APPLYING NORTH AMERICAN INTERIOR CONSTRUCTION PRODUCTS AND SYSTEMS TO THE EGYPTIAN HOUSING MARKET

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ABSTRACT

Due to the high population density in Egypt, the high-rise apartment building has become the most common housing typology. Reinforced concrete serves as the main structural material. Other building components are usually built solidly using rigid materials and traditional techniques. This results in durable buildings, which take relatively long time to erect and are difficult to modify later. New construction techniques and products are necessary in order to speed up construction, and allow flexibility when carrying out required modifications to suit changes in resident's conditions.

This paper examines the application of four North American interior products and systems in Egypt, as an approach to enhance the Egyptian home building industry. The selected products and systems include the drywall, the self-levelling floor underlayment, the electrical baseboard raceways, and the PEX plumbing system. A study of each of these systems and the corresponding Egyptian systems is carried out. The feasibility of applying these North American products and systems and the technical, economic, and psychological consequences of their application are presented based on interviews with Egyptian home building developers and consultants.

The results of the study show that each of the investigated products and systems requires a certain degree of adaptation in order to be successfully implemented in the Egyptian homes. A numerical evaluation based on modification criteria indicates that the electrical baseboard raceway system requires the least modifications. Therefore, an early success of this system in Egypt is expected. On the contrary, the drywall system has the least probability of being widely accepted at an early stage of its application.

RÉSUMÉ

En raison de la densité de population élevée en Égypte, le gratte-ciel d'appartements est devenu la typologie du logement le plus commun. Le béton armé représente le matériel structurel principal. Les autres composants de bâtiment sont habituellement construits en utilisant des matériels rigides et des techniques traditionnelles. Ceci a pour résultat des bâtiments durables, qui consomment longtemps pour être construit, et difficiles à être modifiés plus tard. Des nouvelles techniques de construction sont donc nécessaires pour accélérer la procédure de construction, permettre une sorte de flexibilité, selon les conditions du résident, si des modifications seront nécessaires.

Ce mémoire examine l'application de quatre produits et systèmes de construction intérieurs Nord-Américains en Égypte, dans une approche d' améliorer l'industrie égyptienne de construction des maisons. Ces produits et les systèmes sélectionnés, incluent le cloison sèche, sous-finition de plancher autonivelante, les circuits de plinthe électriques, et le système de plomberie de PEX. Une étude de chacun de ces systèmes et les systèmes égyptiens correspondants est effectuée. La possibilité d'appliquer ces produits et systèmes d'Amérique du Nord et les conséquences techniques, économiques et psychologiques de leur application sont présentés sur la base des entretiens avec des entrepreneurs et consultants en matière de construction des bâtiments

Le résultat de l'étude montre que chacun des produits et des systèmes examinés exige un certain degré d'adaptation pour être appliqué avec succès dans les bâtiments des logements égyptiens. Une évaluation numérique fondée sur des critères de modification, indique que le système de circuit de plinthe électriques est celui qui exige les moindre

modifications. Par conséquent, on s'attend à ce que soit le système le plus réussi une fois mis en application en Egypte. Au contraire, le système de cloison sèche a la plus faible probabilité de réussite

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INTRODUCTION

1.1. GENERAL

Within the last twenty years, the building industry in Egypt has been growing rapidly. The housing industry, as part of the building industry, plays an important role in the Egyptian economy. However, there are some challenges and obstacles confronting this industry, either during construction or after occupancy.

This study focuses on understanding the problems facing the Egyptian housing industry in an attempt to solve them. Merging the Egyptian and North American construction techniques through "technology transfer" or "technology transformation and adaptation" process will be examined as a solution. Although this research is related to the Egyptian home building industry, the research attempts to target audiences who are interested in understanding a different approach for enhancing home building industries in developing countries.

In this introductory chapter, the author will present the rationale and motivation for this study followed by the main research argument and statement of objectives, scope and limitations. Finally, the research question, methodology and outline addressing the research problem will be introduced.

1.2. RATIONALE OF STUDY

1.2.1. Background

By 2008, the population of Egypt had risen to 81,713,517 while the rate of population growth had become 1.68 percent. Although the total area of the Egypt is almost one million square kilometers, which is in theory adequate for the population, there is a problem in the geographical distribution of the population. People are concentrated only in less than 5 percent of the total area, inhabiting mainly the Nile Valley, the Nile Delta, the Suez Canal region and the Northern coastal region of the Sinai Peninsula. The remaining 95 percent of the total area is desert. This concentration of population within 5 percent of the total area raises the average density of habitable land to 1,900 persons per square kilometer (4,900 per square mile) (Stanek, 2008). The main challenge that faces the Egyptian development today is the population growth rate and its uneven concentration.

The population crisis has a strong impact on the Egyptian home building industry. Today, the limited availability of land in the habitable areas causes continuous increase in land price. As a result, expensive high-density apartment buildings are the main housing typology in the Egyptian housing market, not only in major cities but also in rural areas. In addition to this, high land prices create an opportunity for the private sector to be involved in the Egyptian home building industry and to generate high profits.

Significant transformation in many areas from small building types to high-rise apartment buildings is evident. Many owners possessing low-rise buildings seek permission to demolish these buildings in order to construct high-rise apartment buildings instead. Although the private sector normally seeks only profit, it also plays an important part in providing solutions for high demand for accommodation.

On the other hand, the home building industry still depends on traditional materials and ways of construction. Reinforced concrete, rather than steel or wood, continues to be the main building material used in housing construction in Egypt. First, the skeleton of the building is constructed using columns, beams and slabs as the structural system most commonly. Second, masonry is added to the skeleton forming the outer envelope and the inner partitions of the building. Then electrical and plumbing components are installed most of the times by cutting into part of the already-built rough structure. Finishing materials come at the end of the process after finishing the rough work.

The above-mentioned common way of construction used in Egypt may suit some conditions in the Egyptian environment as it relies on affordable materials and existing labor experience. However, many problems and challenges emerge either during construction or after occupancy.

Unfortunately, in Egypt, the building industry is a low-wage industry. Laborers are not well paid compared to laborers in other countries. In addition, issues of safety insurance for laborers are not taken into consideration seriously. Consequently, laborers who became involved in the industry are from the uneducated category. They rely only their previous skills and experiences in solving the problems they face. Second, a big portion of the skilled laborer migrates to other countries, which provide higher labor wages (Zohry, 2006).

1.2.2. Problems Associated with the Egyptian Home Building Industry

Building walls with masonry as an infill creates one of the disadvantages of the building system in Egypt. Although masonry provides a more stable coherent building with better isolation for sound and temperature, the weight of masonry walls applies a relatively heavy load on the structure of the building. The common brick dimension in Egypt is 25 cm x 12 cm x 6 cm. Therefore, one square meter of the outer envelope, consisting of 25 cm thick wall, weighs almost 500 kilograms after adding the finishing material. Interior partitions, consisting of 12 cm thick walls, weigh almost 300 kilograms per square meter after finishing. Consequently, the final load of walls, when built with masonry, forms about 30% of the dead load applied on the structure. This is considerably high compared to the corresponding wall loads, when built using any other material. This means that changing the use of masonry as an infill or even reducing the amount of masonry could reduce the dead loads on the structure and consequently its cost. However, the own weight is not the only negative aspect that results from using masonry.

Another disadvantage resulting from the use of masonry in construction is the problem of installing electrical and plumbing fixtures in the built walls. The process of applying these fixtures requires most of the time cutting into part of the built walls. This consumes not only more time and labor work, but also more materials. (Figure 1.1 & Figure 1.2).

The long time of construction is another problem in this system. The time needed for completing the rough construction work (foundation and building skeleton) for an average size building, consisting of 4 floors, is 6 to 8 months. In addition, another 6 to 8 months are needed to carry out installations (plumbing, electricity, air conditions) and to apply finishing materials. This makes the average time of construction and finishing vary from one year to one-and-a-half years, and sometimes more.

The long time of construction affects the cost in two different ways. First, the more time is spent in construction, the more labor hours are consumed and consequently the more labor costs rise. The second effect is the continuous inflation, especially in the unstable markets. Construction material costs have increased almost 80 to 100 percent over the last two years in Egypt. Steel, as an example, cost 3300 Egyptian Pounds per ton in mid-year of 2007, while in mid-year of 2008 it cost 6200 Egyptian Pounds per ton (El Madany, 2008). Therefore, the long time of construction, especially in the unstable markets, makes it hard in the early stages to estimate the actual construction cost for any project.

Despite the long history of relying on manual labor in the Egyptian construction system, the efficiency of production is not uniform in this system. Laborers, who primarily rely only on their previous experience and have little or no educational or scientific background, fail sometimes to solve emerging problems in the construction system. In addition, the process of labor supervision from higher level staff becomes difficult and could result at the end in a low quality product that is difficult to fix (Figure 1.3 & Figure 1.4).

Furthermore, the problems associated with the Egyptian system extend beyond construction to affect the period of occupancy. The structure of the family changes by time, and consequently its requirements. This makes post-occupancy adaptability in homes an important issue, especially in Egypt where the same dwelling serves one family for a long time. Adaptability requires flexibility in the construction system. However, the construction system commonly used in Egypt is not flexible enough to allow changes. The system relies on using non-flexible components, like masonry in partitions and heavy rigid plumbing and electrical fixtures. Any modification, either minor or major, requires demolition and major changes (Figure 1.5 & Figure 1.6). This means not only more time, cost and complex work, but also the presence of laborers for a long time at home. People tend to change their minds about remodeling their homes when they realize these problems.

Figure 1.1

Figure 1.2

Figure 1.1 & Figure 1.2: Installation of plumbing fixtures and pipes in case of masonry brick wall.
Source: Dharmambal (2008)

Figure 1.3

Figure 1.4

Figure 1.3 & Figure 1.4 : Misfitting of electrical conduits, an example of a problem, which may arise due to relying on unskilled laborers.
Source: The author (2008)

Figure 1.5

Figure 1.6

Figure 1.5 & Figure 1.6: The problem of wall demolition in case of home remodeling.
Source: Dharmambal (2008)

1.3. LITERATURE REVIEW

Through the last 80 years, there have been many research proposals and theories to improve the process of design and construction for housing. Few of those studies have had lasting effect on how homes are designed and constructed (OSBA, 2005). Among those theories is the "Support" and "Infill" theory developed by John Habraken in 1964. However, the origin of the theory can be tracked back to the many years before.

In 1915, Le Corbusier, who was one of the most influential architects of the twentieth Century, built Maison Dom-Ino, a basic building skeleton prototype for mass production with free-standing pillars and rigid floors. The prototype provided a clear distinction between the building's skeleton and all other building components (Hays, 2000). In 1945, Le Corbusier developed the Unite, a residential block for the post-war reconstruction of France. In the Unite, Le Corbusier applied a number of his ideas into practice including the distinction between skeleton and infill elements, which he had explored before in the Manison Dom-Ino. However, the Unite project is considered to be the first large-scale practical application for the idea (Leupen, 2006).

At the end of the 1950's, John Habraken, a dutch architect, inspired by Le Corbusier, wrote his book, *Supports: an Alternative to Mass Housing*. In the book, Habraken introduced his solution to the problem of mass housing by providing a system of supports and finishing elements. Habraken believed that for applying mass housing, the government would have to provide large structures, called supports. Habraken explained such support as the structure consists of a concrete construction of a number of floors one above the other and between these floors are the dwellings, side by side (Leupen, 2006). The description of the support that Habraken introduced was strongly related to Le Corbusier's prototype, Maison Dom-Ino.

In 1964, Habraken together with nine architectural founded SAR (Stiching Architecten Research), a foundation for architectural research to investigate solutions for design and construction of mass housing. SAR gave Haraken an opportunity to develop his idea further. SAR suggested the introduction of two production spheres in house building. First, is the 'support', the fixed part of the building that could be built in rigorous repetition as a single project. The support generally includes the load bearing structure, all common circulation spaces, a portion of the mechanical systems, and sometimes the building envelope. Second, is the 'infill', also called the 'detachable units'. The 'infill' is the part of the building which can be determined for each dwelling. The 'infill' includes the non-bearing interior walls and the building systems on the distribution level such as fixtures, equipment, and all plumbing, wiring and duct work (Lu, 2000).

This idea of clear distinction between systems, which came from the necessity to build large apartment buildings for relatively high-density population, highlighted important concepts in home construction in general, and apartment buildings in particular (Habraken, 2002). Among them are the following three concepts. First, the support and infill constructions should be supplied by different industries, with different life cycles. Second, having a modular coordination system is necessary. In this theory of a basic module of 10 cm and a 'tartan-grid' of 10 and 20 cm, was developed. Finally, the distinction between support and infill was a distinction between levels of decision making.

As mentioned by John Habraken in his report, 'The use of levels' separating the building into different systems offers a good base for improved industrialization leading to a better product for less money. Among the advantages that this system provides for the home building industry, is that the clear separation of the infill levels makes it possible to design and produce infill systems that are independent from individual projects. Therefore, the components of the infill systems could be produced industrially in large numbers. In addition, this clear distinction is a way to save time, labor and reduce complication on site since the systems are independent and are installed separately. Furthermore, because the infill system is a separate industrial product, it can be enhanced with time, and can open doors for new ideas and concepts.

Habraken in his book *Variations***,** mentioned some problems that could face the theory when it comes to its application. Among the problems that were raised, is the problem of coordination between the support and infill and how they will be related to each other. Habraken introduced the tartan grid as a solution for the problem. However, in a study that aims to relate the separated levels introduced by Habraken with Lean[1] Construction, Ype Cuperus stated the following important issue regarding the relation between the support and infill :

> "In order to de-couple, yet co-ordinate the levels mentioned, sub-systems and disciplines, dimensions, positions and interfaces of building parts need to be defined. A small number of connections to a (complex) cluster indicate good conditions for prefabrication. If by a design effort the number of connections can be reduced, the co-ordination problem will be reduced as well." (Cuperus, 2002)

In conclusion, the support and infill theory provides solutions for many problems facing the Egyptian home building industry like time, cost, flexibility and labor work on site.

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[1] Lean construction is concerned with the holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging, and recycling. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela et al., 2002).

Although difficulties could occur when the theory is applied to real world, the author believes that the theory is a strong foundation for applying radical changes in the home building industry in Egypt.

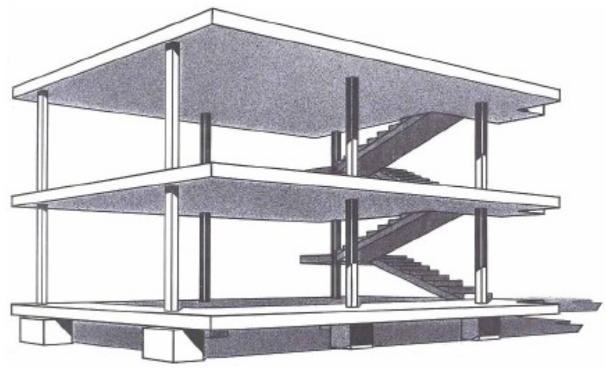

Figure 1.7: Maison Dom-Ino by Le Corbusier.
Source: Habraken (2008)

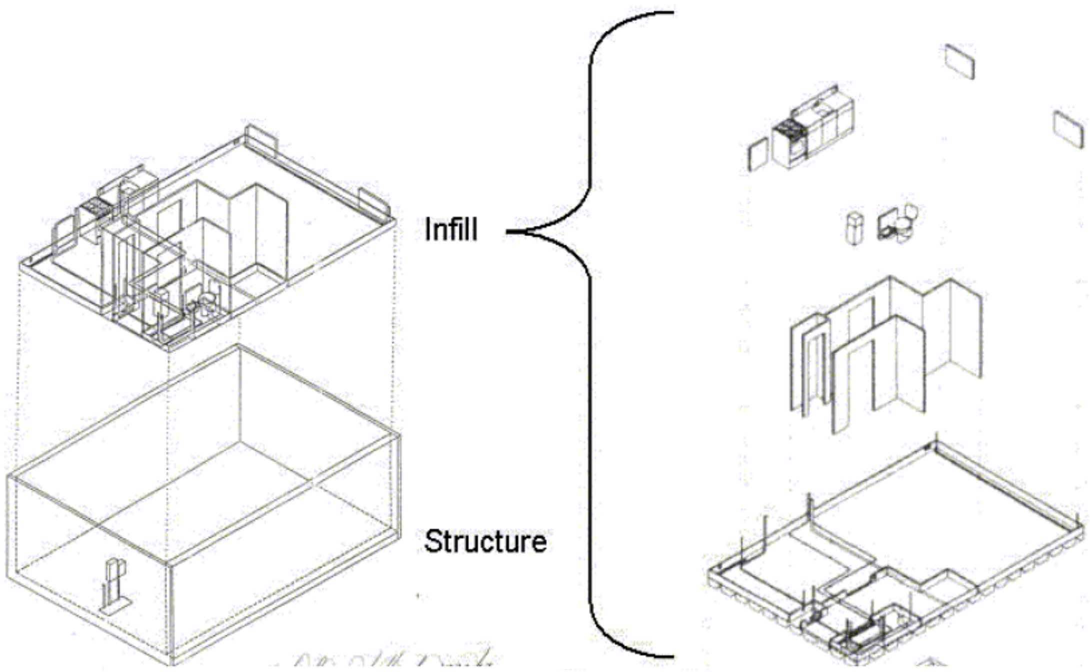

Figure 1.8: Support and infill elements.
Source: Vrijhoef, R.; Cuperus, Y.; Voordijk, H. (2002)

1.4. RESEARCH ARGUMENT

Following Habraken's line of thinking in separating the building components into separate different systems, the author believes that merging some applications and construction techniques from different countries with the Egyptian building system could be a good solution for enhancing the Egyptian home building industry. In general, products and techniques used in North America are suitable, from the author's point of view, to fill part of the gaps and improve most of the disadvantages discussed above concerning time, complications, labor problems and after-occupancy adaptability in the Egyptian system. This paper argues that the Egyptian home building industry could enhance its methods and produce a more efficient building industry by including selected North American construction products and techniques.

