐ دور سكني واحد
☐ عمارة دوبلكس
☐ أخرى:.....

3) ما هي حالة المبنى الذي تسكن فيه؟

☐ ملك
☐ ايجار
☐ ايجار منتهي بالتمليك

4) كم عمر المبنى الذي تسكن فيه منذ أنشئ؟
.....سنة

5) كم الفترة الزمنية التي عشتها في المبنى؟
.....سنة

6) كم الفترة الزمنية المستغرقة في انشاء المبنى الذي تسكن فيه؟
.....شهر

7) هل كان هناك أي من العوائق التالية في فترة انشاء المبنى؟ *(حدد كل ما يطابق ذلك)*

- ☐ انهاء كل مرحلة في الوقت المحدد
- ☐ الجو
- ☐ حركة السيارات
- ☐ حركة المارة
- ☐ تصريف المياه
- ☐ ادراة مواد البناء التي لم تعد صالحة للاستعمال

8) كم التكلفة الاجمالية للمبنى الذي تسكن فيه؟
.....ريال

9) كم تكلفة فاتورة الكهرباء الشهرية في الفصول التالية؟
الصيف:.....ريال
الشتاء:.....ريال
الربيع:.....ريال
الخريف:.....ريال

10) في أي جزء من الرياض يقع منزلك؟

- ☐ الشمال
- ☐ الجنوب
- ☐ الشرق
- ☐ الغرب
- ☐ وسط الرياض

11) ماهي مادة البناء الأساسية لمسكنك؟ *(حدد كل ما يطابق ذلك)*

- ☐ خرسانة
- ☐ طين
- ☐ حجر
- ☐ طوب أحمر
- ☐ أخرى:.....

12) ما السبب الرئيسي وراء اختيارك لتلك المادة؟

---

13) ما نوع التكسية الداخلية لمسكنك حالياً؟

- ☐ دهان
- ☐ تعتيق
- ☐ جيبسون بورد
- ☐ أخرى:.....

14) ما نوع التكسية الخارجية لمسكنك حالياً؟

- ☐ دهان
- ☐ حجر
- ☐ رخام
- ☐ أخرى:.....

15) كم المساحة المبنية لمسكنك؟

.....م^2

16) كم عدد الطوابق الكلية لمسكنك؟

- ☐ دور واحد
- ☐ دور و ملحق
- ☐ دورين
- ☐ دورين و ملحق
- ☐ ثلاثة أدوار أو أكثر

17) أ) هل المبنى الذي تسكن فيه معزول حرارياً؟

- ☐ نعم
- ☐ لا ، *(اذهب مباشرة إلى السؤال 18)*
- ☐ لا أعرف، *(اذهب مباشرة إلى السؤال18)*

ب) ما نوع مادة العزل؟

- ☐ الفلين
- ☐ الصوف الصخري
- ☐ البيرلايت
- ☐ أخرى، .....

ج) كم سماكة مادة العزل؟

- ☐ 5 سم

- ☐ 10 سم
- ☐ سم
- ☐ أكثر من 15 سم
- ☐ لا أعرف

18) ماهي مادة البناء المفضلة لديك؟ و لماذا؟

.....

.....

.....

19) هل سبق و أن سمعت عن " Structural Insulated Panels " الجدران الانشائية العازلة؟

- ☐ نعم
- ☐ لا

20) من قرر اختيار مادة البناء لمسكنك؟

- ☐ أنت أو أحد أفراد عائلتك
- ☐ المعماري
- ☐ المقاول
- ☐ شخص آخر، .....

21) إذا كان هناك مادة بناء توفر خصائص عزل أفضل، تقلص استهلاك الطاقة الشهري، ملائمة بيئياً، و تقلل الوقت المستغرق في انشاء المبنى ولكنها قد تكون ذات تكلفة أعلى نسبياً هل ستختارها؟

- ☐ نعم
- ☐ لا
- ☐ احتمال
- ☐ أحتاج معلومات إضافية لأقرر

22) هل سبق و إن استخدمت أحد تقنيات الطين في البناء؟ لماذا نعم أو لماذا لا؟

.....

.....

.....

شكراً لكم حسن تعاونكم

Architect/Designer Questionnaire

Reason for Survey: This survey is being given to help gather information for my Thesis Paper at Virginia Tech. Your responses are needed and would be greatly appreciated. The data provided would be summarized with all other respondents and analyzed to potentially develop a new building material that could provide changes in the building industry to benefit homeowners and building professionals in the future. Please feel free to answer any and all questions. If you do not know an answer, you can skip it. There are no ramifications if you do not fill out the questionnaire in its entirety.

Architect/Designer Name:
Phone:
Fax:
E-Mail:

Please answer each of the following questions to the best of your ability.

21. Please rank the following aspects from most (1) important to least important (7) in regards to building your home:
    - __ Total cost of construction
    - __ Time from start to finish
    - __ Exterior appearance
    - __ Building structure
    - __ Insulation capability
    - __ Energy efficiency
    - __ Environmentally friendly
    - __ Other:……

22. What is your preferred building material for residential homes? Why? (*Assume no constraints, i.e. cost)*

    .....

    .....

    .....

23. What the percentage of work done in the following? *(Total should equal 100%)*

    _____Retail _____Restaurant
    _____Commercial _____Industrial
    _____Institutional _____Residential/Condominiums/Apartments
    _____Other: …….

24. What is the percentage of work done in each of the following areas? *(Total should equal 100%)*

_____New Construction _____Remodeling

_____Fire/Flood Restoration _____Other……

6. What is the percentage of homes you design that include insulation in the walls?

_____

7. What is the percentage of the homes you design that include insulation in the floors?

_____

8. Have you heard of Structural Insulated Panels (SIPs)

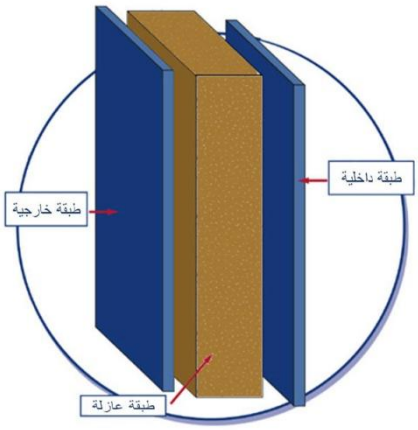
- ☐ Yes
- ☐ No

9. Do you influence the building material selected by the homeowner?

- ☐ Yes
- ☐ No

10. Do you suggest or work with builders to select building materials?

- ☐ Yes
- ☐ No



استبانة المعماري

الهدف من الاستبانة: صممت هذه الاستبانة لجمع معلومات متعلقة برسالتي للماجستير "استخدام الطين في الجدران الإنشائية العازلة لمباني مستدامة بالرياض". يهدف هذا البحث إلى استخدام الطين المضغوط في عمل ألواح مكونة من ثلاث طبقات، طبقة عازلة في الوسط، و قشرتين داخلية و خارجية تهدف إلى حماية المادة العازلة والعمل على توزيع الأحمال و توفير قشرتين للتكسيات الخارجية.

