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Towards Sustainable Buildings in Egypt

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A B S T R A C T

The energy consumption in construction sector consumes a large part of the total energy produced in Egypt. The rise in energy price and its impact on the environment increase the need to study how to save the consumed energy in the construction sector. To achieve such a purpose, new building techniques are used in order to save energy in material's manufacturing process by decreasing the weight of the construction materials and reducing energy for heating and air conditioning by using materials with high thermal insulation. Moreover, the energy can be saved through using local building materials to reduce the consumed energy of manufacturing and transporting. In this paper, the light is shed on the important types of sustainable building systems that are available recently in Egypt. In addition, it provides an evaluation of these systems in terms of their advantages and disadvantages in order to attain the suitable structural systems in Egypt. It is found that reinforced concrete system is the most suitable for buildings in cities and dense populated villages in Egypt, while load-bearing walls system is suitable for one or two stories buildings in the desert areas or low-dense villages due to decreasing the cost.

Keywords: Sustainable, Green, Reinforced, Concrete, Buildings, Bricks

1. Introduction

In developing countries, the construction sector constitutes more than 50% of investments which encourage the economic and social developments. On the other hand, this sector consumes a large portion of resources (raw stone, gravel and sand) and about 30 % of the total solid waste in the world. Also, it consumes about 40-50% of the total energy produced all over the world. It has a negative effect on the environment due to releasing large amount of carbon dioxide which causes global climate change (Adrian, 2004). Energy in buildings is categorized in Embodied (manufacture phase), Operation (use phase) and Demolition (demolition phase) Energy. Manufacture phase deals with the manufacturing and transportation of construction materials and technical installations used both in building construction and renovation. The use phase involves all activities related to the use of the buildings, throughout its service life, including maintenance and material replacement. The demolition phase includes disassembling of the building and transportation of materials to land sites and recycling plants (Kassiani, Marco, & Paolo, 2014).

The sustainable development is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The sustainability achieves the balance between economic development, social development, and environmental protection. Sustainability in the construction sector refers to all practices that should be adopted in order to ensure that a building is environmentally friendly, economically feasible as well as healthy and comfortable to its users. Sustainable building (Green building) refers to both the structure and its processes that are environmentally responsible and resource-efficient throughout a building's life-cycle. The phases of the design of sustainable buildings are: site management and design efficiencies in structural system, energy efficiency, water efficiency, materials efficiency, indoor environmental quality enhancement, operations and maintenance optimization and waste and toxics reduction (U.S. Environmental Protection Agency, 2010). The study focuses on the sustainable materials of structural systems which can be constructed in Egypt.

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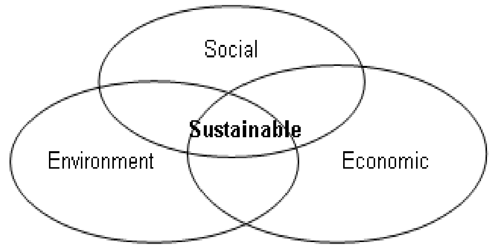


Figure 1. Terms of Sustainability

2. Sustainable Building Materials

The priorities for selecting building materials are:

- Using the minimal amount of materials.
- Using materials with lower embodied energy.
- Using materials created from renewable resources and locally produced materials.
- Using recycled materials.
- Reuse of building components from deconstructed buildings (Chales, 2008).
- Use of materials with high durability, high energy efficiency, high speed construction and required simple skills to manufacture.

The evaluations of available sustainable systems, in terms of their advantages and disadvantages, are presented.

2.1 Buildings of mud bricks

Mud bricks made of a mixture of loam, mud, sand and water mixed with a binding material such as straw, bricks were generally sun-dried. Mud is used as a building material in most countries of the world since ancient times. The important characteristics of the mud as a building material are concentrated in its ease of preparation using the minimum of machines and simple tools, its ability of good thermal insulation, as well as non-consumption of energy in the process of manufacturing, which contributes to the reduction of environmental pollution. The defects of mud are the weakness of mud material to resisting weights and water, large volumetric changings which cause cracks, erosion of surfaces and mud bricks cannot be subjected to particular specifications because of its great diversity of components.