1.5. RESEARCH OBJECTIVES

1. To identify the gaps and problems in the Egyptian home building industry.
2. To analyze selected products and techniques used in North American industry.
3. To examine and measure the feasibility of applying these North American products and techniques in the Egyptian home building industry.
4. To propose solutions that facilitates the process of merging each of the selected North American products and techniques in Egypt.

1.6. SCOPE AND LIMITATIONS

The study will focus on the high-rise apartment building, which is the common building typology for residential use in Egypt. The author realizes that the concept of building with reinforced concrete as the structural element, and masonry as the outer envelope is hard to change in the Egyptian housing industry. For this reason selected North American products are chosen in this study to be the interior components of the home that could be added to the reinforced concrete skeleton.

The idea of merging two different systems from two different environments is similar to Habraken's approach - where the *support* acts as the structural element while the *infill* acts as the interior flexible components. In this research the *support* is considered to be the Egyptian building skeleton, while the *infill* is considered to be the interior imported products.

1.7. RESEARCH QUESTION

"How can the Egyptian housing industry benefit from using North American interior construction products and systems, and what are these products and systems?"

Sub-questions:

"What are the challenges that each of the selected North American products and systems will face if applied in Egypt?"

"How can the North American products and systems be adapted technically, in order to be accepted in the Egyptian markets?"

1.8. METHODOLOGY

The research will follow three steps in order to fulfill each of the objectives of the study.

Stage One:

The author will identify the gaps and problems that the Egyptian home building industry faces regarding the construction and the complications that might arise after occupancy.

Several sources will be used to collect information in order to understand the problem. Information will be gathered from builders, users, and the author's experience working as an architect in Egypt for three years.

Stage two:

The author will study the system of building construction in North America. Products and techniques will be selected in order to carry out deeper analysis.

Stage three:

In the last stage, the author will analyze each of the selected products technically. This technical analysis aims to prove that each of these products is capable of filling part the gaps of the Egyptian home building industry. If the product proves to be appropriate, it will be taken to the next level of study, which will examine the possibility of its acceptance in the Egyptian market industry. Interviews with Egyptian builders and developer will help to identify if these products could be introduced easily to the market, whether they would be hard to be introduced, or if they may be introduced with some modifications.

1.9. RESEARCH OUTLINE

This research is organized into four chapters. An outline of each of these chapters is presented below:

Chapter 1:

In this introductory chapter, the author presents the rationale of study, the problems of building with the Egyptian construction system, and literature review on theoretical approach for the solutions to these problems. In addition, this chapter presents the main research argument, research question, and methodology and outlines the organization of this research.

Chapter 2:

In an attempt to establish the practical methods for solving the problems discussed in the first chapter, this chapter will be divided into two parts. In the first, the author will highlight the main principles that lack in the Egyptian home building industry, thus leading to the problems. In the second part, the topic of technology transfer will be introduced. The author believes that technology transfer is an appropriate solution for enhancing the Egyptian home building industry.

Chapter 3:

The third chapter will include case studies. After establishing the criteria and methodology used in selecting and analyzing the appropriate North American products, the selected products and techniques will be presented. A technical analysis of these products and techniques will be provided. In addition, the information gathered from interviews with Egyptian developers about the selected products will be discussed.

Chapter 4:

This final chapter will contain the summary, conclusions and recommendations for possible methods of enhancing the Egyptian home building industry using the North American products and techniques.

CHAPTER TWO

STRATEGIES FOR IMPROVING THE EFFICIENCY OF THE EGYPTIAN HOME BUILDING INDUSTRY

2.1. INTRODUCTION

This chapter contains a review of some of the topics related to the Egyptian housing industry and other topics relevant to this research. The chapter is divided into two sections. In the first, some deficiencies in the Egyptian housing industry, which caused the problems mentioned in the previous chapter, are elaborated. The second section presents the topic of Technology Transfer in the building industry.

2.2. BASIC PRINCIPLES LACKING IN THE EGYPTIAN BUILDING INDUSTRY

Comparing the home building industry in Egypt with that of developed countries, the industry in Egypt is still far behind, especially in the methods of erecting buildings as mentioned in the previous chapter. Some fundamental principles, if applied, could result in radical changes in the Egyptian home building industry. These principles are already applied in developed countries. In addition, they are taken into consideration in other manufacturing and service industries.

If these principles are applied in the Egyptian home building industry, the industry will be more efficient, less wasteful, faster and more productive. These principles include resorting to modular coordination and standardization, benefiting from research and development, and applying advanced technology. The following sections briefly discuss the importance of each of these fundamental principles.

2.2.1. Lack of Modular Coordination and Standardization

In his book *'Building System for Low Income Housing'*, A. K. Jain (1992) claims that:

> *"The Industrialization of building construction products and materials is necessary in order to speed up building construction in developing countries, raise its quality, and reduce its cost……The adequate volume and continuity of demand are the prime conditions for the success of industrialization."*

Jain describes, modern ways to improve construction industry in developing countries. From the author's point of view, industrialization is an efficient way to simplify the complexity of the industry. However, transition from the traditional methods of home building to industrial production itself is a long and complex process that depends on two basic principles, modular coordination and standardization (Rao; Murthy, 1984).

Adequate volume and continuity of demand are prerequisites as Jain noted. In a United Nations study on prefabrication components, researches found that in countries which have some experience with improved methods of production and assembly of prefabrication components, the overall cost of prefabricated buildings is lower than that of conventional buildings by 10% to 15%. In countries where the production of components is undertaken on a small scale, prefabricated buildings cost more than are traditional ones (Jain, 1992).

In Egypt, the volume and continuity of demand in the housing market are adequate to support large scales of prefabricated building construction. As Ahmed El-Maghraby, the Egyptian Housing minister, stated in November 2008:

"We build 300,000 units annually over an area of 40 million square meters….. Real estate market in Egypt is unique in its structure. Population will grow 20 million over the next 15 years, and that's the lowest estimate. This reflects positively on real estate in Egypt. We are talking about a secure market and not a market that needs effort to create demand." (Maged, 2008)

The concept of industrialization in housing dates back to several decades ago. However, the home building industry in Egypt is still lacking a common language for the diverse building components, which is necessary for industrialization. Moreover, historical precedents have given prefabrication a bad reputation in Egypt. In a report by Ahmed Soliman in 1992 entitled *'A Prognosis for Housing Development in New Towns*', Soliman describes the use of prefabrication in the erection of two cities in Egypt, Sadat City and New Bourg Al Arab in the year 1988. Prefabricated load-bearing wall was the chosen mechanized system for construction of the housing in those two cities.

This system did not produce the desired results for varies of reasons. First, the system took a long time in its implementation, because of delays during both its construction phase and finishing phase. The delays during the construction phase resulted from the lack of skilled labor, weak management in the implementation process, and adoption of traditional construction methods to build the foundation and ground floors. The finishing process was delayed because of the imprecise selection of appropriate finishing systems, the lack of subsidiary industrialized products, and technical drawbacks. The technical drawbacks included inaccurate placement of joints between internal panels – due to unskilled labors – and mixing redbrick internally and externally with prefabricated walls. This resulted in creating non-standardized systems (Soliman, 1992). However, it is obvious that these problems occurred due to the lack of proper management and inadequate pre-implementation studies rather than defects in the system of prefabrication.

As described by Soliman in his report, based on the experience in these two projects, authorities became convinced that prefabrication methods would not achieve good results in Egypt. In April 2008, prefabrication was a topic at the conference *'Economic Challenges Towards Low Cost Construction'*, organized by the Egyptian Housing and Building National Research Center (HBRC) and sponsored by the Egyptian Ministry of Housing. In his remarks at the conference, Dr Mohamed El Demerdash, senior assistant to the housing minister stated, raised hopes for change in the industry in the coming years. He stated:

> *" Since our goal is to reduce cost, we can sometimes combine two or three systems from a wide range that varies from traditional to prefabs…………For example, setting up factories to manufacture some of the materials as opposed to shaping them on the sites would ensure quality. In other cases using prefabs would reduce cost and reduce the reliance on skilled labor" (Maged, 2008)*

In doing this so, Egypt can learn from a number of authors who suggested recommendations to developing countries on how to how to apply the basic principles of industrialization to construction systems. For instance, applying a common module that is used in other countries allows the importation of components and machinery. This would be critical at a time when the domestic industry is developing the capability to produce components and machinery locally (Rao; Murthy, 1984). The industry should reduce as much as possible the number of standard types that result from the use of modular materials. This is necessary in order to create a bigger market for each type, thus making room for a stronger production line and a more affordable product (Jain 1992).

Standardization of the building process and components does not mean that the final outcome will be a monotonous product or building. Architects are capable of designing unique buildings using a high degree of standardization in their components (Egan 1998).

2.2.2. Research and Development

> *"R&D is an important driver of innovation. No valid argument was presented to justify the construction industry being any different – R&D is as important to the construction industry as any other." (Fairclough, J., 2002)*

These words were written by John Fairclough in his review of government R&D policies and practices in the UK, entitled *Rethinking Construction innovation and Research*. Although he was referring to the British industry, the author believes that this element is also required yet is missing in the Egyptian home building industry.

The Housing and Building National Research Center (HBRC) was established in 1954 as an independent government research agency, under the Egyptian Ministry of "Housing, Utilities, and Urban Development". Its mission includes the coordination of the research efforts in the field of construction, the deployment of knowledge in the field of housing and building, and the development of the methods of construction (HBRC, 2009). Unfortunately, the HBRC effective innovations, derived through scientific research, still have not achieved the changes required in the Egyptian home building industry. The methods of erecting buildings are still the same as in the past few decades. According to a report by the embassy of Denmark in Cairo, dated August 2008, Egypt imports approximately one fourth of the total market value of building products and materials. Domestic manufacturers (mainly in the private sector) supply three fourth of the total market demand for building materials and products. The total capital of Egyptian investment in the building material sector was estimated to be $ 1.9 billion in 2008.

These characteristics of the Egyptian housing industry suggest that there is an excellent opportunity for further research and development to take place. Seventy five percent of products and materials are locally manufactured. There is a great investment in the building material sector. There is a well established research center. In order to promote more development through research, the Denmark report suggested the following:

> *"To sustain the momentum toward innovative construction systems, a good awareness campaign should take place with a pilot phase prior to project implementation. These campaigns should target end-users, general contractors, as well as consultants. Contractors are more likely to dump wasteful building techniques in favor of low costing and good timing, which are increasingly appreciated factors in construction projects" (Ministry of Foreign Affairs of Denmark, 2008)*

2.2.3. Advanced Technology

Technology is an important factor for the success of most industries. Azmi (2002), in his report *Reforming Malaysian construction technology towards higher dynamism*, talking about enhancing the Malaysian construction industry wrote:

> *"Through technology development, the developed nations were able to generate a sustainable well-trained, highly skilled and educated workforce to cope with accelerated industrialization to the extent that the economic performance of a country is often intertwined with its performance in science and technology."(Azmi, 2002)*

The home building industry, as one of the most important industries in many countries, needs to employ advanced technology in all its fields; including design, production, communication, and on-site construction. Integrating technology in each of these processes speeds construction and reduces defects (Fung, 2006).

In Egypt, the technology that serves the production of home components and on-site construction in Egypt is still primitive. On the other hand, the Egyptian home building industry has succeeded in integrating advanced technology in the design process, through using advanced computer programs, and in communication between team members (El Shafie, 2006). The technology that came from the field of Information Technology rather than the building industry field has had a great impact on reducing waste and speeding the flow of information. However, the required significant development in the construction industry is still missing in Egypt. This is because major development is usually achieved through the adoption of advanced technologies in building components production and on-site construction production (Jain, 1992). Both are still primitive in Egypt.

One remarkable examples of the application of advanced technology in the home building industry is that of Toyota. Toyota, a leading car manufacturer, is applying mass-production techniques with advanced technologies to also build houses. The company uses methods similar to those used in manufacturing automobiles to construct its houses (Koerner, 2008). About 85% of the housing units are manufactured, inspected, and completed before leaving Toyota's factory with few defects, if any, or no defects. After transportation to site, the manufactured modules are stacked together, in the manner of Lego block, to achieve the desired space. Toyota manufactures about 100 modules per day. A house may contain almost 12 modules. This means that Toyota factory produces about 8 to 9 houses per day (Kageyama. 2006).

In summary, the lack of standardization and industrialization, weak research and development efforts and failure to adopt more advanced technologies are the key deficiencies in Egypt's home building industry. It lags far behind other countries and other industries.

Radical changes are necessary for the development and improvement of the home building industry in Egypt. All industry participants must do their part to enable these changes. Designers and architects should design buildings with a common language to facilitate industrialization of their products and components. Manufacturers and developers should adopt more advanced construction processes appropriate for the Egyptian market. The Egyptian government should facilitate the implementation of new concepts. Clients should encourage new ideas.

There is a great opportunity for Egypt to learn from other countries. Thanks to globalization, markets are more opened in many countries and ideas are easily shared. Egypt should take advantage of the international experience and apply new methods and concepts appropriate to its context.

2.3. TECHNOLOGY TRANSFER

The North American home building industry provides a demonstrated success in applying the previously-mentioned principles. However, such principles are still lacking in the Egyptian home building industry. For this reason the author believes that the technology transfer of products and techniques from the North American home building industry to Egypt could constitute an appropriate solution for enhancing the Egyptian home building industry.

The following sections briefly discuss the concept of technology transfer as related to the present research.

2.3.1. Definitions and Descriptions

The term technology transfer is not new. However, through time, it has been defined by many scholars and has become better understood and accepted. Abbot (1985) defined technology transfer as the "movement of science from one group to another, such movement involving its use". Once the supplier delivered the technology, the transfer process was complete. The ability of the receiver to absorb the knowledge transferred was not taken into consideration. Then Simkoko (1989) modified the definition as the planned transmission of information and acquisition of technical knowledge and techniques. This meant that there is no true technology transfer until the technical knowledge received from the supplier has been put into effective use by the recipient. Li-Hua (2004) further refined the concept by noting that the transfer of knowledge is also crucial.

> *"Without knowledge transfer, technology transfer does not take place, as knowledge is the key to control technology as a whole. Hence, knowledge transfer is crucial in the process of technology transfer"*

Sridharan (1994) implied that technology transfer is a two-way process, and therefore will succeed only when both the supplier and the recipient work together in the process, deciding what needs to be transferred and together implementing a well organized programme for the process to achieve their mutual objectives. Decisions in technology transfer are never one-sided. Geography, culture, as well as social, political and business conditions are all matters to be considered in assessments technology transfers (Samli, 1985).