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اسم المعماري:
رقم التلفون:
رقم الفاكس:
الايميل:

من فضلك أجب على الأسئلة فدر الاستطاعة علماً أنه يمكن تخطي السؤال الذي لا تريد إجابته

23) من فضلك رتب المعايير التالية من الأكثر أهمية إلى الأقل الأهمية بالنسبة لك كمعماري، (1 أكثر أهمية، 8 أقل أهمية)

—— القيمة الأجمالية للبناء
—— الوقت الأجمالي للبناء
—— المظهر الخارجي
—— موقع المبنى
—— نوع العزل الحراري
—— تخفيض استهلاك الطاقة
—— ملائمة للبيئة
—— أخرى :.....

24) ماهي مادة البناء المفضلة لديك؟ و لماذا؟

.....

.....

.....

25) مانسبة المباني المصممة من قبلك بالنسبة للآتي:

تجارية:.....
تعليمية:.....
صحية:.....
مطاعم:.....
صناعية:.....
سكنية:.....
أخرى:.....

26) مانسبة المباني المصممة من قبلك مراعياً فيها استخدام العزل الحراري؟

.....

27) ما أفضل طريقة عزل تقترحها لمبنى سكني في الرياض؟

---

28) ما المعايير التي تتبعونها في اختيار مادة العزل؟

---

29) هل سبق و أن سمعت عن " Structural Insulated Panels " الجدران الانشائية العازلة؟

- ☐ نعم
- ☐ لا

30) هل لديك الدور الأكبر في اختيار مادة البناء؟

- ☐ نعم
- ☐ لا

31) هل تناقش المقاول أو المالك في اختيار مادة البناء؟

- ☐ نعم
- ☐ لا

32) كم الخبرة المهنية لكم في السوق المحلية؟

.....سنة

33) هل تراعي استخدام مواد البناء المحلية في المباني المصممة من قبلكم؟

- ☐ نعم
- ☐ لا

34) هل تواجهون أية صعوبات في اقتراح مادة بناء معينة للمالك أو المقاول؟

- ☐ نعم، *(كيف)*

……
……
……
……
……
……

- ☐ لا

35) هل لديكم ادارة مختصة بالأبحاث والتطوير؟

☐ نعم

☐ لا

36) هل تفكر في تطوير مادة بناء محلية ملائمة لبيئة المملكة العربية السعودية؟

☐ نعم، (ماهي و لماذا؟) .....

.....

.....

.....

.....

☐ لا

37) هل هناك أية صعوبات في موافقة متطلبات كود البناء السعودي؟

☐ نعم، (*ماهي تلك الصعوبات*).....

.....

.....

☐ لا

38) هل هناك أية خطوات أو معايير لمراجعة وتقييم طلب زبون معين من ناحية خصائص المادة قبل الموافقة على التصميم؟

☐ نعم، *(اشرح الخطوات)*

.....

.....

.....

☐ لا

شكراً لكم حسن تعاونكم

Manufacturing Questionnaire

Reason for Survey: This survey is being given to help gather information for my Thesis Paper at Virginia Tech. Your responses are needed and would be greatly appreciated. The data provided would be summarized with all other respondents and analyzed to potentially develop a new building material that could provide changes in the building industry to benefit homeowners and building professionals in the future. Please feel free to answer any and all questions. If you do not know an answer, you can skip it. There are no ramifications if you do not fill out the questionnaire in its entirety.

Manufacturer Name:
Phone:
Fax:
E-Mail:

Please answer each of the following questions to the best of your ability.

11. Please rank the following aspects from most (1) to least important (7) in regards to manufacturing building materials used for residential homes:
    - __ Automated versus manual production
    - __ Exterior appearance of building material on residential building
    - __ Transportation requirements to building location
    - __ Insulation capability
    - __ Energy efficiency
    - __ Environmentally friendly
    - __ Ability to recycle demolition and scrap material

12. What products do you currently manufacture in your factory?

    _____
    _____
    _____

13. What influenced your company's decision to manufacture the above product(s)?

    _____
    _____
    _____

14. How long has your company been in business?

    _____

15. Has your company always made the same product?

    ☐ Yes *(Go to Q. 7)*

☐ No *(Go to Q. 6)*

16. What was the reason for changing the product that was manufactured in the past?
_____
_____
_____
_____

17. What is the percentage of work done for the following? *(Total should equal 100%)*
_____Retail _____Restaurant
_____Commercial _____Industrial
_____Institutional
_____Residential/Condominiums/Apartments
_____Other: ……

18. How do you sell your products in Saudi Arabia?
☐ Direct to builders and contractors
☐ Distributors
☐ Other

19. Where do your raw materials come from?
___Within Saudi Arabia *(Go to Q.8)*
___Imported from outside Saudi Arabia *(Go to Q. 9)*

20. Where in Saudi Arabia do your raw materials come from?
___ArRiyadh area
___Outside ArRiyadh

21. What percentage of your raw materials is imported from outside Saudi Arabia?
____%

22. Do you have difficulties obtaining your raw materials for production of building materials?
☐ Yes
☐ No

23. Do you anticipate any shortages of availability of the raw materials necessary for production in the near future?
☐ Yes
☐ No

24. Do you foresee any long-term supply issues of the raw materials necessary for production?
☐ Yes

☐ No

25. What process does your company use to invest in new products/production?

_____
_____
_____
_____
_____

26. Do you have your own research group to improve or develop new building materials?
    ☐ Yes
    ☐ No

27. Are you looking to invest in any other building products?
    ☐ Yes
    ☐ No

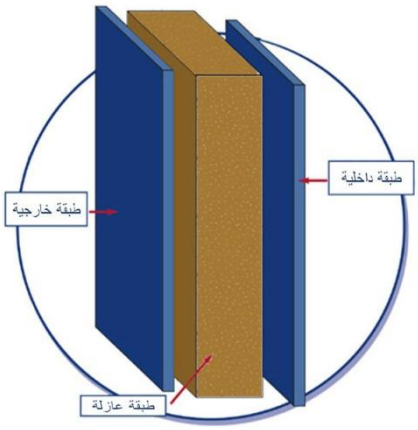
28. What type of production process is used to manufacture the materials?
    ☐ Automated, computer controlled
    ☐ Manual
    ☐ Combination of manual and automated

29. Is there technical information on your products available for insulation values, durability, and structural properties?
    ☐ Yes, if yes please attach brochures
    ☐ No

30. Do you have any warranty on your products?
    ☐ Yes, if yes please attach warranty
    ☐ No

31. What steps are taken to review and evaluate the customer requirements prior to accepting an order?

_____
_____
_____
_____



استبانة المصانع

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إجابتكم على الأسئلة التالية سوف تُحلل مع بقية إجابات أفواد العينة للتوصل إلى تطوير مادة بناء مستدامة و ملائمة لبيئة المملكة العربية السعودية. الرجاء الإجابة على الأسئلة التالية قدر الإمكان، شاكرين لكم حسن اهتمامكم و تعاونكم.