2.1.1 Mud Buildings by architect Hassan Fathy

The architect Hassan Fathy provided an approach of poor architecture in the last century through constructing a mud village in Qurana (south of Egypt). The architecture of buildings allows retention of cool air at night to be spread during the day when heat increases. The thickness and type of the walls increase the thermal resistance of walls which makes homes cool in summer and warm in winter. On the other side, some experts believe that the application of this system at this time is not suitable due to: the scarcity of clay materials, higher labor cost, the difficulty of maintaining the quality of execution, the difficulty of providing safety and short life in this type of construction compared to other. Therefore, this approach is no longer valid for our time, as it was not successful at the time of its appearance. This kind of architecture is used for tourism and recreation (Katab, 2007). The amendments of these buildings have been made through demolishing some components and rebuilding by the burned bricks and reinforced concrete (Mohamed, 2013).

Figure 2. Current State of Qurana Buildings [7]

2.2 Buildings of Sandbags

A sandbag is a bag made of polypropylene or other materials that is filled with sand or soil. Sandbags are also used to make inexpensive, environmentally sustainable homes. The bags, when empty, are compacted and light-weighted for easy storage and transportation. They can be brought to a site and filled with local sand or soil. The bearing walls are constructed by stacking the bags in a similar way to build a traditional bricks. The ceiling can be constructed using the same bags or using wood. Figure 3 illustrates a one story building constructed using plastic bags in Site Area of Housing & Building National Research Center at 6 October City, Cairo, Egypt. Sandbags building model was constructed from plastic bags of polypropylene filled with soil from the site with adding cement to sand (HBRC, 2011).This system is recommended for the remote desert areas where it is difficult to provide materials and skilled labor.

Figure 3. Sandbags Building at 6 October City, Cairo, Egypt

2.3 Rammed Earth Buildings

Rammed earth is a technique for buildings using natural raw materials such as earth, lime or gravel. Rammed earth walls are executed either by a solid wall of earth or individual blocks which are stacked like regular blocks but are bonded together with a thin mud slurry. Rammed-earth structures are considered to be more sustainable and environmentally friendly due to: available local materials, simple construction, good thermal insulation, low embodied energy and very little waste. The soil mainly contains sand and gravel and the percentage of soft material (shale or mud) in the range of 30% of soil weight which are mixed manually or mechanically. A small percentage of cement (5% to 10% of soil weight) is added to increase the strength and improve the durability. Floors are created usually in the shape of domes or cellars. On the other hand, the compressive strength of rammed earth bricks is equal to 3-5 N/mm^2 which is less than those of ordinary bricks. They are susceptible to water damage if inadequately protected (HBRC, 2011). The scarcity of skilled labor for this kind of construction can increase the cost.

Figure 4. Rammed Earth Building Model in Site of Housing & Building National Research Center at Giza, Egypt

2.4 Masonry Buildings

Masonry structure is one of the oldest building techniques. The common materials of masonry construction are clay or shale or sand brick, stone such as limestone, and concrete block. Masonry has many attributes that make it green and sustainable. Masonry is generally a highly durable form of construction as well as is a sound attenuation. It also offers protection from fire damage and increase the thermal mass of building. Although the wood is an important construction material because of its renewability, the masonry buildings are more resistant to projectiles than wood buildings. Moreover, they consume less reinforcement steel and cement and less expensive compared to reinforced concrete buildings. The disadvantages of masonry structures are the vulnerability during earthquakes as well as inability to remove walls or modifying their places after its creation.

Figure 5. Masonry Building in Aswan, Egypt

2.5 Structural Insulated Panel Buildings (SIP)

Panel systems are defined as those building components that arrive at the site either partially or fully fabricated, which are joined to other panels to create walls, floors, and roofs of a house. A structural insulated panel (SIP) is an engineered composite product composed of an insulating core sandwiched between two face materials. SIPs are most commonly made of expanded polystyrene insulation board laminated between two oriented-strand boards but other materials can be used (such as plywood, aluminum, fiber-reinforced plastic, and magnesium oxide). Some SIPs use fiber-cement for the panels, and agricultural fiber such as wheat straw for the core. The core provides the insulation and rigidity while the face materials provide durability and strength. Currently, there is no specific prescriptive language in building codes addressing SIP systems. Most of manufacturers provide technical design and support services to ensure code acceptance.