The 2nd international conference on *Creating a Sustainable Construction Industry in Developing Countries* was held in November 2000 in Gaborone, Botswana under the theme

'Challenges Facing the Construction Industry in Developing Countries'. The conference was organized by the International Council for Research and Innovation in Building and Construction (CIB). The purpose of CIB is to serve its members by encouraging and facilitating international co-operation and information exchange in building and construction research and technology development. The conference introduced several important definitions.

'Construction Globalization' was defined by Ssegawa, Ngowi and Kanyeto (2000) as:

> *"A process, driven largely by business and facilitated mainly by technology, by which natural, cultural and man-made barriers preventing individuals and enterprises concerned with construction operating anywhere in the world are eliminated, resulting in activity spreading from many parts of the world to all over the globe."*

Ssegawa, Ngowi and Kanyeto (2000) also emphasized the importance of the receiver of new technology to use it and adapt it in a self reliant and sustainable manner. To them, this means:

> "*the receiver has gained capabilities to produce/ construct by using the technology components; and the receiver gained capabilities to adapt, maintain and even generate technology components more or less based on the originally received ones. In the end the receiver might be a competitor of the supplier."*

The term *Technology Transfer* is related to all fields and industries, not only to the construction field. Therefore, the concept and fundamentals illustrated in the previously-mentioned definitions could be applicable to all fields and industries. The following sections in this chapter investigate the term *Technology Transfer* as related to the construction industry.

2.3.2. Technology Transfer in the Construction Industry

The issue of technology transfer in today's globalized world has gained importance because it has an enormous impact on the economic growth and development. Technology transfer has taken place strongly through the past 20 years in Western Europe, North America and the Pacific Rim. It is estimated that 50% of products and processes in general, will come into existence from outside the primary developer; academic and research institutions are clearly generators of much of this new technology (Inzelt; Hilton, 1999).

The construction industry is generally one of the beneficiaries of technology transfer (Awil, 2004). As for developing countries, technology transfer catalyzes much faster the development in the construction industry, and thereby in the economy (Simkoko, 1989). Moreover, as Haug (1992) stated:

> *"Study of imported technology may also be the best means of promoting local R&D, which in turn is the core of a developing country's ability to generate its own technology."(Haug, 1992)*

However, the precise methods used for technology transfer by an individual country will differ depending on its unique characteristics and nature. In the construction industry, technology is transferred in three forms (Haug, 1992). First, it can be transferred via machinery or other intermediate goods. This is normally appropriate for manufacturing purposes where the nature of the technology is not complex and where no proprietary techniques or processes are involved. Secondly, it can also be transferred through individual experts. This generally occurs through small and medium sized projects in which the technology transferred is simple and unpatented. Finally, technology can be transferred through technical know-how, patented or unpatented, or other information subject to proprietary rights.

In the construction context technology transfer, no single organization controls the process of technology transfer in its entirety. Major players are involved with different objectives and tasks. Success requires effective collaboration between: (BH Consulting Limited, 2001)

- Technology supplier who has the process, systems and know-how.
- Technology buyer's who will use the process, systems and know-how.
- Contractors who will engineer and construct the physical facilities using the technology.
- Equipment vendors who will provide equipment systems if necessary.

2.3.3. Selecting the Appropriate Technology to be Transferred

> *"When technology is imported too rapidly or is too advanced it is inexpertly used….. Before selecting specific methods and rejecting others, any nation intent on technological development is encouraged to consider establishing a national, comprehensive technological developmental scheme"(Haug, 1992)*

As mentioned by Haug the process of selecting the technology require careful attention. During this phase, different technology options should be sought and explored. The purpose is to select, develop and analyze a small number of options that fit the market's objectives. At the end of this phase a technology decision is normally taken and there should be a well-constructed transfer plan. The selection process consists of: (BH Consulting Limited, 2001)

1. Identifying the needs of the system, and the requirements for improvement.
2. Establishing criteria for the selection.

3. Identifying available sources and suppliers.
4. Gathering technical performance and cost data about the new technology, and sufficient information from technology transferor to make informed decisions.
5. Analyzing the data taking into consideration the risks that could emerge.
6. Selecting the appropriate technology option.

Miljana Horvat in a report entitled '*Technology Transfer: Can Canadian Affordable Homes be built in the Countries of Former Yugoslavia*' dated 1998, discussed briefly the selection criteria for transferring a new construction system for homes between Canada and Yugoslavia. Although the study conceived the Canadian market as a transferor and countries of former Yugoslavia as a transferee, the criteria recommended in her research can be used for transferring any construction system to different countries. The recommendations were classified in three main areas; technical, economic and psychological. The following sub-groups were suggested:

1. <u>Technical Aspects</u>

a) Codes and Regulations. These codes and regulations include load bearing capacity, earthquake resistance, fire resistance, energy efficiency and acoustic performance.
b) Implementation. Criteria that focus on the appropriateness of the construction time of the new technology, the requirements of skilled labor and the requirements of specialized equipment or tools.

c) Adaptability of building systems to be transferred and their compatibility with the established local measurements and modular units, and consequently with local products and materials.

d) Durability of the transferred system or product when compared to the existing ones.

2. Economic Aspects

a) Construction cost of building materials and components.

b) Labor cost, including the cost of learning the new system particularly when unskilled laborers are involved.

c) Transportation cost for components and materials that might need to be shipped from one country to another.

3. Psychological Aspects (Acceptance)

a) Barriers to acceptance by users in terms of accepting the building performance and its maintenance requirements.

b) Barriers to acceptance by builders in terms of incorporating new or different technical requirements.

2.3.4. Problems Associated with Technology Transfers

Although several developing countries have made attempts to transfer technology from developed countries, most such trials have met with little success. Real and successful transfers of technology are few, especially in the construction industry (Kumaraswamy; Shrestha 2002; Carrillo, 1994; Haug, 1992). Reasons for these shortfalls have been identified by researchers.

One of the most important causes of these failures is the lack of continuity and long-term vision on the side of the transferee (Kumaraswamy; Shrestha, 2002). The most important long-term goals of technology transfer, as defined by Devapriya & Ganesan (2002), should be widespread dissemination within the transferee's domestic market of advanced technologies, to enhance and sustain domestic construction, and limit the reliance on foreign industry.

Recipients' and clients' suspicion regarding usefulness of technologies transferred sometimes prevents the process from reaching its objectives. Consequently, few sponsoring agencies or developers are willing to fund the additional costs incurred, although they may believe that technology transfer is desirable (Carrillo, 1994).

Another problem in transferring technology to the developing world is that the technology acquired from developed nations is sometimes inappropriate to the developing world's needs. This is because technology is not usually produced for global commercial markets. The small technology markets in developing countries and the limited profit-making offered there discourage technology exporters from modifying their technology to meet the particular context of developing countries. Instead, the same technology that is sold in developed countries is offered to developing countries as it is, thus increasing the risk of failure (Haug, 1992).

One of the consistent problems that the developing world has faced when importing technology is making poor choices due to a lack of information. This is because the variety of choices is often too much that the recipient is unaware of the full range of alternatives, which often leads to inappropriate technology being transferred (Haug, 1992).

2.4. CONCLUSION:

In conclusion, technology transfer can be one of the successful methods that could fill the gaps in the Egyptian home building industry. However, the attempt of developing countries to leap ahead technologically without proper planning will cause them, most of the time, to ignore some basic stages, which are crucial for the industry to absorb and to utilize technology effectively.

Appropriate policies at all levels, including government, institutions, industrial organizations, project teams and labor organizations, will be needed to strengthen the process of technology transfer in its long-term plan (Kumaraswamy; Shrestha 2002). Egypt and other developing countries seeking to adopt new technology through transfers from developed nations should learn from previous mistakes of other countries. A well studied plan based on the previously mentioned criteria in selection process is essential, together with a clear, long-term vision for a stronger domestic industry in the future.

CHAPTER THREE

TECHNOLOGY TRANSFER OF
NORTH AMERICAN PRODUCTS AND SYSTEMS

3.1. INTRODUCTION

The principal objective of this chapter is to present the analyses carried out for selected North American interior products and systems, which are proposed as alternatives to the corresponding products and systems existing in Egyptian home building industry. As mentioned Chapter 2, certain steps are required for a successful transfer of these new products and systems.

The first step is to identify the needs and problems of the systems used in Egypt. This was described in Chapter 1. The second step is to identify the requirements for improvement, presented in Chapter 2. Then the third step is to identify the available suppliers of the new technology needed to realize these improvements. In this research project, the North American home building industry was selected as a potential source of this new technology. The final step is to establish a methodology for the selection of the new technology, to gather technical performance about this technology, and to analyze the available data, taking into consideration the risks that could emerge. This final step is the subject of this chapter.

The chapter is divided into three sections. The first section presents the methodology and criteria used in selecting the North American products and systems for study. The second section illustrates the method used in analyzing the chosen products and systems. The final section focuses on presenting and analyzing the selected products and systems.

3.2. METHODOLOGY FOR SELECTION

In the North American home building industry, and particularly in interior products and systems, some distinct concepts become evident. These concepts include the Do-It-Yourself (DIY), the degree of flexibility, the speed of installation, and the notion of waste reduction. These concepts are used as guidelines in the process of selecting the North American products and systems in the present study. Each of these concepts and properties are discussed below.

3.2.1. Do-It-Yourself

Do-it-yourself (DIY) products are those which users themselves are involved in their final assembling. The market for DIY products in North-America is now well structured. A large number of people are involved in renovating their own spaces and assembling their subsystems. One of the main reasons of the success of the DIY concept is the high cost of manual labor, especially in developed countries (Santos, Razera and Dangelo, 2006).

However, the concept of DIY products has many benefits in addition to reduction in labor cost. It allows simplification in the home building industry by separating the building process into clear, simple subsystems. This facilitates maintenance for these subsystems since accessing them becomes easier and less complicated. Moreover, the users' awareness of the domestic materials and systems used reduce future problems. Although DIY depends on users' participation due to the ease of assembling subsystems, it could, on the other hand, increase employment opportunities by allowing laborers with low or non-technical skills to be involved in the process.

DIY may require the distribution of handbooks for the products, which state clearly the materials used and their properties. In addition, these handbooks describe step-by-step how to use the product and, sometimes, the best choice of material and equipment to be used with it.

3.2.2. Flexibility

In North America, the idea of home flexibility and adaptability has gained importance after the World War II due to the increasing rate of social and economical changes. It allows decision makers to adapt their homes to meet changing needs, producing a more efficient home building industry.

The home building industry's strategy in North America has been to incorporate flexibility into each subsystem or component through the use of new materials and techniques, in order to create an overall building flexibility. Prefabrication is one approach that has been used to achieve housing flexibility. Consequently, this approach has created a wide range of products and systems with better performance and efficiency.

Flexibility in products and systems may take different forms and types. Lu, in his research *'Construction Products that Contribute to Increase Flexibility in Wood-Frame Low-Rise Housing'* (2000), mentions various types of physical flexibility in North-American products and systems. These types include:

1. Material flexibility: The material itself could yield, deform or be molded, bent, compressed, extended, twisted, or altered as a result of the direct application of exterior forces. This occurs without causing the loss of the basic integrity of the entity affected.

2. Mechanized flexibility or flexibility of joints and connections: It refers to the components or sub-assemblies jointed by means of hinges, loops or slides allowing more flexibility in the system.
3. Dimensional and/or modular flexibility: The products and systems depend in their design and manufacturing upon a modular system to provide an appropriate medium for assembly compatibility and coordination. In this type of flexibility, matching or fitting of items is comprehensive and easy to achieve
4. Infrastructure flexibility: It refers to flexibility in designing the mechanical, electrical, heating, ventilation, air conditioning, and plumbing systems in homes. This improves maintenance and ability for modifications and future changes. Infrastructure flexibility is strongly related to the property of material used and the degree of installation work required.

The case studies, presented later in this chapter, show examples of these various forms of flexibility.

3.2.3. Speed of Installation

One of the features, which strongly distinguishes the North-American home building industry, is the speed of installation of its components and parts. Modularity, prefabrication and flexibility of its products and systems are all factors that lead to the reduction of installation time in North American home construction. The used products and systems allow building parts to be completely assembled on site in about one to two months.

The home typology in North America, which depends mostly on prefabricated wood-frame structure, helps in reducing the time of construction. In addition, interior products and systems play an important role in reducing the time. Assembling all interior products and systems can take place in a few days.

3.2.4. Waste Reduction

Generally, the construction industry consumes large amounts of natural resources and produces a significant quantity of construction and demolition waste. This waste has a serious impact on the environment. In addition, it is considered as an extra cost in material purchases. However, the North American system applies three different strategies in its products and systems to reduce this waste. First, the industry depends on prefabrication, which is considered to be one of the most effective waste minimization methods in the construction industry (Mokhtar and Mahmood, 2008). Second, it minimizes the interface between its systems and products. This results in reducing the amount of demolition and waste in the process of initial construction and future adaptation. Finally, the industry relies on materials that can be recycled.

3.3. METHODOLOGY FOR ANALYSIS

The analysis of the selected North American products and systems is carried out according to the following steps:

1. *Studying the product and system existing in the Egyptian home building industry.* This step focuses on studying the existing system's advantages, disadvantages and reasons why improvement is needed. Information gathered in this step is based on

the author's experience in the home building industry, as an architect in Egypt for three years.

2. *Studying the alternative North American product and system.* This step includes studying the system's concept, properties, and method of installation. Data gathered in this step is based on two main sources. The first source is the previous researches, which discuss the same selected product and system. The second source is the product and system's data issued by North American manufacturers.

3. *Analyzing the application of the North American product and system in Egypt.* Three main aspects are examined: technical, economic and psychological. The potential problems that could emerge when applying the new system in Egypt are highlighted. Moreover, the possible strategies for adapting the new system to the Egyptian housing market are investigated in order to reduce the potential problems. Data used in this analysis has been gathered through separate telephone interviews with five engineers involved in the Egyptian home building industry for a long time. These interviewees are:

    a) <u>Khaled El Hammamy</u>: An architect having a fifteen-year experience in the Egyptian home building industry. The interview took place in May 2009.

    b) <u>Mohamed Hamdy:</u> A developer and a general contactor who has been in charge of many housing projects. Mohamed has an experience exceeding thirty-five years involving the construction of most types of structures. The interview took place in July 2009.

c) Ashraf Adel: A civil engineer having a nineteen-year experience; first as a contractor for nine years, then in a technical office for four years, and finally as the head of the quantity surveying department in a large consulting firm. Ashraf is fully aware of on-site construction methods and techniques. The interview was conducted on July 2009.

d) Mohamed Fekry: An electrical engineer involved in the design and construction of electrical systems for housing and industrial uses for twenty-three years. The interview was conducted July 2009.

e) Mohamed Mehanna: A civil engineer and contractor having a nineteen-year experience in the field of plumbing, water supply, wastewater networks, pumping stations, and treatment plants. The interview took place in July 2009.

3.4. SELECTED PRODUCTS AND SYSTEMS

3.4.1. INTERIOR WALL SYSTEM

3.4.1.1. Introduction

The main function of interior walls is to subdivide space within a building. However, their construction should also provide the required degree of acoustical and fire separation, to accommodate necessary runs of services such as mechanical and electrical lines, and to support the desired finish materials. Interior wall systems can be implemented in many forms. They may be solid like stone, brick and concrete walls; or framed structures made from wood, steel or plastics. In addition, they may be classified according to their structural use as either load bearing structural walls or non-load bearing walls.

3.4.1.2. Interior Walls in Egypt

As mentioned in the first chapter, the interior walls in Egypt are usually erected from non-load bearing, 12 cm thick, bricks (Figures 3.1 and 3.2). Among the advantages of interior brick walls, besides being durable, is that they provide the desired sound and fire performance without the need of additional materials. On the other hand, erecting a brick wall consumes too much time. One day is required by a mason to erect 3 m x 5 m wall. This means that an average size apartment, a 100 square-meter apartment, requires about one week erecting its interior walls without finishing. In addition, since service lines run embedded in walls, all building services are not installed until all interior walls are completely constructed.