اسم المصنع:
رقم التلفون:
رقم الفاكس:
الايميل:

من فضلك أجب على الأسئلة فدر الاستطاعة علماً أنه يمكن تخطي السؤال الذي لا تريد إجابته

39) من فضلك رتب المعايير التالية من الأكثر أهمية إلى الأقل الأهمية بالنسبة لانتاج مادة بناء معينة*(1 أكثر أهمية، 8 أقل أهمية)*

—— تصنيع أتوماتيكي مقابل تصنيع يدوي

—— المظهر الخارجي لمادة البناء

—— متلطبات النقل من المصنع إلى الموقع

—— نوع العزل الحراري

—— تخفيض الطاقة المستهلكة في الانتاج

—— ملائم للبيئة

—— القدرة على استخدام مادة البناء مرة أخرى بعد هدمها أو انتهاء عمرها الزمني

—— أخرى :.....

40) ماهي مادة البناء الأساسية المنتجة لديكم ؟

.....

41) ما الأسباب الرئيسية وراء اختيار تلك المادة كمنتج أساسي لديكم؟

.....

.....

42) كم الفترة الزمنية لشركتكم في السوق المحلية؟

.....سنة

43) هل شركتكم متخصصة في انتاج تلك المادة فقط منذ انشاءها؟

☐ نعم، (اذهب إلى السؤال 7)

☐ لا، (اذهب إلى السؤال 6)

44) ما السبب وراء أختيار مادة آخرى؟

.....
....

45) ما نسبة توريدكم للمشاريع التالية: *(المجموع 100%)*

تجاري:.....
تعليمي:.....
سكني :.....
صحي:.....
صناعي:.....
أخرى:.....

46) كيف يتم بيع منتجاتكم في السوق؟

- ☐ مباشرة إلى المقاول أو إلى الموقع
- ☐ موزعين أو تجار
- ☐ أخرى،.....

47) هل خام مادة البناء المنتجة لديكم محلية أو مستورة من خارج المملكة العربية السعودية؟

- ☐ محلية، (المدينة أو المنطقة:.....)
- ☐ مستورة، (بلد الاستيراد:.....)

48) كم النسبة الكلية للمواد المستورة والداخلة في عملية انتاج مادة البناء؟

.....%

49) هل تواجهون أية صعوبات في الحصول على المواد الخام؟

- ☐ نعم، *(كيف)*

.....
.....
.....
.....
.....
.....

- ☐ لا

50) هل تتوقع أية صعوبات مستقبلية في وجود أو توفر المواد الخام؟

- ☐ نعم
- ☐ لا

51) هل هناك أية خطة مستقبلية للاستثمار في أي منتج جديد؟

- ☐ نعم
- ☐ لا

52) ما الآلية المستخدمة لديكم في الاستثمار في منتج جديد؟

---

53) هل لديكم ادارة مختصة بالأبحاث والتطوير؟

- ☐ نعم
- ☐ لا

54) ما نوع خط الانتاج لديكم؟

- ☐ أتوماتيكي
- ☐ يدوي
- ☐ مزيج ما بين أتوماتيكي و يدوي

55) هل هناك أية معلومات تقنية متوفرة عن منتجكم؟

- ☐ نعم، *(من فضلك أرفقها بالاستبانة)*
- ☐ لا

56) هل هناك أية صعوبات في موافقة متطلبات كود البناء السعودي؟

- ☐ نعم، (*ماهي تلك الصعوبات)*.....

.....

.....

- ☐ لا

57) هل توفرون ضمان لمنتجاتكم؟

- ☐ نعم، *كم المدة* :.....
- ☐ لا

58) هل هناك أية خطوات أو معايير لمراجعة وتقييم طلب زبون معين من ناحية خصائص المادة قبل الموافقة على الطلب؟

- ☐ نعم، *(اشرح الخطوات)*

.....

.....

.....

- ☐ لا

شكراً لكم حسن تعاونكم

Builders' Questionnaire

Reason for Survey: This survey is being given to help gather information for my Thesis Paper at Virginia Tech. Your responses are needed and would be greatly appreciated. The data provided would be summarized with all other respondents and analyzed to potentially develop a new building material that could provide changes in the building industry to benefit homeowners and building professionals in the future. Please feel free to answer any and all questions. If you do not know an answer, you can skip it. There are no ramifications if you do not fill out the questionnaire in its entirety.

Builder's Name:
Phone:
Fax:
E-Mail:

Please answer each of the following questions to the best of your ability.

11. Please rank the following aspects from most (1) to least important (8) in regards to building a residential home:
    - __ Total cost of construction
    - __ Time from start to finish
    - __ Exterior appearance
    - __ Building structure
    - __ Insulation capability
    - __ Energy efficiency
    - __ Environmentally friendly
    - __ Ease of job site clean-up

12. What is the percentage of work done in the following? *(Total should equal 100%)*
    _____Retail _____Restaurant
    _____Commercial _____Industrial
    _____Institutional
    _____Residential/Condominiums/Apartments
    _____Other: …….

13. What is the percentage of work done in each of the following areas? *(Total should equal 100%)*
    _____New Construction _____Remodeling
    _____Fire/Flood Restoration _____Other……

14. Is any work performed above three stories in Height from grade?
    - ☐ Yes. If yes, what is the maximum number of stories? _____
    - ☐ No

15. What are typical lead times needed for building materials?
    _____

16. What is the percentage of homes you build that include insulation in the walls?
    _____

17. What is the percentage of the homes you build that include insulation in the floors?
    _____

18. Have you heard of Structural Insulated Panels (SIPs)
    - ☐ Yes
    - ☐ No

19. Please provide data for the last three years in the table below.

	Number of jobs	Average Length of jobs, start to finish (in days)	Percent sub contractors	Number of permanent employees on work crews
Last year				
2nd Prior Year				
3rd Prior Year				

20. Do your permanent work crews have knowledge in multiple building materials?
    - ☐ Yes
    - ☐ No

21. How do you handle building materials that work crews are not trained to use?
    - ☐ Send individuals away for training
    - ☐ Hire a subcontractor
    - ☐ Only use products that permanent work crews are trained to use
    - ☐ Other_____