The plastering process becomes essential in order to provide the implemented brick wall with a smooth surface. This plastering process also consumes time. One plasterer will require about 7 to 10 days for plastering an apartment of the same size. Moreover, the brick wall system does not allow accessibility to the embedded service lines. This means that, in case of maintenance or an upgrade for these lines, brick demolishing is necessary and the whole finishing process has to be applied again.

Figure 3.1

Figure 3.2

Figure 3.1: Production of 25 cm x 12 cm x 6 cm bricks in a brick factory, Mansoura, Egypt.
Source: Internet - http://www.coastweek.com/xinhua-300509-3.JPG (Accessed on 9 July, 2009)

Figure 3.2: Construction of brick wall.
Source: Internet - http://www.coworkforce.com/sjh/BrickLayer.jpg (Accessed on 9 July, 2009)

3.4.1.3. Drywall System in North America

Unlike the Egyptian system, which depends mostly on brick in erecting interior walls, the traditionally framed interior wall is the most common system for residential spaces in North America (Figures 3.3 and 3.4) (PorterCorp, 2007). Stud partition, which is the old version of the drywall system, was often made by securing a framework of wood to the floor, and then covering both sides with lath and plaster. The lath and plaster did not allow future flexibility. In case alterations were required later, the complete demolition of the wall was necessary. Drywall boards first appeared in 1910 as a direct substitute for plaster and lath wall construction.

The ease of the drywall's installation helped to ensure its widespread use (Lu, 2000). Presently North-America is one of the greatest gypsum board users in the world with a total wallboard plant capacity of about 4 billion square meter per year, which is about 50% of the world wide production (Founie, 2006).

Figure 3.3

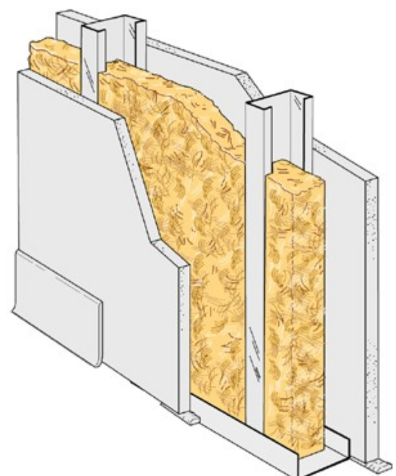

Figure 3.4

Figure 3.3 and Figure 3.4: Simple methods of installation for drywall partitions.
Source: USG Corporation (2009) and Thermafiber Inc.(2009)

Properties & Types of drywall

Drywall is made of a layer of gypsum plaster pressed between two thick sheets of paper, then kiln dried (Clarke, 2009). They are typically produced in 120 cm wide segment lengths. Their thickness varies from 6.35 mm (one quarter inch) to 25.4 mm (one inch) according to the desired use. The gypsum boards offer a number of advantages. One of the most important advantages in using gypsum boards is the ease and speed of installation. An entire house can be drywalled in one or two days by two experienced drywallers. Moreover, there has been a constant enhancement in the performance of drywalls to suit their uses in residential applications. This enhancement has assured that such wall systems are now able to reach good level of performance in the areas of acoustic insulation and resistance to fire, as discussed in more detail below.

Interior brick walls or concrete walls without insulation have STC [2] ratings of about 40, which is acceptable within the residential units. On the other hand, if no insulation is used, the STC rating for drywall partitions is about 33, which is relatively low. Adding insulation like rock wool in the wall cavity would increase the STC to a value between 45 and 50 STC. Hence, unlike brick or concrete walls for which the STC rating is usually controlled only by the choice of material, drywall partitions' STC performance can be enhanced by different methods. These methods include the increase of the space between boards, the staggering of the studs, and the provision of insulation between the boards. Such methods could provide an STC value as high as 63 (Building Construction Authority, 2006).

The drywall's performance regarding fire resistance is also acceptable. Gypsum, which is the primary component in drywall, contains large amounts of water bound in crystalline form. By weight, the compound is 21% water. By volume, it is nearly 50% water (Blachford, 2009). When exposed to fire, the water is vaporized, delaying heat transfer. Therefore, a fire in a room, separated from another by a fire-resistance drywall, will not cause the adjacent room to get any warmer than the boiling point (100°C) until the water in the gypsum is evaporated. The fire rating for the typical 12.7 mm thick drywall is about

[2] Sound Transmission Class (STC) is a measure of the reduction in noise level that a partition can provide (measured in decibels). It is used to rate interior partitions, ceilings/floors, doors, windows and exterior wall configurations.

1 hour (Maguire, 1988), which satisfies the fire safety requirement for residential buildings. Using a double layer instead of a single layer at each side of the studs improves the fire rating.

The development of drywall system in North America has introduced different types of panels used for various functions. The drywall panels include the following types:

- Standard: Regular white board, from 1/4" to 3/4" in thickness.
- Fire-resistant "Type X": It is manufactured by adding glass fibers to the gypsum to increase its resistance to fires.
- Greenboard: It contains an oil-based additive in green colored paper covering. These additives provide moisture resistance. It is used in washrooms and other areas expected to contain high levels of humidity.
- Blueboard: The blue face paper forms a strong bond with a skim coat or a built-up plaster finish. This type provides both water and mould resistance.
- Cement board: It is more water-resistant than greenboard. It is used in showers and sauna rooms as a base for ceramic tiles in walls and flooring.
- Soundboard: It is made from wood fibers in order to increase its STC.
- Soundproof drywall: It is laminated drywall made from gypsum, other materials, and damping polymers to increase its STC.
- Enviroboard: It is a board made from recycled agricultural materials.
- Lead-lined drywall: It is a drywall that is used around radiological equipment.

Installation

The drywall installation steps are simple and could be carried out by the following DIY method. The light, non-structural vertical members are the first elements to be installed using studs. Traditionally, in North America, studs were made of wood, usually 2 cm × 4 cm or 2 cm × 6 cm dimensional lumber. However, now steel studs are gaining popularity. This is because steel studs are lighter, stronger, moisture and insect resistant when compared to wood studs (Guy and Ciarimboli, 2006). Moreover, they are now manufactured with regularly spaced holes in the webs in order to accommodate raceways for electrical, mechanical and plumbing lines (Figures 3.5 and 3.6). Consequently, the construction time is reduced since electricians and plumbers do not have to drill or cut through studs to install their work. In addition, the risk of damaging the studs is reduced.

Figure 3.5

Figure 3.6

Figure 3.5 and Figure 3.6: Steel studs with regularly spaced holes in webs to accommodate raceways for electrical, mechanical and plumbing lines. *Source: Harvel (2008)*

The studs are typically placed 40 cm apart, centre to centre. Sometimes, this spacing is reduced to 30 cm or increased to 60 cm. Panels are then installed on one side by gluing, nailing or screwing them to the wood or steel framework. Because panels are manufactured in standard sizes, usually 1.2 m by 2.4 m or 3.6 m, sometimes they need to be cut to fit special dimensions, such as around the doors and windows. The drywall is easily cut by a utility knife. For small openings such as those for electrical outlets, air-conditioning units and plumbing; a keyhole saw or a small bit in a high-speed rotary tool is used to create the holes. Then the electricians and plumbers install their lines and pipes after one side of the drywall is installed and the stud spaces are filled with insulation material. The second layer of drywall is then installed with the same method used for the first layer.

After the panels are secured to the wall studs, the seams between the panels are filled with a joint compound. The compound is spread into and along each side of the joint with brush-like strokes using the wide, flat tip of a special trowel. Then a paper tape is pressed immediately using the trowel into the wet compound to reinforce the drywall, hide the imperfections and smooth away excess material. Nails, screw depressions, and imperfection caused by the installation of services are covered with the same method used for panel joints. In large projects, automatic taping tools, which apply the joint compound and tape in one step, are sometimes used.

Then tapers apply second and third coats of the compound and sand the treated areas after each coat to make them smooth as the rest of the wall surface. This results in a seamless and almost smooth surface, which is able to receive the painting or finishing layers.

3.4.1.4. Application of Drywall System in Egypt

The gypsum material and gypsum panels could be found in the Egyptian market as they are used sometimes in false ceilings in commercial areas. However, they are not used in establishing interior partitions in residential buildings. The technical, economical and psychological aspects of applying the drywall system in Egypt are summarized in a table form below.

1. Technical Aspects

Issue	Raised with	Details and Conclusions
Brick Hacking	Khaled El Hammamy Mohamed Hamdy	All mechanical, electrical and plumbing services in the drywall system are located between the boards. Therefore, the waste that results from the messy hacking of bricks to embed the services within conventional brick walls in Egypt is totally eliminated. Consequently, the drywall provides a cleaner and environmentally safer system than brick wall.
Plastering	Khaled El Hammamy Mohamed Hamdy	The use of the drywall system facilitates dry construction. It avoids the use of messy plastering as the drywall is smooth enough to receive directly the paint finishes. Without the need of plastering, the defects, which may result from poor workmanship, are also eliminated.
Weight	Khaled El Hammamy Mohamed Hamdy Ashraf Adel	Despite of being heavy duty and capable of withholding a load of 25 kg at any point, drywalls are lightweight. They weigh 21 kg/m^2 (in case of using 5/8 inch thick panels), whereas a conventional brick wall weighs about 300 kg/m^2. Therefore, the weight of drywall is only 7% of the weight of a conventional brick wall. This reduces the structural loads and, consequently, reduces construction cost.
Stud Types	Khaled El Hammamy Mohamed Hamdy	When it comes to implementing the drywall system in Egypt, the steel stud system will be preferred over the wooden stud system. This is because wood in not a local material and is, consequently, expensive.

Time	Khaled El Hammamy Mohamed Hamdy Ashraf Adel	Time is one of the major factors that will affect strongly the Egyptian construction system if the drywall system is introduced to the market. In the drywall system, two professional hangers are capable of erecting 180 square meters per day. However, in the conventional brick system, two laborers are capable of erecting 2800 bricks daily, which correspond to about 50 square meters. This means that the new system will save about 70% of the time required to implement the interior walls. Moreover, the additional time required by the plasterer, which is about 20 minutes per square meter, is totally eliminated.
Laborer Skills	Mohamed Hamdy	Most Egyptian laborers are not aware of the drywall partitioning system and the way it is installed. However, because of the easiness of its installation, it is expected that builders will easily learn the system without the need for special technical or training sessions.

2. Economic Aspects

Cost of	Raised with	Details and Conclusions
Wall Erection	Mohamed Hamdy Ashraf Adel	Materials and components In Egypt, the 12 mm thick gypsum panel costs 75 LE/ m^2. However, the total cost reaches about 110 LE/m^2 when adding the cost of the necessary accessories to construct the false ceiling. The drywall is composed of two panels. Therefore, its cost is expected to be about 185 LE/m^2 including the cost of studs and accessories. As for the cost of existing brick wall system, the 57 bricks used to erect one square meter cost about 25 LE. In addition, the bonding material (mortar) used for the same area costs about 6 LE. This makes the total cost of materials necessary for wall erection in the existing brick wall system, without plastering, 31 LE/m^2. Labor In Egypt the average wage of mason is 12 LE/hour (about 6 LE/m^2). However, compared to the existing brick wall system, the drywall system's implementation is much easier, requires less physical effort and allows the DIY method to be applied. Accordingly, it could be expected that the cost of drywaller will be 70% less than the labor cost in case of conventional brick wall. In other words, the labor cost could be 2 LE/m^2 in case of drywall. However, it is suggested that the drywaller's wage be based on a job basis rather than hourly rate.
Plastering	Mohamed Hamdy Ashraf Adel	Material and components In the existing brick wall system, the wall plastering, which is mainly composed of cement mortar, costs about 7 LE/m^2 (50 kg bag costs 30 LE and covers about 4 m^2) , whereas the plasterer's wage is 8 LE/m^2. As mentioned in the technical aspects, the plastering process, which composes 50% of the total cost in brick construction, is eliminated in the drywall system.

Total Cost		Based on the previously-mentioned data, it could be concluded that the total cost (material & labor wage) of: - Brick wall system is 67 LE/m^2 (including plastering the two wall sides) - Drywall system is 187 LE/m^2
Structure	Khaled El Hammamy Mohamed Hamdy	Since the drywall is only 7% of the weight of conventional brick wall, the reduction in the structural dead load will reduce the thickness and reinforcement of the structural elements and, consequently, the cost.
Future Changes	Khaled El Hammamy	Generally, the cost of future modifications is reduced in case of using the drywall system. Modifications in brick walls usually require complete demolishment of the walls and the embedded service lines and erection of new walls and service lines. However in case of drywalls, panels and service lines can be relocated without messy works and extra accompanied actions.

3. Psychological Aspects

Issue	Raised with	Details and Conclusions
Drywall's Performance	Khaled El Hammamy Mohamed Hamdy	The Egyptian mindset hardly accepts any changes. The difference between the performance of the brick wall system and that of the drywall system is what makes people in Egypt until now unwilling to accept the drywall system for residential uses. Both security and sound transmission are the two main obstacles in introducing the drywall system. Security The drywall is relatively weak. Brick provides a much stronger wall, which requires more effort to penetrate unlike gypsum boards. In terms of safety, the Egyptian user has difficulty in accepting these gypsum walls, since most of the units in residential buildings are side by side apartments. However, one of the ways to facilitate the acceptance of the drywall system is to use it only internally within one dwelling. The walls, which separate different dwellings, are recommended to stay brick walls. Another solution will be to use a filling material of relatively high density between panels, thus providing a layer that is hard to penetrate. Rough finishing materials could also play a role to enhance the user's psychological acceptance. This is because rough finishing materials give the user a good impression of the rigidity of the wall. Sound transmission Gypsum panels are known in Egypt for their poor acoustic performance. The individual's privacy in Egypt is not only related to psychological effects, but more to traditions that could hardly change. This is one of the reasons why people reject the use of sound-transmitting materials in walls separating residential uses. However, the Egyptian users and even most developers are not aware of the developments in the field of acoustics for drywall systems. For enhancing the reputation of the drywall's acoustical performance, developers will have to introduce a system that performs not less than that of brick regarding sound. In this case, insulation material rather than staggering studs or increasing the spacing between panels will be the best

		solution. This is because insulation material, which is recommended to be a strong dense material, will help to strengthen the wall as discussed in the previous point.
Space incensement	Mohamed Hamdy	Drywall partition is slimmer than conventional brick walls. A drywall after finishing could be about 10 cm thick while a brick wall is 17 cm thick. Consequently, more usable space is generated in case of using drywall partitions. If this point is well highlighted when the system is introduced to the Egyptian users, people may be more willing to accept the new system.

It could be concluded from the present study that construction time reduction and weight reduction are the greatest advantages of using the drywall system in the Egyptian home building industry. On the other hand, the drywall cost, which is about four times the cost in the present brick wall system in Egypt, is the greatest obstacle.

The cost study suggests that the drywall system will not be affordable when implemented in Egypt. However, this system can still be affordable in several situations. First, the system will be suitable and affordable in buildings where masonry modifications, such as wall additions, could affect the safety of the structure. In Egypt, this situation often occurs in old buildings because of the lack of regular maintenance and, consequently, the deterioration in its structural elements. Moreover, applying the drywall in renovation work, where modifications are not of big scale, could sometimes be economical. This is because there is always additional work associated with brick works. This additional work, such as fixing and finishing adjacent walls and floors, and the mess it causes sometimes cost more than the cost of using clean drywall for a specific renovation job.

The gypsum panel is expensive in Egypt because it is not a widely-used product. If the drywall system proves its success in specific situations as mentioned above, the mass production will cause the price of these panels to go down. However, the drywall system will not be successful in any situation unless the security and sound transmission problems are solved appropriately.

3.4.2. FLOOR UNDERLAYMENT

3.4.2.1. Introduction

Floor underlayment refers to the material placed under resilient flooring, or other finished flooring, to provide a suitable smooth installation surface. The underlayment layers sit on the subfloor. Subfloor is the structural part of every flooring system, which means it is the base layer. A concrete slab for example is a subfloor in case of concrete structures. Underlayment flooring layer serves other functions in addition to being a smooth installation surface. They help deaden the sound and slightly soften the feel when walking on floor.

Known materials and methods of preparing floor surfaces vary. In concrete structures, they may include the application of a 50 mm thin Portland cement concrete topping or a sand layer, 100 mm thick. In wooden frame structures, they may include one or two layers of plywood, securely fastened to the floor surface. Alternatively, they may consist of prefabricated cement fiberboard or cement backerboard, which is a composition of Portland cement with light weight aggregate.

3.4.2.2. Floor Underlayment in Egypt

In Egypt, common finishing floors are ceramic tiles, marble, porcelain, laminated wood, parquet and hardwood. However, the sand layer is the only type of floor underlayment and substrate used over concrete slabs in residential buildings. In cases where the finishing layer requires a hard underlayment surface, as in laminated wood floor finishing, a cheap tiling material is applied over the sand layer to act as a secondary underlayment. The sand and finishing layers are usually 80 mm to 100 mm thick. In addition to being a substrate and leveling material, the sand layer in the Egyptian system acts as a medium for the drainage pipes. The concrete slabs in wet areas are usually 100 mm lower than the remaining slabs in non-wet areas. This allows about 200 mm for the underlayment and finishing layers in wet areas to accommodate the appropriate pipe slopes (Figure 3.7).

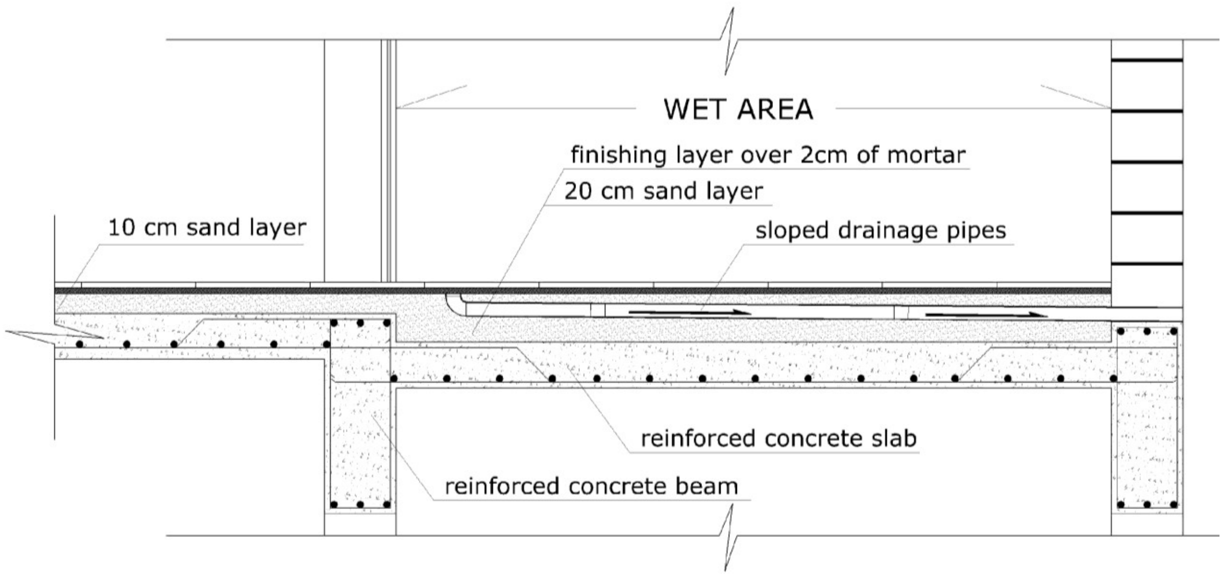

Figure 3.7: Section in wet area

Sanding as an underlayment has several advantages. First, sand is widely available and, consequently, affordable because 95% of the Egyptian land is composed of deserts, partly covered by a sandy layer of varying thickness. Moreover, sand is a leveling material that absorbs shocks and impacts. Therefore, it protects the finishing floor from being damaged, especially in case of rigid floor finishes such as tiles.

When it comes to implementation and after-occupancy efficiency, the disadvantages of using sand become obvious. A layer of sand as an underlayment with a thickness of about 80 mm weighs about 144 kg/m^2. In wet areas, the sand layer, which is about 180 mm thick, weighs about 324 kg/m^2. This weight forms a significant excess load on the structure. In addition, in case of moisture intrusion, the capillarity of sand allows water to be easily distributed within the layer. The only mechanism of drying the sand becomes upwards through the finishing floor layer and downwards through the reinforced concrete slab. This affects the finishing floor layers, rusts the steel in the reinforced slab, and affects the ceiling's finishing layers in the lower floor. The moisture intrusion problem often occurs in case of damage or leakage from pipes embedded in the sand layers.

Sand is usually sold in bags that weigh about 30 kg each. Therefore, one square meter requires the distribution of five bags. The contents of these bags are manually distributed over the floor area, manually compacted, and then manually leveled. This requires too much physical effort. In addition, in case of misdistribution or inefficient compaction, the problem of floor failure appears with time after occupancy takes place.

3.4.2.3. Self-leveling Floor Underlayment in North America

Pouring the floor underlayment is one of the methods used in applying the underlayment layer. Cellular light-weight concrete and latex-modified patching mortars are the common examples used as pouring materials. However, in North America, self-leveling underlayments, although relatively new, are considered much more efficient than traditional pouring underlayments.

Unlike traditional poured underlayments such as cellular light-weight concrete (CLWC) and latex-modified patching mortars, which must be screeded or troweled, self-leveling underlayments do not require these time-consuming finishing steps. They are poured or pumped directly into a subfloor, where they flow and cover it easily. The term self-leveling is not accurate. This is because most of the products have to be spread out with a tool. However, they are self-smoothing, which means that no troweling is required.

The self-leveling system can be used in both new construction and rehabilitating old floors, which are out of level. It can be used over concrete slabs as it can correct roughness caused by poor concrete finishing. It can also be used over wood subfloors. However, since most self-leveling underlayment products are not designed as permanent wearing surfaces, they should be covered with floor finish.

Figure 3.8

Figure 3.9

Figure 3.8: Troweling traditional lightweight concrete.
Source: Internet - http://www.concretedecor.net/images/Feature_Photos/CD306/cd306pp_ardex01.jpg (Accessed on 15 July, 2009)

Figure 3.9: Self-smoothing surfaces in the self-leveling underlayment products
Source: http://www.qualifiedremodeler.com/images/article/1197314779151_03.jpg (Accessed on 15 July, 2009)

<u>Properties and types of self-leveling underlayment</u>

There are many factors and properties that distinguish self-leveling underlayments when compared to traditional cellular light-weight concrete. Self-leveling underlayments cause less cracking in the underlayment layer, better sound control, and faster setting and drying time (Tanski, 2006). A self-leveling underlayment usually can be walked on in few hours and covered with finishing flooring within a couple of days. On the other hand, cellular light-weight concrete usually can't be walked on until the next day, and floor covering can't take place for about 28 days after placement (ARDEX, 2006).

Moreover, time savings give self-leveling underlayments an advantage over trowel-on mortars. At least eight times as much area can be covered within one day when self-leveling underlayment is applied instead of CLWC or trowel-on latex-modified cement mortar (Wallace, 2003). Typical properties of two North American self-leveling underlayments are outlined, as provided by the producers, in the following tables:

"Maxxon" Level Right Product
Compressive Strengths (with time)
3000 psi (20.6 MPa) (3 days)
4500 psi (31 MPa) (7 days)
5500 psi (38 MPa) (28 days)
Walked on after 2 to 4 hours
Ceramic tile can be thin set within 2 to 4 hours. Other floor goods can be installed once a moisture test is passed.

Table 3.1: Properties of "Maxxon" Level Right Product
Source: Maxxon Inc. (2009)

QUICKRETE® Fast-Setting
Compressive Strengths (with time)
2 hours 2000 psi (13.8 MPa)
24 hours 3000 psi (20.7 MPa)
28 days 6000 psi (41.4 MPa)
Walked on after 2 to 4 hours
Can be covered in 24 to 48 hours.

Table 3.2: Properties of QUICKRETE® Fast-Setting
Source: QUICKRETE (2009)

Presently, Portland cement-based self-leveling underlayment and gypsum-based self-leveling underlayment are the two main types of self-leveling underlayments in the North American market. Thickness, weight and strength are among the properties that distinguish these two systems.

When applied on concrete structures, gypsum-based underlayments are often 12 mm thick, whereas cement-based underlayments are often 3 mm to 10 mm thick. On the other hand, traditionally poured underlayments, like CLWC, are at least 38 mm. Consequently, the applied weight of the underlayment is significantly reduced. Cement-based underlayment weighs between 5 kg/m^2 to 15 kg/m^2 according to the thickness, while gypsum-based underlayment weighs 32 kg/m^2. If compared to traditional CLWC that weighs 60 kg/m^2, it is clear that the new system reduces the weight of floor underlayment by about 50% to 90%.

In terms of strength, Portland cement-based products are two to five times stronger than gypsum materials. Tables 3.3 and 3.4 outline the typical compressive strength values of cement-based and gypsum based products. In addition to the strength, Portland cement-based products are water resistant while gypsum-based products are not.

Cement-based Products: Compressive Strength
Level-Right® : 5500 psi
Level-Right® Plus : 7000 psi
F-10® : 4800 psi
BONSAL® : 5500 psi

Table 3.3: Compressive strength of cement-based products

Source: Data collected by the author

Gypsum-based Products: Compressive Strength
Gyp-Crete® : 2000 psi
Gyp-Crete® 2000/3.2K : 2000 - 3200 psi
LEVELROCK® 2500 : 2500 - 3200 psi
SPECCRETE® HIGH FLOW : 4020 psi

Table 3.4: Compressive strength of gypsum-based products

Source: Data collected by the author

However, gypsum-based self-leveling underlayment products have other advantages over Portland cement-based products. Gypsum products are less likely to shrink and crack. The cracks that might occur in the underlayment layers reduce sound control, fire resistance, and energy conservation. Thus, gypsum-based underlayment products can usually be installed without joints in a continuous pour. On the contrary, most Portland cement-based underlayment products require joints or divided pours to control cracking because of its shrinkage tendency while drying (Wallace, 2003).

Installation

Self-underlayment products are usually produced and sold in bags. The steps of installation recommended by different manufacturers are almost the same. They include:

1- Cleaning and priming subfloor

All dust and other contaminants must be removed from the subfloor in order to provide a strong bond between the subfloor and the underlayment layer. Holes, floor drains and other cut outs that would allow the self-leveling underlayment to run or leak must be filled or sealed. Patching compounds and caulk are usually used.

The subfloor is then coated with primer. This primer, which seals the subfloor, improves the bond between the subfloor and the underlayment and prevents any penetration of air or any other substance from the subfloor to the underlayment. The primer is usually applied with a brush, roller, or by spraying according to the manufacturer's instruction. Then the primer is left to dry before applying the underlayment. The drying period is usually few hours according to the manufacturer's guidelines. However, most manufacturers do not allow the drying time for the primer to exceed a certain period. If exceeded, the primer will have to be applied again. The following table illustrates the curing time and window to install the self-leveling material for three commercial primers.

	Primer L (High-performance acrylic primer for porous concrete)	**Primer WE** (Water-based epoxy primer)	**118 Primer/ Admixture**
Curing Time	3 hours	2 hours	1 to 3 hours
Window to install the underlayment	3 to 18 hours	2 to 12 hours	3 to 24 hours

Table 3.5: Curing time and window to install self-leveling material for three commercial primers

Source: Data collected by the author

2- Mixing underlayment

In mixing the underlayment ingredients, water addition is the most important step. Overwatering the mix reduces the strength of the underlayment and causes excess shrinkage to occur during the drying period (Tanski, 2007).

- *Portland cement-based underlayment*

Portland-cement based underlayments are often mixed with water only. In small jobs, the ingredients can be mixed together in a pail using a 12 mm drill with a mixing paddle attachment. Applying the product takes place by pouring the material directly from the pail onto the subfloor (Figure 3.12). Whereas in large jobs, the Portland-cement underlayments can be produced using an automatic equipment, small enough to fit in an elevator, that mixes and pumps the product onto the subfloor (Figures 3.13 and 3.14).

Figure 3.10

Figure 3.11

Figure 3.12

Figure 3.10: Pouring product directly from pail onto subfloor in small jobs. *Source: ARDEX (2006)*

Figure 3.11 and Figure 3.12: Automatic equipment to mix and pump product onto subfloor in large jobs. *Source: Maxxon (2009) and ForConstruction Pro (2009)*

- *Gypsum-based Underlayment*

Gypsum underlayments are most of the time installed by the manufacturer's authorized applicator. They require sand and water to be added to the mixture. Unlike Portland cement-based underlayments, they require large volumetric mixing and pumping machinery (Figure 3.13). In small jobs, gypsum-based underlayments are not economical because of the bulky equipment (Wallace, 2003).

Figure 3.13: Gypsum-based underlayment's large volumetric machinery.
Source: Wallace (2003)

3- Placing leveled underlayment

For thick underlayments, it is recommended to attach plastic pins or brick ties to the subfloor as a guide. The plastic pins are spaced 75 cm to 300 cm apart, according to how flat the underlayment must be. After fixing the pins to the subfloor, a string line is pulled between the top of the pins to form the leveling guideline. In addition, chalk lines on the perimeter of walls and columns assist in placing the underlayment to its right level. A squeegee or rake is usually used in order to spread out the poured mix on the subfloor.

4- Waiting for floor to set and dry

As mentioned earlier, every product differs from another regarding the time for walking on or covering it with floor finish. However, most Portland cement-based underlayments can allow construction traffic to take place, unlike gypsum-based underlayments, which must be protected from construction traffic with wood planking. On the other hand, for both types, complete dryness is necessary in order for floor covering to take place. A test for excessive moisture is usually carried out by taping a square polyethylene sheet tightly against the tested underlayment surface. After several hours, the sheet is examined for entrapped moisture. If condensation exists, flooring should not be applied until the test results indicate a dry surface.

Installation conditions

Self-leveling underlayments should not be installed in a temperature less than 5°C for Portland cement-based products and 10°C for most gypsum-based products. Heat and ventilation may be required for proper underlayment dryness. Direct sunlight should be avoided in order not to allow fast surface drying (Tanski, 2007). Finally, the products should not be applied under high humidity conditions.

3.4.2.4. Application of Self-leveling Floor Underlayment in Egypt

The concept of pouring the underlayment material is not new to the Egyptian construction industry. Light concrete is used sometimes in commercial buildings. However, the self-leveling products have some properties that distinguish them and make them more suitable for floor underlayments than sand and light concrete. The technical, economical and psychological aspects of applying the new self-leveling underlayment products in the Egyptian home building industry, as discussed with the interviewees, are outlined in the following table form.

1. Technical Aspects

Issue	Raised with	Details and Conclusions
Plumbing	Khaled El Hammamy	Applying the new underlayment system may require modifications in the plumbing system. Keeping the 20 cm underlayment thickness in wet areas to accommodate the slope of the drainage system pipes, as in the present system in Egypt, will not be efficient. Both cost and weight on floor will increase. A possible modification is to move away the drainage pipes from the floor underlayment and keep them exposed either below the floor within a false ceiling or along walls. This allows the concrete floor slabs to be at the same level in both wet areas and dry spaces. Consequently, the self-leveling underlayment could be spread directly over the entire flooring with the same thickness.
Labor Quality	Khaled El Hammamy	In Egypt, the labor production of concrete works is usually of low quality. Concrete's surface is usually not smooth and the difference between concrete subfloor levels in one space could sometimes reach 5 cm to 7 cm. An efficient application of the self-leveling material requires a relatively smooth concrete subfloor and a minimum level

		difference between the subfloor edges. One of the challenges facing the new system will be to improve the quality of the concrete subflooring. Continuous site supervision may be needed to check the product's quality of the concrete laborers.
Material usage	Mohamed Hamdy Ashraf Adel	In self-leveling system, one bag of self-leveling product (LevelLite self-leveling underlayment), which weighs 13.6 kg is capable of covering an area of 5 m^2. On the other hand, in the present Egyptian system, the same area will require the use of 24 bags, each weighing of 30 kg. This means that the quantity of material used in the present system could be up to 50 times the quantity used in the proposed self-leveling system.
Weight	Mohamed Hamdy	When compared to sand, the load caused by the application of the self-leveling material will be reduced by more than 77%. This is because floor sand underlayment weighs 144 kg/m^2, whereas the self-leveling underlayment ranges from 5 kg/m^2 to 32 kg/m^2 depending its thickness.