22. Do you hire sub contractors?
    - ☐ Yes
    - ☐ No

23. What is your current inventory of building materials for residential homes?
    _____SR

24. What is the key factor that drives your inventory levels of building materials?
    _____

25. Do you influence the building material selected by the homeowner?
    - ☐ Yes
    - ☐ No

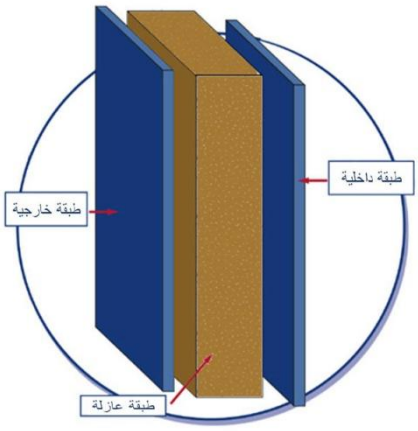
26. Do you suggest or work with Architects and Designers to select building materials?
    - ☐ Yes
    - ☐ No

27. If there was a material that offered better insulation properties, was more energy efficient, was environmentally friendly, and reduced building time would you choose it to build with even if it cost more?
    - ☐ Yes
    - ☐ No
    - ☐ Maybe
    - ☐ Need additional information

28. Rank the following in their effects on delays in construction. *(1 most delays, 6 fewest delays)*
    _____weather
    _____product delivery delays
    _____man power shortages
    _____quality of materials upon arrival (damaged goods)
    _____lack of space to stage materials
    _____equipment failures

29. What is your preferred building material for residential homes? Why?
    _____

30. Who influences your decision making when it comes to selecting a building material?
    _____



استبانة المقاول

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اسم المقاول:
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رقم الفاكس:
الايميل:

من فضلك أجب على الأسئلة فدر الاستطاعة علماً أنه يمكن تخطي السؤال الذي لا تريد إجابته

59) من فضلك رتب المعايير التالية من الأكثر أهمية إلى الأقل الأهمية بالنسبة لك كمقاول، (*1 أكثر أهمية، 8 أقل أهمية*)

—— القيمة الأجمالية للبناء

—— الوقت الأجمالي للبناء

—— نوع المواد المستخدمة في البناء

—— موقع المبنى

—— نوع العزل الحراري

—— طبيعة الجو

—— سهولة البناء

—— أخرى :.....

60) ماهي مادة البناء المفضلة لديك كمقاول؟ و لماذا؟

.....

.....

.....

61) مانسبة المباني المصممة من قبلك بالنسبة للآتي: *(المجموع 100%)*

تجارية:.....

تعليمية:.....

صحية:.....

مطاعم:.....

صناعية:.....

سكنية:.....

أخرى:.....

62) هل انشأت مباني سكنية اكثر من ثلاثة طوابق ؟

☐ نعم,ما أعلى عدد طوابق تم بنائها،.....

☐ لا

63) كم متوسط الوقت المستغرق في بناء منزل 400 م^2 ؟

.....

64) كم يلزم من الوقت لطلب توفير مواد البناء في الموقع؟

.....

65) مانسبة المباني المنفذة من قبلك مراعياً فيها استخدام العزل الحراري؟

.....

66) هل سبق و أن سمعت عن " Structural Insulated Panels " الجدران الانشائية العازلة؟

☐ نعم

☐ لا

67) املأ الفراغات التالية:

	عدد المباني منتهية الإنشاء	متوسط الوقت المستغرق لكل مبنى	نسبة الإستعانة بمقاولين آخرين	متوسط عدد العمال في الموقع
2007				
2006				
2005				

68) هل لديك دور أكبر في اختيار مادة البناء؟

☐ نعم

☐ لا

69) هل تناقش المصمم في اختيار مادة البناء؟

☐ نعم

☐ لا

70) هل لدى جميع العمال لديكم المعرفة الكافية للتعامل مع مواد البناء المختلفة و الموجودة في السوق؟

☐ نعم

☐ لا (ما المحددات لبعض المواد)

71) هل ارتفاع أسعار مواد البناء يؤثر على اختيارك لنوع مادة البناء؟

☐ نعم

☐ لا

72) هل تعاني من شح أو عدم توفر في مواد البناء؟

☐ نعم

☐ لا

73) كيف يتم التعامل مع العمال الذين ليس لديهم الخبرة الكافية في التعامل مع مواد البناء المختلفة؟

☐ ارسالهم للتدريب

☐ التعاقد مع عمال آخرين

☐ اختيار مادة بناء وحيدة يكون لدى العمال الخبرة للتعامل معها

☐ أخرى، .....

74) هل تتعاقد مع مقاولين بالباطن؟

☐ نعم

☐ لا

75) إذا كان هناك مادة بناء توفر خصائص عزل أفضل، تقلص استهلاك الطاقة الشهري، ملائمة بيئياً، و تقلل الوقت المستغرق في انشاء المبنى ولكنها قد تكون ذات تكلفة أعلى نسبياً هل ستختارها؟

☐ نعم

☐ لا

☐ احتمال

☐ أحتاج معلومات إضافية لأقرر

76) قيم الاعتبارات التالية من ناحية التأثير على تأخير انهاء المبنى في الوقت المحدد، *(1 أكبر تأثيراً، 7 أقل تأثيراً)*

—— الجو

—— التأخير في وصول مادة البناء إلى الموقع

—— نقص طاقة العمال

—— جودة مواد البناء التي تصل إلى الموقع (غير صالحة للاستعمال)

—— عدم وجود المكان الكافي لاحتواء مواد البناء في الموقع

—— عدم كفاءة الأجهزة أو المعدات

—— أخرى، .....

77) هل سبق و إن استخدمت أحد تقنيات الطين في البناء؟ لماذا نعم أو لماذا لا؟

شكراً لكم حسن تعاونكم

9.2. APPENDIX B: RESPONSES OF OPEN- ENDED QUESTIONS

Homeowners

Current Building Material	Frequency
Concrete	88
Soil	1
Stone	0
Red Brick	11

Reason for choosing current material	Frequency
Structurally Sound	69
Readily available	42
insulation properties	21
Cost	18
Life-cycle	16
Appearance	15
Availability of trained contractors	12
Reasonable weight	6

Preferred Building Material	Frequency
Concrete	33
Red Brick	4
Compressed soil	4
Stone	3
Wood	1

		Reason why yes/no	Frequency
Use of soil in future buildings	Yes (12)	Better insulation properties	6
		Readily available	1
		Historical material	1
	No (67)	Not available in today's market	31
		Difficult maintenance	7
		Negative perspective	5
		Expensive laborers	4
		High thickness needed	3

9.3. APPENDIX C: IRB Approval Submittal

VirginiaTech

Institutional Review Board
Research Protocol

Email completed form and all applicable supporting documents (see, http://www.irb.vt.edu/pages/researchers.htm#supporting) to irb@vt.edu (PDFs preferred). Copy all investigators listed on the application.

Section 1: Project Information

1.1 PROJECT TITLE:

Soil Use in Panelized Wall Systems for Sustainable Buildings in Riyadh

1.2 PRINCIPAL INVESTIGATOR (Virginia Tech faculty only)

Name: **Annie Pearce**	Virginia Tech department: **Building Construction**
Email address: **apearce@vt.edu**	VT PID: Apearce
Human subject protections training (required, see http://www.irb.vt.edu/pages/training.htm) completed through: ☒ VT IRB Training ☐ Other, certificate is attached ☐ Other, training is on file with IRB office	

1.3 CO-INVESTIGATORS (Include any individual responsible for the design and conduct of the study, or who will use data for publication purposes. Attach separate pages as necessary.)

Name: **Ali Bintarhash**	
Email address: **ali818@vt.edu**	VT PID -or- organization name if non-VT employee or agent: **Ali666**
Human subject protections training (required) completed through: ☒ VT IRB Training ☐ Other, certificate is attached ☐ Other, training is on file with IRB office	

Name: **Christine Fiori**	
Email address: **cfiori@vt.edu**	VT PID -or- organization name if non-VT employee or agent: **Cfiori**
Human subject protections training (required) completed through: ☒ VT IRB Training ☐ Other, certificate is attached ☐ Other, training is on file with IRB office	

Name: **James Jones**	
Email address: **jajone10@vt.edu**	VT PID -or- organization name if non-VT employee or agent: **Jajone10**
Human subject protections training (required) completed through: ☒ VT IRB Training ☐ Other, certificate is attached ☐ Other, training is on file with IRB office	

Include with this application a current CV, resume, or biosketch for all investigators listed above

1.4 DEPARTMENTAL REVIEWER

If required, view http://www.irb.vt.edu/pages/researchers.htm - click on "instructions" under Research Protocol.

Name:	VT PID:	Email:
_____ Signature	_____ Date	Mail (campus code: 0497), fax (540-231-0959), or scan/email (irb@vt.edu) signed page to the IRB office.

1.5 DO ANY OF THE INVESTIGATORS OF THIS PROJECT HAVE A REPORTABLE CONFLICT OF INTEREST? (http://www.irb.vt.edu/pages/researchers.htm#conflict)

☒ **No**
☐ **Yes**, explain:

1.6 WILL THIS RESEARCH INVOLVE COLLABORATION WITH ANOTHER INSTITUTION?

☒ **No,** go to question 1.7
☐ **Yes,** answer questions within table

IF YES
Provide the name of the institution [for institutions located overseas, please also provide name of country]**:**
Indicate the status of this research project with the other institution's IRB: ☐ Pending approval ☐ Approved ***[include approval letter with protocol]*** ☐ Other institution does not have a human subject protections review board ☐ Other, explain:
Will the collaborating institution(s) be engaged in the research? (http://www.hhs.gov/ohrp/humansubjects/assurance/engage.htm) ☐ No ☐ Yes
Will Virginia Tech's IRB review all human subject research activities involved with this project? ☐ No, provide the name of the primary institution: ☐ Yes *Note: primary institution = primary recipient of the grant or main coordinating center*

1.7 IS THIS RESEARCH FUNDED?

☐ **No,** go to question 1.8
☒ **Yes,** answer questions within table

IF YES
Provide the name of the sponsor [if NIH, specify department]: Ministry of Higher Education in Saudi Arabia
Provide the VT Office of Sponsored Programs (OSP) proposal, grant, or fund number related to this project: ☐ OSP number pending ☒ Submission through OSP not required for this project
Is this project receiving federal funds? ☒ No ☐ Yes ***[include grant application, OSP proposal, or "statement of work" with protocol]*** **If yes,** **Does the grant application, OSP proposal, or "statement of work" related to this project include activities involving human subjects that are not covered within this IRB application?**

☐ No, all human subject activities are covered in this IRB application
☐ Yes, however these activities will be covered in future VT IRB applications, these activities include:
☐ Yes, however these activities have been covered in past VT IRB applications, the IRB number(s) are as follows:
☐ Yes, however these activities have been or will be reviewed by another institution's IRB, the name of this institution is as follows:
☐ Other, explain:

Is Virginia Tech the primary awardee or the coordinating center of this grant?
☐ No, provide the name of the primary institution:
☐ Yes

1.8 DOES THIS STUDY *ONLY* INVOLVE THE COLLECTION OR STUDY OF EXISTING DATA?

Please note: it is not considered existing data if a researcher transfers to Virginia Tech from another institution and will be conducting data analysis of an on-going study.

☒ **No,** go to question 1.9
☐ **Yes,** respond only to the following sections within this document: **Section 1** (Project Information), **Section 2** (Justification), **Section 8** (Confidentiality/Anonymity), and **Section 14** (Research Involving Existing Data)

1.9 DOES THIS STUDY INVOLVE CONFIDENTIAL OR PROPRIETARY INFORMATION (OTHER THAN HUMAN SUBJECT CONFIDENTIAL INFORMATION), OR INFORMATION RESTRICTED FOR NATIONAL SECURITY OR OTHER REASONS BY A U.S. GOVERNMENT AGENCY?

For example – government / industry proprietary or confidential trade secret information

☒ **No**
☐ **Yes,** describe:

1.10 DOES THIS STUDY INVOLVE SHIPPING ANY TANGIBLE ITEM, BIOLOGICAL OR SELECT AGENT OUTSIDE THE U.S?

☒ **No**
☐ **Yes**

Section 2: Justification

2.1 DESCRIBE THE BACKGROUND, PURPOSE, AND ANTICIPATED FINDINGS OF THIS STUDY:

The study discusses the panelized wall systems, most specifically with soil as the filler for insulation. In Riyadh, Saudi Arabia, temperatures can reach 120 ºF in the summer and 40 ºF in the winter. Also in Riyadh high growth in population is expected. Specifics will be given to show the number of units needed to keep up with the population explosion and thus a tremendous amount of material will be consumed. In the past, soil was used as a main building component and it some cases the only building component, but now with the advances in building materials, concrete, glass and steel have replaced soil as the main building components today. This paper will focus on what steps need to be taken to convince the building construction professionals and the stakeholders of today that returning to the use of soil as a main or key component in building materials has many advantages. Some of the key areas that are touched on deal with offsite manufacturing where quality and quantity of panels can be closely monitored, labor requirements for handling and installation, equipment necessary to assemble the panelized wall systems and one of the largest contributions, the effect on the environment. Each of these areas is expanded on with some specific details given to more positively represent the soil filled panelized wall systems. A clear outline of the approach to be taken is detailed including such items as examining different studies and research findings, distributing questionnaires and surveys to building professionals to understand their key concerns and obtain their suggestions, and most importantly to analyze the data findings to allow for a completed system

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that not only will work and work better than other systems, but that others will be willing to and want to use. The expected outcomes discussed by the use and development of the panelized wall systems with soil as the filler for insulation is a reduction in energy consumption, reduced time from start to completion of a project, significant reduction of on-site labor requirements and a substantial decrease in the amount of waste going to landfills. Once the findings are complete and a successful final product is developed the results will be communicated to the public and specialized companies and agencies in a professional manner and steps will be taken to motivate them to use natural raw materials and recycled products when making panelized wall systems, in this case using soil as the insulating material.