2. **Economic Aspects**

Cost of	Raised with	Details and Conclusions
Material cost	Mohamed Hamdy Ashraf Adel	Because the main ingredients of self-leveling underlayment, either cement or gypsum, are widely available in Egypt, it could be easily produced locally and become available. However, it is recommended in Egypt to use the cement-based products rather than the gypsum-based materials. This is because of the need for special equipment in case of the gypsum-based products. Such equipment, which are presently unavailable in Egypt, will result in extra cost. Moreover, the cost of gypsum is about 60% more than the cost of cement, which means that the cement-based products will be probably more affordable. The new product could be assumed to cost two to three times the cost of the base material (as is the case in North America). This means that a bag of 50 kg cement-based self leveling material will cost between 60 LE to 90 LE, based on the present cement bag cost of 30 LE. Accordingly, and taking into consideration the material usage as discussed above in the technical aspects, the cost of the cement-based self-leveling underlayment is expected to be in the range of 5 to 8 LE/m^2, compared to the cost of present system of sand underlayment of 4 LE/m^2.
Structure	Ashraf Adel	In addition to the structural cost reduction due to the significant reduction in the underlayment load, pouring the entire concrete floor in one level, as suggested above in the technical aspects, will lead to more cost reduction. This is because changing levels of reinforced slab increases the cost of slab reinforcement by about 20%. Eliminating this level change will, consequently, reduce the structural cost.

3. Psychological Aspects

Issue	Raised with	Details and Conclusions
Performance	Ashraf Adel	Unlike drywall, where the system's performance is easily felt by users, self-leveling underlayment is totally embedded underneath the floor finishing. Therefore, as long as the new system performs not less than the sand performance, the normal users will not have a problem in accepting the new system.
Time	Ashraf Adel	The self-leveling underlayment, unlike sand, requires drying time to install the finishing floor. The drying time varies significantly from one manufacturer to another. Some require few hours as drying time while others require days (Table 3.1 and 3.2). This could be one of the aspects that the users may raise. It is believed that the products requiring a maximum of four hours as drying time will be accepted by the Egyptian user. If the drying time exceeds four hours, the risk of the product's failure is expected to increase.
Flexibility of finishing selection	Ashraf Adel	Sand can be hardly walked on and this is why sand underlayment is applied directly prior to the floor finish. On the other hand, self-leveling underlayment can be walked on when it dries. This means that application of this type of floor underlayment can be an independent task, not related to floor finishing selection. This task separation gives a better chance for the user to select the floor finishing material at the latest stage without delaying the progress of the rough construction work. This advantage will encourage the users to accept the new system as it provides time flexibility to users.
Space incensement	Ashraf Adel	Another issue that could affect positively the user's acceptance of the new system is the elimination of the slab level difference in the wet areas as discussed above in the technical aspects. This change will increase the clear height in wet areas by 10 cm, which could be felt by users.

To conclude, the self-leveling underlayment, compared to sand underlayment, is distinguished by the easiness of its installation, the significant reduction in the quantities of material used and the associated reduction in own weight acting on the structure. Economically, the cement-based products appear to be more appropriate than gypsum-based products. On the other hand, the cost of the cement-based material is significantly more than that of the sand material. However, the cost difference between the two underlayment systems is much less than the difference in material cost because of the significant reduction in the quantity of material used in the self-leveling underlayment.

The usually low quality of the concrete subfloors in Egypt is still the main challenge facing the use of the self-leveling products for new building construction. However, these products can still be used successfully in the renovation process. Moreover, the use of such products in the renovation process could constitute a start for the introduction of the DIY to the Egyptian home building industry.

3.4.3. ELECTRICAL/COMMUNICATION SYSTEM

3.4.3.1. Introduction

Electrical and communication networks within homes could be considered as one of the most extensive utility systems. Electrical power outlets, switches, power supplies to appliances, telephones, cables, and networking combine to a great number of end points in an electrical system through wires. These wires run from a room to room and from one floor to another through floors, walls, and ceilings. In addition to the complexity of the system, the rapid advancement in technologies introduces new inventions and upgrades to the home industry. These new inventions, most of the time, require corresponding upgrades in the previously-installed network and communication system. However, wires are most of the time exposed as little as possible in an attempt to keep the aesthetic value, as well as for security reasons (Phillips, 2002). Thus an extensive system is created, which becomes integrated with other building systems. Moreover, this increases the challenges for creating organized and accessible electrical/communications systems.

Several strategies may be implemented to enhance the electrical/communication system. These strategies include making traditional wiring pathways more accessible, removing them entirely from walls, or even using wireless systems where possible (Era and Lyons, 2005).

3.4.3.2. Electrical/ Communication Wiring System in Egypt:

Wires are mainly composed of copper and insulated by PVC (polyvinyl chloride) cover. In order to be protected from external forces, the wires run through conduits. Flexible PVC conduits are commonly used for concealing the wires in Egypt (Figure 3.14). The conduits vary in diameter according to the number of wires inside, diameter of wires, length of the line from the distribution panel to the end point, and number of bends through the line. In the Egyptian home building industry, these PVC conduits are embedded in the walls, as well as in the reinforced concrete slabs. Unlike plumbing pipes, the electrical conduits are installed at an early stage. Conduits penetrating the slabs are installed with the steel reinforcing bars before pouring concrete. On the other hand, conduits which run in brick walls are installed after erecting the walls.

The correctly-installed conduits should allow wires to be pushed in and out easily for maintenance and repairs to takes place. However, the system faces two main problems. First, the conduits themselves are inaccessible along most of their lengths (Figure 3.15). Second, the interference of the electrical system with the structural elements at an early stage restricts the interior arrangement of home later.

Figure 3.14

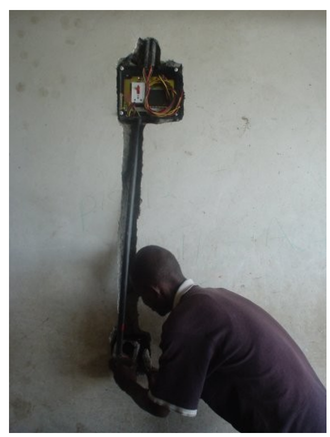

Figure 3.15

Figure 3.14: The flexible PVC conduit.
Source: Internet - http://www.tradeeasy.com/supplier/122745/products/p1081274/plastic-flexible-conduit.html (Accessed on 9 July, 2009)

Figure 3.15: Inaccessible of conduits along most of their lengths
Source: Dharmambal (2008)

3.4.3.3. Baseboard Raceway System in North America

In North America, many buildings retain traditionally framed interior walls and floors, which give some flexibility regarding the wiring system. This is because the wires are easily installed in the cavity of interior walls and along the exposed overhead beams with less effort compared to concrete and masonry buildings. Although traditional methods in North America do not allow easy accessibility of wires, new residential products, which increase the flexibility and accessibility of the wiring system, are emerging. Among these products is the baseboard raceway.

The main idea in the raceway system is to permit wires to be run along interior walls in a separate channel instead of wall cavities. This separation simplifies the on-site electrical work as it reduces physical interdependencies with interior walls. Moreover, this system allows wiring to be accessible for repairs, upgrades and remodeling (Figure 3.16). Most raceway systems not only accommodate wires, but also serve as a distribution system for electrical, TV, telephone and network outlets (Figure 3.17). This method is faster and more cost-effective when compared with wiring within wall cavities, especially in the remodeling processes (Warde, 1991).

<u>Properties</u>

There are different types of available electrical raceways. However, most types are surface-mounted systems, which run along the floor or up the side of the wall. According to Wiremold, a leading manufacturer of electrical/communication raceways in North America, there are three main types of prefabricated raceways as follows:

1. Steel Raceway,
2. Nonmetallic Raceway, and

3. Aluminum Raceway

The nonmetallic baseboard raceways are the most common type of raceway used in residential buildings (ToolBase Services, 2008). The baseboard raceway could serve a dual function as an attractive baseboard trim in addition to being a conduit for wires and outlets. Most nonmetallic raceways are made from PVC with a wide range of finishes to match interior finishes. Surface nonmetallic raceways can withstand up to 300 volts. However, they should be installed only in dry locations (Croft, Summers, and Hartwell, 2008). Shapes, finishes and number of compartments within the raceway may differ from one function to another and from one manufacturer to another. In addition, numerous fittings, adapters and boxes, specially designed for this system, are readily available from the manufacturers of this wiring system.

Switches and wires for ceiling fixtures or wall fixtures are not included in the baseboard raceway systems. Therefore, another exposed surface raceway system could be used along walls and ceiling to accommodate wires between those fixtures and their switches. Unlike the baseboard system, this system is not acceptable by most of the users because of its poor aesthetic as shown in Figure 3.18 (Lu, 2000).

Figure 3.16

Figure 3.17

Figure 3.16: Accessibility of wires in the baseboard raceway system. *Source: Wiretracks (2005).*
Figure 3.17: Baseboard raceways serving as a distribution system for outlets. *Source: Wiremold (2009).*

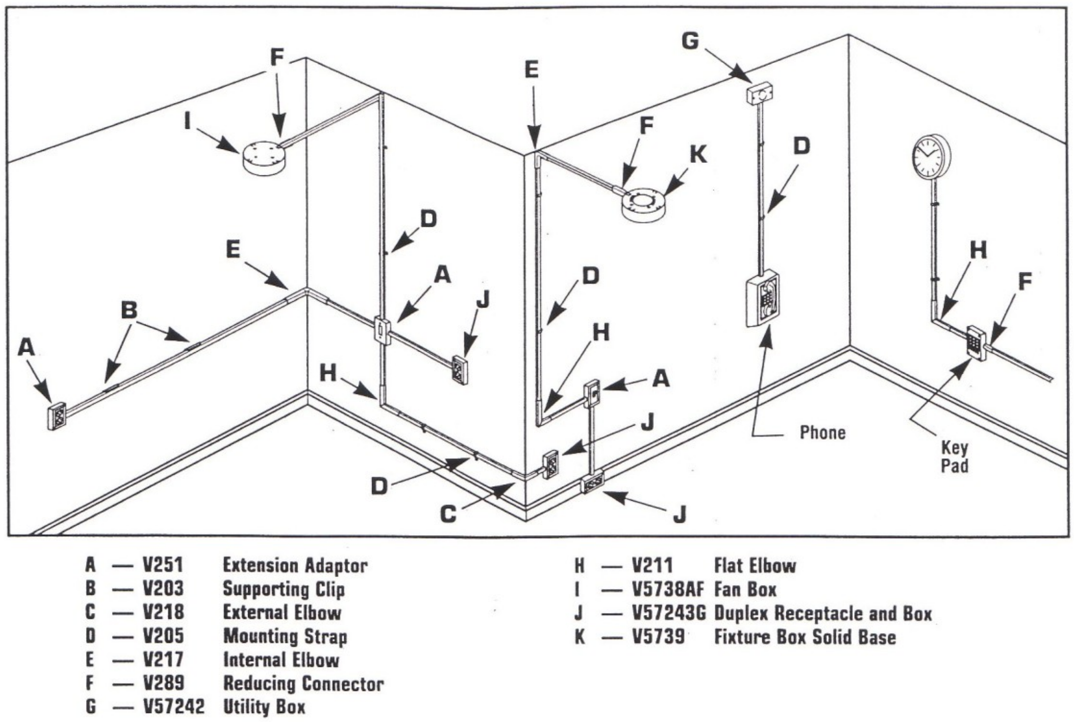

Figure 3.18: Exposed surface raceway accommodate wires between fixtures and their switches.
Source: Lu (2000).

Installation

The surface mounted raceway system is easily installed and does not require special tools or equipment. The installation process is mainly composed of three steps. First, the back-plate or the base is fixed to the desired place through screws (Figure 3.19). In places where the raceway encounters a 90-degree connection, an elbow is inserted into the ends of the two adjacent bases (Figure 3.20). Then trim covers for both the bases and the elbow are fixed to improve the system's appearance.

The second step consists of roughing-in and wiring. Wires are fed from either the back of the base, or from the end of the raceway system. Wires are held in place along the raceway using wire clips, which are fastened to the wall of raceway every about 1.5 m (5 ft). Before installing the receptacles, a device bracket is installed using a locking mechanism.

Receptacles are then mounted to the device bracket using screws. Finally, the external baseboard and receptacle covers are snapped into place.

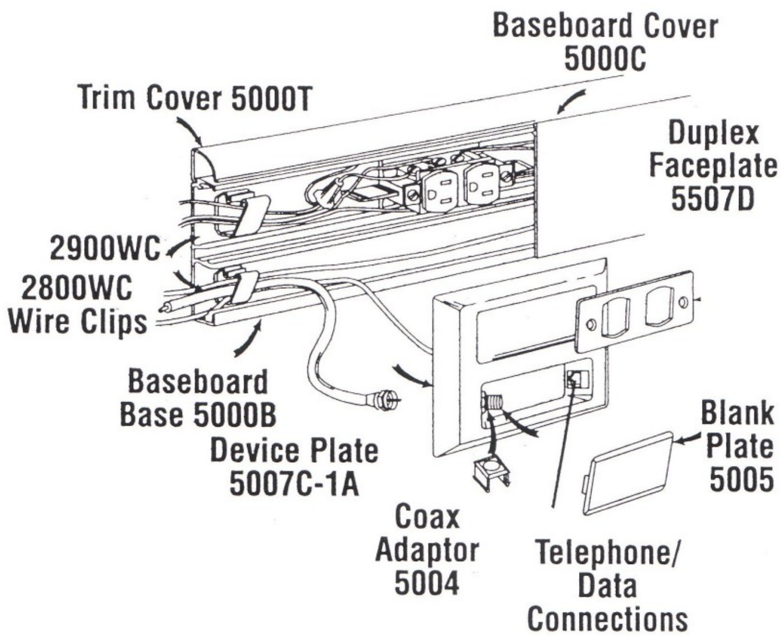

Figure 3.19: Baseboard raceways serving as a distribution system for outlets with simple methods of installation. *Source: Lu (2000).*

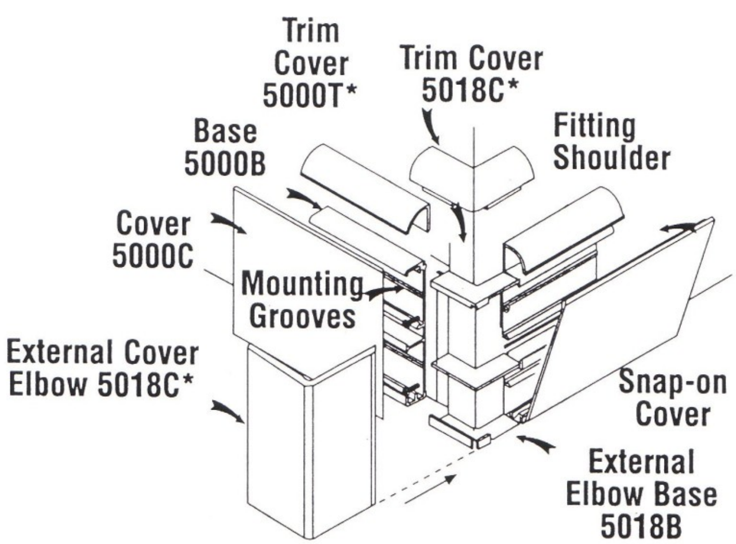

Figure 3.20: 90-degree elbow inserted into ends of two adjacent bases. *Source: Lu (2000)*.

3.4.3.4. Application of Baseboard Raceway System in Egypt

The North American baseboard system is a system that is totally independent from other building systems. This could assure a better performance. However, its application in Egypt may have some negative aspects as well as positive ones. These effects are highlighted in the following table.

1. <u>Technical Aspects</u>

Issue	Raised with	Details and Conclusions
Voltage	Mohamed Hamdy Mohamed Fekry	The nature of electrical system in Egypt is different from that in North America. This is because the electric voltage used in Egypt is 220 volts while that in North America is 110 volts. The 220-volt electric current is more dangerous and can be deadly. Although the nonmetallic raceway system used in residential spaces can withstand up to 300 volts, more secure accessibility to wiring system is needed in case of high voltages. This is not only due to the danger of voltages, but also because baseboards are easily reached by children. Increasing the security could be obtained by not allowing the covers protecting the wires to be easily removed. Using screws instead of the clipping methods for example could be an appropriate solution.
Time	Mohamed Fekry	In the Egyptian home building industry; hacking in brick, fixing the flexible conduit into grooves, and installing electrical boxes consumes about 40% of the electrician's time. Since the baseboard system eliminates all these time-consuming steps, significant time reduction in the electrical work can be obtained.
Application with brick wall	Mohamed Hamdy Mohamed Fekry	The baseboard raceway system is applicable with any type of walls. However, its application with the existing brick wall system may enhance the brick wall's implementation from two different points.