2.2 EXPLAIN WHAT THE RESEARCH TEAM PLANS TO DO WITH THE STUDY RESULTS:
For example - publish or use for dissertation

Publish the results of the study after analysis of data gathered has been performed

2.3 DESCRIBE THE RELATIONSHIP (IF ANY) THIS IRB APPLICATION HAS WITH ANY PREVIOUS OR UPCOMING VT IRB APPLICATIONS, INCLUDING INTERIM APPROVALS:

The SIP study will include two phases of data collection in which the IRB will need to approve. First one is during the summer of 2008. The intent is to collect data from some key individuals in Saudi Arabia reguarding soil and other building materials, understanding constraints of different groups and getting information on the performance expectations.
The second set of data will use the findings from the first set of data to develop a prototype. This will be presented to the stakeholders to get feedback on their impressions and any suggestions or comments. The inputs from all will be used to develop a final product. At this time it is expected to be a SIP using soil as the insulation layer which will then be used to convince people to use in place of current building materials as the main building component.

Section 3: Recruitment

3.1 DESCRIBE THE SUBJECT POOL, INCLUDING INCLUSION AND EXCLUSION CRITERIA AND NUMBER OF SUBJECTS:
Examples of inclusion/exclusion criteria - gender, age, health status, ethnicity

Homeowners in Riyadh, Saudi Arabia (pool will be evenly split to include north, south, east, west and center regions): have basic information on current performance of building materials used in their homes and also the requirements they want from the building materials
Manufacturers located near Riyadh and other regions of Saudi Arabia based on where current production occurs: have the knowledge of the market needs and understanding on the requirements to manufacture the different building materials
Builders/Contractors in Riyadh, Saudi Arabia (mainly to include those that build residential homes): understand the requirements required at a job site based on the material chosen for construction
Architects/Designers in Saudi Arabia, but focused on those located in Riyadh: have the ability to integrate and suggest a variety of building materials in the designs to meet the homeowner's needs

3.2 WILL EXISTING RECORDS BE USED TO IDENTIFY AND CONTACT / RECRUIT SUBJECTS?
Examples of existing records - directories, class roster, university records, educational records

☐ **No,** go to question 3.3
☒ **Yes,** answer questions within table →

IF YES
Are these records private or public? ☒ Public ☐ Private, describe the researcher's privilege to the records:

Will student, faculty, and/or staff records or contact information be requested from the University?

☒ No

☐ Yes, visit the following link for further information: http://www.policies.vt.edu/index.php (policy no. 2010)

3.3 DESCRIBE RECRUITMENT METHODS, INCLUDING HOW THE STUDY WILL BE ADVERTISED OR INTRODUCED TO SUBJECTS:

[Include all recruitment materials with this application *(required for all protocols if data will be collected from people)* ***e.g., flyers/posters, invitation letter/e-mail, telephone recruitment script, SONA announcement, etc.]***

In person recruitment based on information gathered from public data (i.e. phone books) and personal knowledge of Riyadh area

3.4 PROVIDE AN EXPLANATION FOR CHOOSING THIS POPULATION:

Note: the IRB must ensure that the risks and benefits of participating in a study are distributed equitably among the general population and that a specific population is not targeted because of ease of recruitment.

I'm planning to meet with my colleagues who have graduated in the past three years from the Architecture Department at King Saud University in Riyadh, Saudi Arabia. They usually have a weekly meeting in which several architectural topics can be discussed. During the meeting, I will explain the study in detail and data needed to be collected from these architects as well as some homeowners and other building professionals including architectural expertise, builders, and manufacturers in Riyadh. My colleagues work in different jobs and have diverse experiences, which will help to capture the opinions of the stakeholders in regards to the questions being asked. The goal also is to use the colleagues' diverse backgrounds to help recruite stakeholders with diverse backgrounds in Riyadh. It is intended to use their help also to collect the data from the participants. This method will help to draw the whole image of different stakeholders in Riyadh. The variety of stakeholders (homeowners, architects/designers, builders/contractors, and manufacturers) has been chosen since they are the key players in the use of building materials. Each has a specific role in either the manufacturing or the integration in designs. Homeowners would be working with architects and builders when building their homes and decisions would be made based on information they gather from each of these sources. By understanding the requirements, demands, and how each make decisions on building materials will help in designing a new product that meets the requirements and expectations while also adding additional benefits.

Section 4: Consent Process

For more information about consent process and consent forms visit the following link: http://www.irb.vt.edu/pages/consent.htm

If feasible, researchers are advised and may be required to obtain signed consent from each participant unless obtaining signatures leads to an increase of risk (e.g., the only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting in a breach of confidentiality). Signed consent is typically not required for low risk questionnaires (consent is implied) unless audio/video recording or an in-person interview is involved. If researchers will not be obtaining signed consent, participants must, in most cases, be supplied with consent information in a different format (e.g., in recruitment document, at the beginning of survey instrument, read to participant over the phone, information sheet physically or verbally provided to participant).

4.1 CHECK ALL OF THE FOLLOWING THAT APPLY TO THIS STUDY'S CONSENT PROCESS:

☐ Verbal consent will be obtained from participants ***[include verbal script with this application]***

☐ Written/signed consent will be obtained from participants ***[include consent form(s) with this application]***

☒ Consent will be implied from the return of completed questionnaire. Note: The IRB recommends providing consent information in a recruitment document or at the beginning of the questionnaire (if the study only involves implied consent, skip to Section 5 below)

☐ Other, describe:

4.2 PROVIDE A GENERAL DESCRIPTION OF THE PROCESS THE RESEARCH TEAM WILL USE TO OBTAIN AND MAINTAIN INFORMED CONSENT:

In order to collect the needed data, there are four questionnaires that were developed to gather information from key individuals, homeowners, architects, builders, and manufacturers, regarding the building materials use and selection criteria in Riyadh, Saudi Arabia. In each questionnaire, participants will be supplied with consent information at the beginning of the survey instrument.

4.3 WHO, FROM THE RESEARCH TEAM, WILL BE OVERSEEING THE PROCESS AND OBTAINING CONSENT FROM SUBJECTS?

Ali Bintarhash

4.4 WHERE WILL THE CONSENT PROCESS TAKE PLACE?

Most will occur in Riyadh, Saudi Arabia, but other locations in Saudi Arabia may be done as needed

4.5 DURING WHAT POINT IN THE STUDY PROCESS WILL CONSENTING OCCUR?

Note: unless waived by the IRB, participants must be consented before completing any study procedure, including screening questionnaires.