		First, because the system runs totally independent from the walls except by mounting, the defects, which results sometimes in the plastering layer due hacking in brick, are reduced. In addition, the delay usually caused by the interference between the masonry work and the electrical work is eliminated, reducing the time of wall implementation.

2. <u>Economic Aspects</u>

Cost of	Raised with	Details and Conclusions
Materials	Mohamed Hamdy Mohamed Fekry	Although the electrical conduits presently existing in Egypt and the proposed baseboard raceway system are both made of PVC plastics and have the same function, which is to secure the wires, the cost can hardly be comparable. The cost of the proposed baseboard raceway is expected to be more expensive than the existing PVC conduits for the following reasons. First, the present conduit system in Egypt is a simple rounded cross section PVC flexible pipe. On the other hand, the proposed system is composed of many rigid PVC components: the base, elbows, device bracket and external covers. This makes the manufacturing process more complicated in case of the proposed system and, consequently, more expensive. In addition, because the existing PVC conduits are embedded in walls and floors, a low quality conduit with some defects is sometimes acceptable. However, in the case of electrical baseboard raceway, where the conduit is exposed, the quality is an important aspect, and variation in colors and types is also important. Consequently, the production of the new system is expected to be more expensive. The existing flexible PVC conduits cost about 1.7 LE/m^2. It is usually sold in a role of length 45 that costs 75 LE. It is believed that the recommended baseboard system will cost about 3.5 LE/m^2 for the 2 channel baseboard, without its electrical/communication outlet. This cost could vary significantly according to the quality of the product offered by the manufacturers.
Laborer	Mohamed Hamdy	In the existing system, the electrician's wage is about 100 LE/day with an outcome of 1/2 apartment per day (50 m length). This means that the average labor cost in the existing system is 2 LE/m. Due to the time and effort reduction in the proposed system, as discussed above in the technical aspects, the electrician's wage is expected to be reduced by about 40% to be in the range of 1 LE/m to 1.25 LE/m.

Total cost		Based on the previously-mentioned data, it could be concluded that the total cost (material & labor wage) of: The existing PVC conduit system is 3.7 LE/m^2 The proposed baseboard is 4.5 to 4.7 LE/m^2
Other advantages	Mohamed Hamdy Mohamed Fekry	The baseboard raceway system is expected to be cost effective due to the following: - The new system will eliminate the cost of the traditional baseboards, which varies in the existing system according to the materials used. - Although in the existing system the pipes are not embedded in large volumes, removing the conduits from walls in the new system will result in a great reduction in the amount of waste (resulting from brick demolishing and the usage of excess plastering that fill the grooves). - Costs of future upgrades and maintenance will be significantly reduced.

3. Psychological Aspects

Issue	Raised with	Details and Conclusions
Type of users	Mohamed Fekry	It is expected that the new system be easily accepted in Egypt among users who change their home arrangements regularly and who are related to technology upgrades. In order to facilitate its acceptance among all users, developers introducing the new system must focus on the long-term benefits of the system, especially when maintenance of wires becomes necessary.
Aesthetic appearance	Mohamed Hamdy	The user's aesthetic acceptance is one of the concerns that should be highlighted when introducing the new system in Egypt. Traditional baseboard materials usually match the flooring in both texture and color. However, in the new system, this will be limited only to the PVC material raceways. Users may not accept the appearance of other materials. Manufacturers will have to introduce a variety of finishes, either in texture or color, to match the different decorations as well as the different prices. Painting the baseboard on-site is one of the methods used in North America to simplify production and enhance matching the system with the interior home decoration. However, applying this solution is not recommended in Egypt. This is because the on-site painting of the meticulous products in Egypt is usually of low quality, which reduces the chances of its acceptance by the user.
Safety	Mohamed Fekry	Securing the access to the wires in the new system, as discussed above in the technical aspects, positively affects the psychological acceptance of users. However, people may have concerns about accidental impacts that may cause wiring exposure. In order to ensure the system's safety to users, it is necessary to use only rigid PVC. It is recommended to add some materials and additives in the manufacturing process to allow the baseboard to withstand strong impacts.

It can be concluded that time reduction and system's independency from other building parts and systems are the main advantages of the baseboard system when compared to the embedded conduit system existing in Egypt. Because of this independency, the new system could be applied to the existing brick wall system. This increases the probability of its acceptance in the market. In addition, the cost of the proposed system is affordable when compared to that of existing system. This affordability is due to the reduction in the labor wage rather than the cost of materials. Finally, security and aesthetical appearance should be the developers' main concern when introducing the system to the Egyptian home building industry. Moreover, they should focus when marketing the new product on the long-term savings of the new system.

3.4.4. PLUMBING SYSTEM

3.4.4.1. Introduction

Like other building service systems, the indoor plumbing system is formed of a large network of different components. Hot water heater, supply lines, drainage and waste lines, and vent stacks constitute its major components. Plumbing components are usually difficult to access. This is why users rarely concern themselves with this system until they discover a leak, run out of water, or begin to remodel their toilets and kitchens.

Laying out an efficient, well-designed system requires an experienced plumber. This is because it requires understanding how to safely integrate a complex maze of pipes with the wires and ducts which travel through walls. However, when designing or repairing plumbing systems, the work done by plumbers is always dictated by local, state and federal plumbing codes.

3.4.4.2. Plumbing System in Egypt

Installation

In Egypt, wet areas are located most of the time adjacent to a central utility core. This is because the Egyptian Codes and Regulations demand natural ventilation and lighting to wet areas, especially bathrooms and kitchens. This central core, which is opened from above, should have a minimum area of 7.5 m^2 and minimum side dimension of 2.5 m. The central core system also has several advantages in addition to the provision of natural light and ventilation. First, it improves the efficiency and organization of the plumbing system layouts through common exposed supplies, drains, and vents for the different floors.

Moreover, its size provides easy accessibility for repairs and maintenance of pipes. However, when the plumbing system becomes an indoor system, problems of its accessibility appear.

The 12 mm water supply pipes usually run from the utility core to the interior fixtures embedded in the masonry brick wall. The 50 mm sloped drainage pipe runs from fixtures to the common drainage pipe located in the central duct through the floor underlayment layer. The 100 mm solid stack pipes are the only pipes that run directly to the outdoor vertical stack without interfering with other building systems. This is because water closets are always back to back with the central duct.

Materials

Water supply pipes running inside homes are usually galvanized steel. These metal pipes are inexpensive and resistant to corrosion. However, they have some disadvantages. First, galvanized steel pipes may contain lead, which corrodes quickly and consequently reduces the lifespan of the piping. In addition, galvanized steel may leave rough patches inside pipes, resulting in serious failures and stoppages, which can be expensive to repair (Ketcham, 2009). Moreover, because galvanized steel pipes are relatively heavy and very rigid, the system does not possess any degree of flexibility in its installation.

For indoor drainage system in newly constructed buildings, polypropylene has become the most common pipe used after replacing the lead pipes. This is because polypropylene is of lightweight, easily replaced, cheap, non-conductive and will not rust or corrode. The easiness of its installation, replacement and maintenance allows the material to be handled by the DIY concept. However, the way it is embedded and interlinked with the floor underlayment and brick walls eliminates the advantage of dealing with this pipe easily.

3.4.4.3. Plumbing System in North America

Installation

Generally, light wood frame construction allows for drilling small sections in walls and roof structural members to run plumbing pipes (Guy and Shell, 2002). In addition, the drywalls and suspended ceilings facilitate the installation, replacement and maintenance of the plumbing pipes and fixtures. This is because pipes are embedded in cavities (Figure 3.21), which can be easily accessible through a removable panel (Figures 3.22 and 3.23).

Figure 3.21

Figure 3.22

Figure 3.23

Figure 3.21: Pipes embedded in cavities between panels.
Source: Internet - http://www.terrylove.com/images/washer_rough_b.jpg (Acessed on 21 May, 2009)

Figure 3.22 and Figure 3.23: Removable panels to access plumbing pipes between panel cavities.
Source: Formisano (2006)

PEX Material

Efforts to enhance the performance of plumbing systems brought new technologies and materials to the home building industry. Among these efforts is the invention of PEX pipes, which are now widely used in North American homes. Cross-linked polyethylene piping (PEX) is a multipurpose pressure piping, that is widely used for hot and cold-water distribution in North American domestic plumbing (NAHB Research Center, 2006). When compared to rigid pipes, PEX possesses several advantages.

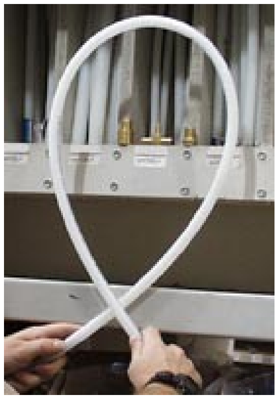

Figure 3.24 Figure 3.25

Figure 3.24 and Figure 3.25: Flexibility of PEX material.

Source: Internet - http://images.lowes.com/general/p/pex_pipe_bent.jpg (Accessed on 5 June, 2009) and http://media.rd.com/dynamic/82/39/74/200702_PEX_011_size2.jpg (Accessed on 27 February, 2009)

Due to the flexibility of PEX, the installation of a PEX pipe is easier than a rigid pipe. First, PEX pipes are available in long coils and the material can be bent easily around obstructions. Thus it could be installed as one continuous run without fittings. Slight changes in direction are made by bending the pipe by hand (Figures 3.24 and 3.25). However, in case a mechanical fitting is needed, many types of fittings are available. The easiest to use among these types is the push-type fittings (Figure 3.26) and the metal- or plastic-insert fitting (Figure 3.27). These fittings eliminate the need for solders, solvents and chemical joints. The mechanical fittings are secure and reliable when installed properly. In addition, when properly secured, PEX piping can be significantly quieter than rigid systems. This is because the pipe itself absorbs energy from pressure surges and eliminates or reduces the occurrence of water hammer.

PEX piping does not suffer from problems associated with metallic piping, such as reduced interior dimension, corrosion, electrolysis, filming and mineral build-up. In addition, the plastic material is able to expand if the system is allowed to freeze. The system returns to its original size when the water thaws without cracking or splitting unlike metallic pipes, which burst when they freeze. On the other hand, PEX cannot be used outdoors. This is because PEX, as many other plastic materials, is sensitive to ultraviolet rays and could be damaged if left in direct sunlight for a long period of time.

PEX pipes are manufactured with diameters that range from 6 mm to 25 mm. The pressure rating and corresponding design temperature of this piping system are 1,100 kPa at 23ºC, 690 kPa at 82ºC and 551 kPa at 93ºC. However, in the event of water heating system malfunction or maintenance, for example, PEX pipes can stand for 48 hours at 99ºC and 1,030 kPa until repairs are carried out (NAHB Research Center, 2006). Moreover, there is now a new type of PEX tubing suited for high pressure and temperature applications in the residential and commercial sectors. This new type of flexible tubing has a PEX inner core, which is surrounded by a reinforcing structure, such as a braid, to enhance the pipe's performance.

Figure 3.26

Figure 3.27

Figure 3.26: Push-type fittings
Figure 3.27: Metal- or plastic-insert fittings
Source: NAHB Research Center (2006)

Plumbing Manifolds

One of the successful systems used as part of the PEX installation for water distribution, is the manifold system (Figure 3.28 and 3.29). The manifold system is a system for residential water distribution. It controls hot and cold water flow feeding flexible PEX supply lines to individual fixtures. The systems equalize pressure, and therefore allow several fixtures to be used simultaneously without dramatic changes in pressure or temperature.

The accessible manifolds facilitate the maintenance and repairs and allow additional fixtures to be added in the future, if extra ports are provided in a clean and easy way. Lines on the manifold can even be labeled according to the fixture they serve, similar to the way in which electric panels can indicate the destination of each circuit. Manifolds together with plastic piping offer installation-related cost advantages over conventional rigid pipe plumbing systems (Era and Lyons, 2005).

Figure 3.28

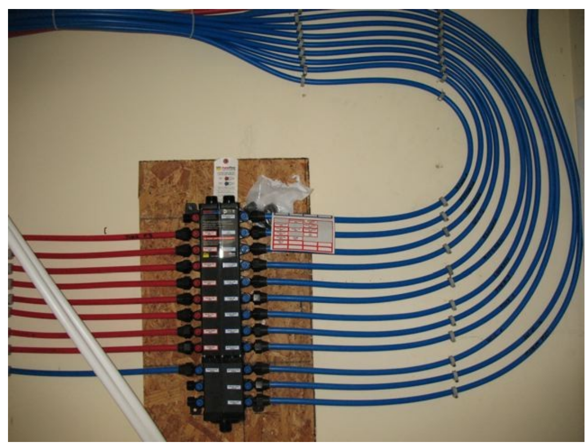

Figure 3.29

Figure 3.28 and Figure 3.29: Central manifold system.
Source: Viega (2009) and Internet:
http://www.transplantathlete.com/uploaded_images/pexmanifold-774175.jpg (Accessed on 5 June, 2009).

3.4.4.4 Application of North American Plumbing System in Egypt

The application of a plumbing system in Egypt that uses exposed accessible pipes, made of flexible materials such as PEX, is a good solution for the present plumbing problems in Egypt. However, the introduction of such a system in Egypt may raise the following issues.

1. <u>Technical Aspects</u>

Issue	Raised with	Details and Conclusions
Pipes accessibility	Khaled El Hammamy	Installing pipes that can be both accessible and hidden is directly related to the way walls, flooring and ceiling are erected. If the drywall system is successfully applied in Egypt with a removable panel, accessibility of water supply pipes will be assured. As for the drainage pipes, which normally run underneath the floor between wooden beams in the North American system, an alternative solution in Egypt could be one of the following: 1. Application of suspended ceiling where pipes run 2. Application of pipe box along the walls where pipes run 3. Running the pipes between drywall panels These options are discussed below within the psychological aspects.
Codes and regulations	Mohamed Hamdy Mohamed Mehanna	In Egypt, PEX is a new material. The current Egyptian plumbing building code does not refer to this material. However, it is expected that the Housing and Building National Research Center (the authority that issues the plumbing codes) will easily accept PEX as a new piping material since it is widely used in North-American and European countries. On the other hand, the success of PEX in the plumbing system in Egypt depends mostly on the success of the drywall system. Using PEX with the existing brick wall system does not constitute an efficient option.

Time	Mohamed Hamdy Mohamed Mehanna	Among the benefits of using PEX plumbing system is the time reduction in the installation of water supply pipes. For the system existing in Egypt, the time taken to cut the galvanized steel pipes to the required lengths and install the fittings consumes about 50% of the plumber's time and is usually carried out by a plumber assistant. On the other hand, these activities are almost eliminated in case of the PEX system. A simple cutter will easily cut the PEX, and pipes are just pushed into the fitting fixture if fittings are necessary. This means that the new suggested system will save about 50% of the time required to install the water supply lines.
System's efficiency	Mohamed Mehanna	Due to fitting reduction in the PEX system, the piping system's efficiency will be affected positively. Constant pressure through the whole pipe line is likely to occur. Moreover, the probability of leakage, which could take place in fitting areas, is reduced. Finally, because PEX is less thermally conductive that steel, heat loss through pipes is reduced.