Upon presentation of the questionnaire

4.6 IF APPLICABLE, DESCRIBE HOW THE RESEARCHERS WILL GIVE SUBJECTS AMPLE TIME TO REVIEW THE CONSENT DOCUMENT BEFORE SIGNING:

Note: typically applicable for complex studies, studies involving more than one session, or studies involving more of a risk to subjects.

☒ Not applicable

Section 5: Procedures

5.1 PROVIDE A STEP-BY-STEP THOROUGH EXPLANATION OF ALL STUDY PROCEDURES EXPECTED FROM STUDY PARTICIPANTS, INCLUDING TIME COMMITMENT & LOCATION:

After identifying participants, each will be contacted and a time set up to distribute the questionnaire. It is expected to take no more than 30 minutes to complete the questionnaire. If this can be done while there, this is the best as participation would be greatest. It will be encouraged, but not required. There will be no pressure to fill out the questionnaire and if anyone does not want to or does not feel comfortable that will be acceptable. The locations will be based on the stakeholders, but is expected to be at the residents of the homeowners and the office location or building site of the architects, builders, and manufacturers.

5.2 DESCRIBE HOW DATA WILL BE COLLECTED AND RECORDED:

[Include all data documents (e.g., questionnaire, interview questions, etc.) with protocol]

Questionnaires will be distributed and collected from each of the stakeholders and the data compiled and analyzed.

5.3 DOES THE PROJECT INVOLVE ONLINE RESEARCH ACTIVITES (INCLUDES ENROLLMENT, RECRUITMENT, SURVEYS)?

View the "Policy for Online Research Data Collection Activities Involving Human Subjects" at
http://www.irb.vt.edu/documents/onlinepolicy.pdf

☒ **No,** go to question 6.1
☐ **Yes,** answer questions within table

IF YES
Identify the service / program that will be used: ☐ www.survey.vt.edu, go to question 6.1 ☐ Blackboard, go to question 6.1 ☐ Center for Survey Research, go to question 6.1 ☐ Other **IF OTHER:** Name of service / program: URL: This service is… ☐ Included on the list found at: http://www.irb.vt.edu/pages/validated.htm ☐ Approved by VT IT Security ***[Include approval correspondence with protocol]*** ☐ An external service with proper SSL or similar encryption (https://) on the login (if applicable) and all other data collection pages. ☐ None of the above (note: only permissible if this is a collaborative project in which VT individuals are only responsible for data analysis, consulting, or recruitment)

Section 6: Risks and Benefits

6.1 WHAT ARE THE POTENTIAL RISKS (E.G., EMOTIONAL, PHYSICAL, SOCIAL, LEGAL, ECONOMIC, OR DIGNITY) TO STUDY PARTICIPANTS?

Very limited as it is not required to fill out the questionnaires. If they are not comfortable, we would ask for them to not continue.

6.2 EXPLAIN THE STUDY'S EFFORTS TO REDUCE POTENTIAL RISKS TO SUBJECTS:

An explanation is on each questionnaire describing the reason for the survey and how there is no ramifications to the participant.

6.3 WHAT ARE THE DIRECT OR INDIRECT ANTICIPATED BENEFITS TO STUDY PARTICIPANTS AND/OR SOCIETY?

A clearer understanding of the requirements and expectations for building materials as well as how and why the decisions are made to use certain products are benefits of the study. This information will be used to help in the development of a new building product as well as helping with the steps that would need to be done to convince the stakeholder to use a new product.

Section 7: Full Board Assessment

7.1 DOES THE RESEARCH INVOLVE MICROWAVES/X-RAYS, OR GENERAL ANESTHESIA OR SEDATION?

☒ **No**
☐ **Yes**

7.2 DO RESEARCH ACTIVITIES INVOLVE PRISONERS, PREGNANT WOMEN, FETUSES, HUMAN IN VITRO FERTILIZATION, OR MENTALLY DISABLED PERSONS?

☒ No, go to question 7.3

The IRB strongly suggests and may require that all data documents (e.g., questionnaire responses, interview responses, etc.) do not include or request identifying information (e.g., name, contact information, etc.) from participants. If you need to link subjects' identifying information to subjects' data documents, use a study ID/code on all data documents.

8.3 WHERE WILL DATA BE STORED?

Examples of data - questionnaire, interview responses, downloaded online survey data, observation recordings, biological samples

Hard copy of Questionnaires and computer where data will be analyzed

8.4 WHO WILL HAVE ACCESS TO STUDY DATA?

the team members

8.5 DESCRIBE THE PLANS FOR RETAINING OR DESTROYING THE STUDY DATA

All questionnaires will be kept until project is complete and Thesis paper is written.

8.6 DOES THIS STUDY REQUEST INFORMATION FROM PARTICIPANTS REGARDING ILLEGAL BEHAVIOR?

☒ **No,** go to question 9.1
☐ **Yes,** answer questions within table

IF YES
Does the study plan to obtain a Certificate of Confidentiality? ☐ No ☐ Yes (Note: participants must be fully informed of the conditions of the Certificate of Confidentiality within the consent process and form) *For more information about Certificates of Confidentiality, visit the following link:* *http://www.irb.vt.edu/pages/coc.htm*

Section 9: Compensation

For more information about compensating subjects, visit the following link: http://www.irb.vt.edu/pages/compensation.htm

9.1 WILL SUBJECTS BE COMPENSATED FOR THEIR PARTICIPATION?

☒ **No,** go to question 10.1
☐ **Yes,** answer questions within table

IF YES
What is the amount of compensation?

Will compensation be prorated? ☐ Yes, please describe: ☐ No, explain why and clarify whether subjects will receive full compensation if they withdraw from the study? *Unless justified by the researcher, compensation should be prorated based on duration of study participation. Payment must not be contingent upon completion of study procedures. In other words, even if the subject decides to withdraw from the study, he/she should be compensated, at least partially, based on what study procedures he/she has completed.*

Section 10: Audio / Video Recording

For more information about audio/video recording participants, visit the following link: http://www.irb.vt.edu/pages/recordings.htm

10.1 WILL YOUR STUDY INVOLVE VIDEO AND/OR AUDIO RECORDING?

☒ **No,** go to question 11.1
☐ **Yes,** answer questions within table →

IF YES
This project involves: ☐ Audio recordings only ☐ Video recordings only ☐ Both video and audio recordings
Provide compelling justification for the use of audio/video recording:
How will data within the recordings be retrieved / transcribed?
How and where will recordings (e.g., tapes, digital data, data backups) be stored to ensure security?
Who will have access to the recordings?
Who will transcribe the recordings?
When will the recordings be erased / destroyed?

Section 11: Research Involving Students

11.1 DOES THIS PROJECT INCLUDE STUDENTS AS PARTICIPANTS?

☒ **No,** go to question 12.1
☐ **Yes,** answer questions within table →

IF YES
Does this study involve conducting research with students of the researcher? ☐ No ☐ Yes, describe safeguards the study will implement to protect against coercion or undue influence for participation:

Note: if it is feasible to use students from a class of students not under the instruction of the researcher, the IRB recommends and may require doing so.