2. Economic Aspects

Cost of	Raised with	Details and Conclusions
PEX Material	Mohamed Mehanna	In Egypt, plastic pipes are not expensive. A polypropylene pipe is 40% cheaper than a galvanized steel of the same diameter. However, plastic fittings are expensive. A 90 degree fitting costs 15 Egyptian pounds, which is about 5 times the cost of one meter of plastic pipe. Therefore, the price of PEX pipes, similar to other plastic pipes, will not be a problem when manufactured in Egypt. Moreover, the price of PEX pipes is about 50% less than that of rigid plastic pipes in North America. Similarly in Egypt, the price of PEX is expected to be relatively cheap. In addition, the overall cost of fittings, which consist the expensive part in the Egyptian system, will be reduced as their number in the new system is much less than in case of the existing system.
Laborer	Mohamed Hamdy Mohamed Mehanna	In Egypt, a plumber usually works with an assistant who helps in cutting the pipes, installing the fittings and fixing pipes in their place. The average wage of a plumber is 80 LE/day and his assistant 40 LE/day. Since pipe cutting and fitting installation are almost eliminated as discussed above in the technical aspects, it expected that there will be no need for a plumber assistant. This may reduce the total labor cost to be 80 LE/day instead of 120 LE/day. Even though PEX system is easy to install, its initial installation is relatively difficult for the untrained (Warren, 2009). This means that an initial additional cost is required from developers in order to train plumbers on the new system.
Manifold	Mohamed Mehanna	In North America, the cost of a manifold system varies depending on the number of ports, whether they include gate valves, and the material they are made from. Prices range from $35 to $200 plus. The same case is expected to occur in Egypt if the PEX system is successfully applied. However because the manifold is optional in the PEX system and its price varies significantly, the cost of manifold system will not be an obstacle.

3. **Psychological Aspects**

Issue	Raised with	Details and Conclusions
Plumbing in Egypt and user's psychology	Mohamed Mehanna	In Egypt, users are aware of the danger of plumbing system's failure. Inaccessible plumbing pipes in wet area run in both walls and floors, where relatively expensive finishing materials, such as ceramics and marbles, are usually applied. A small leakage in the drainage pipe will require demolishing a significant amount of the finishing material. Therefore, Egyptian users are usually concerned about the initial installation of plumbing pipes.
Drain pipes exposure	Khaled El Hammamy	The reactions of Egyptian user to the idea of exposing the drainage pipes or running them through cavities, as suggested above in the technical aspects, could be outlined as follows: 1. Exposing the plumbing drainage pipes beneath the floor through a false ceiling system may not be accepted by the user. This is because in case of maintaining, repairing or upgrading these drainage pipes all the work will be carried out from the lower floor, which is usually another apartment. 2. Exposing the drainage along the walls or in boxes will not be acceptable due to the poor aesthetical appearance and the reduction of usable space. 3. The recommended solution will be to adapt technically the drywall to accommodate the drainage pipes, as well as the water supply pipes. In this case, the spacing between the drywalls may need to be modified to accommodate the polypropylene drainage pipes. Moreover, the sound treatment of drywalls may need to be examined.
PEX	Mohamed Mehanna	In addition to the Egyptian user's awareness of plumbing problems discussed above, cost reduction, quickness of installation, and the clean environment the PEX system provides in both initial installation and maintenance work are all reasons that assures the user's acceptance of PEX systems.

In summary, the North American plumbing system could be a successful alternative to the existing Egyptian plumbing system. Time and cost of both laborer and material are reduced. However, a deeper cost study may be required from the manufacturers' side in order to provide a more accurate cost estimation of the new plastic material. Considering the North American plumbing system alone may face only few minor obstacles in Egypt, like code acceptance and necessity of training laborers. However, its success still cannot be assured. This is because the North American plumbing system depends on other systems that the Egyptian home building industry is unfamiliar with, particularly the drywall system. The success of applying a similar plumbing system depends on the success of applying the drywall system.

Chapter 4

CONCLUSION

4.1. INTRODUCTION

This chapter presents the final conclusion related to the research undertaken. The chapter is divided into four sections. The first outlines a numerical evaluation of the products and systems studied in the present research. The second section presents general interpretations and conclusions. In the third, suggestions for future researches that could be carried out as an extension to the present research are provided. Finally, in the fourth section, the author suggests recommendations to facilitate the implementation of the research findings in Egypt.

4.2. NUMERICAL EVALUATION

A numerical evaluation of each of the four North American products and systems is given below separately. This evaluation is based on a simple quantification of the modifications required for each of the North American product or system in order to facilitate its application in Egypt. The aim of this evaluation is to rate each product or system according to the degree of modification required. The determination of this degree is based on the information obtained during interviews with experienced Egyptian contractors and engineers. Moreover, the basic technical changes for each of the studied products and systems are summarized.

4.2.1. Evaluation Criteria

Points are allocated for each of the studied products and systems. The product that gains fewer points would require fewer modifications when being applied in Egypt and, consequently, the easier to apply (according to this simplified analysis). The necessary modifications and evaluation points could be categorized as follows:

1. Modifications in product's materials or components

One of the following two numerical values is assigned in the evaluation of the product:

(+1) If the materials or components of the product will require modifications,

(Zero) If the materials or components of the product will not require modifications.

2. Modifications in product's design

One of the following two numerical values is assigned in the evaluation of the product:

(+1) If the product's design will require modifications,

(Zero) If the product's design will not require modifications.

3. Restriction of product's use at some places or locations

One of the following two numerical values is assigned in the evaluation of the product:

(+1) If the product's use will be restricted to some places or locations,

(Zero) If the product's use will not be restricted to specific places or locations.

4. Product's requirements for modifications in other building systems

One of the following two numerical values is assigned in the evaluation of the product:

(+1) If the product will require changes in another building system,

(Zero) If the product will not require any change in other building systems.

5. Compatibility with existing Egyptian national code

One of the following two numerical values is assigned in the evaluation of the product:

(+1) If the product and the existing Egyptian national code are incompatible. In this case either the product will require modifications to suit the codes, or the code will need to be revised.

(Zero) If the product and the existing Egyptian national code are compatible.

4.2.2. Evaluation Analysis and Results

The evaluation analysis and results for each of the products and systems under consideration are presented below in a table form. Table 4.1 outlines the analysis and results of the evaluation for the drywall system while Table 4.2 summarizes the case for the self-leveling floor underlayment. The baseboard raceway and plumbing systems are evaluated as given briefly in Tables 4.3 and 4.4, respectively.

Table 4.1: Summary of drywall system evaluation

Modification in	Need for Modification	Points
Materials or components	No material modifications are required. However, a filling material or insulation of relatively high density will be required between panels in order to avoid easy panel penetration.	1
Product's design	The drywall's design does not require any modifications.	zero
Location restrictions	The use of drywalls could be acceptable inside each apartment. However, its use will probably be restricted between different apartments.	1
Other related systems	The drywall application will have an effect on the methods of installation for both the plumbing and electrical systems.	2
Existing Egyptian code	The national Egyptian fire code requires one hour fire rated walls between different apartments. For interior walls within one apartment, there are no requirements regarding wall resistance to fire. This means that the drywall system is applicable according to the current Egyptian code without modifications.	zero

Required modification rating: 4

Table 4.2: Summary of self-leveling floor underlayment evaluation

Modification in	Need for Modification	Points
Materials or components	Underlayment's materials will not require modifications because of their availability in Egypt at affordable prices.	1
Product's design	No design modifications are required.	zero
Location restrictions	The underlayment system could be used for all floors of the building without restrictions.	zero
Other related systems	The product will certainly affect the way the Egyptian plumbing system is installed. The drainage pipes need to be removed away from the self-leveling floor underlayment.	1
Existing Egyptian code	Floor underlayment systems are not addressed in the Egyptian national code. Therefore, the application of the proposed system is acceptable.	zero

Required modification rating: 2

Table 4.3: Summary of baseboard raceway system evaluation

Modification in	Need for Modification	Points
Materials or components	No material modifications are required when applying the baseboard raceway in Egypt.	zero
Product's design	The design of electrical raceways will require modifying the way of accessing the wires for safety reasons.	1
Location restrictions	The electrical raceways could be used in Egypt, similar to the North American system, at all locations without restriction.	zero
Other related systems	This electrical system will not affect other building systems.	zero
Existing Egyptian code	The Egyptian electrical code accepts the rigid PVC conduits as electrical conduits. Moreover, the code accepts exposing these conduits along walls as long as the conduits are secured from impacts and used indoors. Therefore, the electrical baseboard raceway system will be compatible with the existing code, as long as the security aspects are taken into consideration,	zero

Required modification rating: 1

Table 4.4: Summary of plumbing system evaluation

Modification in	Need for Modification	Points
Materials or components	In general the same materials used in the North American plumbing system could be used in Egypt. However, a more detailed study may be needed to assure the success of using PEX as a new water supply material in Egypt.	zero
Product's design	The design of the plumbing system may need to be revised. This is because the pipes of the system may need to be embedded into the drywalls instead of being suspended from the lower floor's ceiling.	1
Location restrictions	In case of accepting the new plumbing system, the system could be used in all wet areas without restrictions.	zero
Other related systems	The plumbing system will certainly affect the drywall system. The distance between the drywall boards and the sound deadening methods should be reexamined.	1
Existing Egyptian code	PEX is an unfamiliar material to the existing Egyptian plumbing code. This means that the existing code will need to be revised if the code committee accepts the new plumbing material.	1

Required modification rating: 3

The above numerical evaluation reveals that the drywall system requires the highest degree of modification (the required modification rating is 4). Therefore, the drywall is expected to be the most demanding system, from the present analytical point of view, in order to be applied in Egypt. This means it will be the most difficult to apply. On the other hand, the product that requires the least modifications to be applicable in Egypt is the baseboard raceway system (the required modification rating is 1). Consequently, the baseboard raceway system is the easiest to be applied in Egypt according to the analytical approach under consideration. The self-leveling floor underlayment comes second and the plumbing system third.

4.3. GENERAL INTERPRETATIONS

A building consists of a giant mixture of systems, subsystems and components. These systems and subsystems are divided between many disciplines. The present study confirms that the relationships and dependencies between the different building parts strongly influence the performance and efficiency of homes.

The conventional way of construction used in the Egyptian home building industry has become a burden on the dynamic and changing society of the 21st century. This conventional way of construction depends upon closed building and system configuration in which all elements and components rely on each other in order to provide the desired functionality of the building. The examples presented in this study illustrate a frequently occurring scenario in the Egyptian home building industry. Some specific subsystems perform well within their own limited design reference. However, these subsystems could cause real problems for other units and subsystems of the overall system within which they function.

On the other hand, the examples collected from the North American home building industry reveal a different picture. Building in North America relies on an open structure, in which partially independent subsystems are assembled together to form the interior systems of homes. These partially independent subassemblies work together with minimum interfaces that integrate the building parts. This partial independency allows the interior systems to be easily modified, replaced, reconfigured and sometimes reused in other situations. In addition, minimizing the interfaces helps in the process of industrializing the home building industry. A greater opportunity is given to the manufacturer to develop the independent components, which are mutually compatible. Consequently, the home building in North America moved from a conventional construction of a building to an industrialized production of building components.

The author doesn't mean that building systems should be totally separated. There will always be interfaces between building parts. However, the minimum the interfaces are and the more they are studied, the better the efficiency of the building will be.

4.4. DIFFERENT APPROACHES FOR EXTENDING PRESENT STUDY

The aim of this research has been not only to study specific products, but to investigate new concepts and ideas in construction that could enhance the Egyptian building industry. The products and systems, which have been examined, cover different fields in an attempt to improve various major building systems. However, this research study could be extended in two main directions by:

1. Extending Examined Transferor

The building construction is characterized by its great prudence and limited inertia. Too sudden development or too advanced innovation is often rejected by the home building industry. Therefore, the best way to influence the evolutionary process is to begin with known products (Yamin, 1990). This is because pre-established systems offer the potential advantage of demonstrated success. As a result of the success of products and systems of the North American home building industry, the author has chosen it as a transferor in this study. However, products and systems used in the building construction in other regions, and even those used in other fields, could also constitute suitable alternatives and deserve an extended study similar to the present one.

2. Extending Examined Products

As mentioned earlier, buildings are complex structures and the topic of their construction is accordingly extensive. In order to fit the present research, the study was limited to four building systems. These are the drywall, self-leveling floor underlayment, electrical raceway and plumbing systems. Therefore, the present study could be extended to include other products and systems for the home building industry.

4.5. RECOMMENDATIONS

The author believes that the following recommendations could facilitate the application of new concepts and ideas, such as the North American ones, to the Egyptian home building industry:

1. It is understandable that the private sector in Egypt will be conservative at the beginning in applying new technologies in the market to avoid risks that could emerge. Moreover, the newly introduced building subsystems need to be implemented in a large number of units to become economically feasible. Consequently, the best way to introduce these new systems and products is to encourage the Egyptian government to implement them in its housing projects, which usually consist of a large number of units.

2. Interaction between different subsystems and products should be taken into consideration in home building construction in Egypt. Designers and manufacturers of all subsystems must be kept updated with other subsystems affecting their subsystems, whether these effects are minor or major. In addition, each designer or

manufacturer should be aware of the major implications of his or her own work on other subsystems.

3. The proposed new building system is separated into components that are independently developed by different manufacturers and used by different organizations. Therefore, new organizational and management techniques should be introduced in Egypt to integrate the new subsystems efficiently (Figure 4.1).

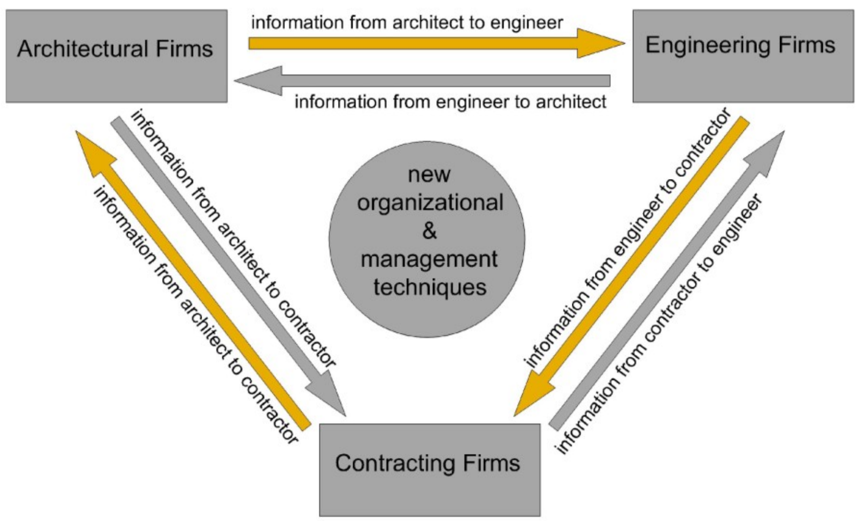

Figure 4.1: New organizational and management techniques

4. The cultural mindset in Egypt needs to be prepared to accept new ideas in home construction. A series of lectures, articles, and web sites could be prepared to illustrate the advantages of the new products and systems. This is because the concept of a home in Egypt is significantly different from that in North America. In North America a house is a product that can be sold, replaced or modified easily when it no longer meets the family requirements. However, in Egypt, the family stays in the same home for generations. Therefore, the Egyptian home is built solidly of hard

material. Consequently, the promotion of the new products and systems should clearly indicate that the durability of the building in the present time is not only achieved through rigidity, but could also be realized through flexibility of the building subsystems.

In conclusion, the introduction of new products and systems to the Egyptian market is not an easy task, especially in case of the home building industry. This is mainly because many participants are involved in this industry. Moreover, many aspects should be studied in order to achieve the success of transferring new technologies. The present report is simply an attempt to enhance the Egyptian home building industry through the gradual introduction of components, materials, and assemblies. However, implementing the presented ideas in reality will require future intensive research and in-depth investigation.

APPENDIX 1

Interview Questions

Date …………………………………………………..

Person Interviewed……………………………………..

1. Are you familiar with the North American …………..system?
   (A brief explanation of the North American system should be provided)

2. How could this system improve the existing conditions, if applied in Egypt?

3. What are the obstacles that this system could face when transferred to the Egyptian Market?

4. What is the current production rate of the laborers needed to install the present conventional system existing in Egypt? What is their wages or how much does each laborer get daily?

5. What is the current cost of installing the present conventional system existing in Egypt? What is the break down of this cost (material cost and labor cost)?

6. What are your expectations regarding the fair cost of the North American system when applied in Egypt, considering the availability of the system materials and components locally?

7. What are your expectations regarding the availability of suitable laborers to install, maintain, and repair the North American system in Egypt? Is a special or extensive training needed to prepare efficient laborers for dealing with the new system?

8. Do you think a majority of the Egyptian users will accept this North American system? Why do you think they will tend to accept it or reject it?

9. Regarding the expected problems raised in this conversation, how do you think we can adapt this system in order to minimize or overcome these problems?

10. Do you have further comments?

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