Will the study need to access student records (e.g., SAT, GPA, or GRE scores)?
☐ No
☐ Yes ***[Include release consent / assent / permission form(s) with this application]***

11.2 DOES THIS PROJECT INCLUDE ELEMENTARY, JUNIOR, OR HIGH SCHOOL STUDENTS?

☒ **No,** go to question 11.3
☐ **Yes,** answer questions within table →

IF YES
Will study procedures be completed during school hours? ☐ No ☐ Yes **If yes,** **Students not included in the study may view other students' involvement with the research during school time as unfair. Address this issue and how the study will reduce this outcome:** **Missing out on regular class time or seeing other students participate may influence a student's decision to participate. Address how the study will reduce this outcome:**
Is the school's approval letter(s) attached to this submission? ☐ Yes ☐ No, project involves Montgomery County Public Schools (MCPS) ☐ No, explain why: *You will need to obtain school approval (if involving MCPS, click here: http://www.irb.vt.edu/pages/mcps.htm). Approval is typically granted by the superintendent, principal, and classroom teacher (in that order). Approval by an individual teacher is insufficient. School approval, in the form of a letter or a memorandum should accompany the approval request to the IRB.*

11.3 DOES THIS PROJECT INCLUDE COLLEGE STUDENTS?

☒ **No,** go to question 12.1
☐ **Yes,** answer questions within table →

IF YES
Some college students might be minors. Indicate whether these minors will be included in the research or actively excluded: ☐ Included ☐ Actively excluded, describe how the study will ensure that minors will not be included:
Will extra credit be offered to subjects? ☐ No ☐ Yes **If yes,**

What will be offered to subjects as an equal alternative to receiving extra credit without participating in this study?

Include a description of the extra credit (e.g., amount) to be provided within question 9.1 ("IF YES" table)

Section 12: Research Involving Minors

12.1 DOES THIS PROJECT INVOLVE MINORS (UNDER THE AGE OF 18 IN VIRGINIA)?

Note: age constituting a minor may differ in other States.

☒ **No,** go to question 13.1
☐ **Yes,** answer questions within table →

IF YES
Does the project reasonably pose a risk of reports of current threats of abuse and/or suicide? ☐ No ☐ Yes, thoroughly explain how the study will react to such reports: *Note: subjects and parents must be fully informed of the fact that researchers must report threats of suicide or suspected/reported abuse to the appropriate authorities within the Confidentiality section of the Consent, Assent, and/or Permission documents.*
Are you requesting a waiver of parental permission (i.e., parent uninformed of child's involvement)? ☐ No, **both** parents/guardians will provide their permission, if possible. ☐ No, **only one** parent/guardian will provide permission. ☐ Yes, describe below how your research meets **all** of the following criteria (A-D): Criteria A - The research involves no more than minimal risk to the subjects: Criteria B - The waiver will not adversely affect the rights and welfare of the subjects: Criteria C - The research could not practicably be carried out without the waiver: Criteria D - (Optional) Parents will be provided with additional pertinent information after participation:
Is it possible that minor research participants will reach the legal age of consent (18 in Virginia) while enrolled in this study? ☐ No ☐ Yes, will the investigators seek and obtain the legally effective informed consent (in place of the minors' previously provided assent and parents' permission) for the now-adult subjects for any ongoing interactions with the subjects, or analysis of subjects' data? If yes, explain how: *For more information about minors reaching legal age during enrollment, visit the following link:* *http://www.irb.vt.edu/pages/assent.htm*
*The procedure for obtaining assent from minors and permission from the minor's guardian(s) must be described in **Section 4** (Consent Process) of this form.*

Section 13: Research Involving Deception

For more information about involving deception in research and for assistance with developing your debriefing form, visit our website at http://www.irb.vt.edu/pages/deception.htm

13.1 DOES THIS PROJECT INVOLVE DECEPTION?

☒ **No,** go to question 14.1
☐ **Yes,** answer questions within table

IF YES
Describe the deception:
Why is the use of deception necessary for this project?
Describe the debriefing process: ***[Include debriefing form with this application]***
Provide an explanation of how the study meets <u>all</u> the following criteria (A-D) for an alteration of consent: Criteria A - The research involves no more than minimal risk to the subjects: Criteria B - The alteration will not adversely affect the rights and welfare of the subjects: Criteria C - The research could not practicably be carried out without the alteration: Criteria D - (Optional) Subjects will be provided with additional pertinent information after participation (i.e., debriefing for studies involving deception): *By nature, studies involving deception cannot provide subjects with a complete description of the study during the consent process; therefore, the IRB must allow (by granting an alteration of consent) a consent process which does not include, or which alters, some or all of the elements of informed consent.*
The IRB requests that the researcher use the title "Information Sheet" instead of "Consent Form" on the document used to obtain subjects' signatures to participate in the research. This will adequately reflect the fact that the subject cannot fully consent to the research without the researcher fully disclosing the true intent of the research.

Section 14: Research Involving Existing Data

14.1 WILL THIS PROJECT INVOLVE THE COLLECTION OR STUDY/ANALYSIS OF EXISTING DATA DOCUMENTS, RECORDS, PATHOLOGICAL SPECIMENS, OR DIAGNOSTIC SPECIMENS?

Please note: it is not considered existing data if a researcher transfers to Virginia Tech from another institution and will be conducting data analysis of an on-going study.

☒ **No,** you are finished with the application
☐ **Yes,** answer questions within table

IF YES
From where does the existing data originate?
Provide a detailed description of the existing data that will be collected or studied/analyzed:
Is the source of the data public? ☐ No, continue with the next question ☐ Yes, you are finished with this application
Will any individual associated with this project (internal or external) have access to or be provided with existing data containing information which would enable the identification of subjects: ▪ **Directly** (e.g., by name, phone number, address, email address, social security number, student ID number),

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or

- **Indirectly through study codes** even if the researcher or research team does not have access to the master list linking study codes to identifiable information such as name, student ID number, etc

or

- **Indirectly through the use of information that could reasonably be used in combination to identify an individual** (e.g., demographics)

☐ No, collected/analyzed data will be completely de-identified
☐ Yes,

If yes,

Research will not qualify for exempt review; therefore, if feasible, written consent must be obtained from individuals whose data will be collected / analyzed, unless this requirement is waived by the IRB.

Will written/signed or verbal consent be obtained from participants prior to the analysis of collected data? -select one-

This research protocol represents a contract between all research personnel associated with the project, the University, and federal government; therefore, must be followed accordingly and kept current.

Proposed modifications must be approved by the IRB prior to implementation except where necessary to eliminate apparent immediate hazards to the human subjects.

Do not begin human subjects activities until you receive an IRB approval letter via email.

----------END----------