Figure 6. Structural Insulated Panel system (SIP) (foam core sandwiched)

SIP systems bring many benefits and some drawbacks when compared to traditional buildings. The energy efficiency of homes constructed using SIPs can be very high compared to standard framing techniques. Although SIPs have a higher initial cost than traditional framing materials cost, saving will be achieved in the long run due to reducing of energy for heating and air conditioning. In addition, SIPs provide a more airtight dwelling, which makes a house more comfortable and quieter. The structural insulated panels have a high strength-to-weight ratio so they are useful to reduce energy of material’s manufacturing process and transporting. Also, SIPs are used for buildings that required high speed of execution. On the other hand, SIP systems will require a skilled labor and special inspections and tests. The installation of electrical wiring and plumbing lines may require special techniques. In addition, the modification of SIP walls position is often expensive and difficult. Generally, builders should compare the energy savings with the skilled labor required and precautions of panel constructions to make sure that panel system is the right choice (Toolbase, 2008).

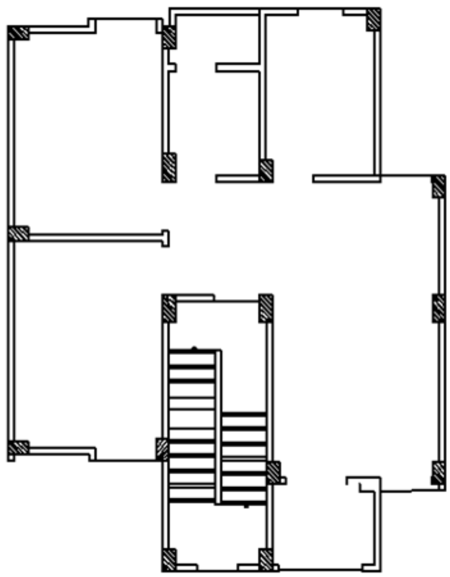
2.6 Reinforced Concrete Buildings

Reinforced concrete is one of the most important available materials for construction in Egypt and all over the world. In addition, reinforced concrete has many positive qualities: high compressive strength, thermal mass, low maintenance material, durability, great resistance to fire, ability to be cast in a variety of shapes. Therefore, concrete conforms to the ideal sustainable building material concept. But, the key issue with concrete is carbon dioxide emitted in the cement manufacturing process. Fly ash and blast furnace slag can also be blended with cement, resulting in reduced carbon dioxide emissions, reduced energy consumption, and expanded production capacity (Chales, 2008).

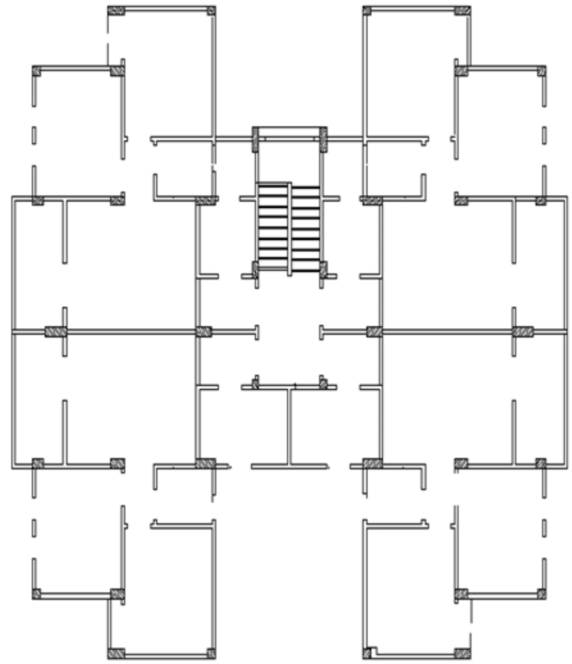
3. Selecting a Suitable Structural System of Typical Buildings in Egypt

The selection of structural system for building is influenced primarily by the intended function, architectural considerations, internal traffic flow, height and aspect ratio and the intensity of loadings (Paulay & Priestly, 1990). The structural system can be considered as sustainable when all the three dimensions of sustainability (environmental, economic, social) are taken into consideration. The choice of the material of structural system which achieves all of these aspects is not easy to make, however, the most suitable design is likely to satisfy these aspects.

Two case studies were selected as typical low-rise residential buildings that currently constructed in Egypt to know the suitable structure system of these buildings. Figure 7 shows the architectural building plans of the case studies. The first case study is a model called “build your home” whose plan dimensions, typical at all floors, are 10.3 meters by 8.6 meters. The typical floor height is 3.0 meters except for the ground story, which is 3.5 meters. The second case study is a model called “Youth housing” which is a five stories typical residential buildings in new cities. The plan dimensions, typical at all floors, are 21.2 meters by 17.5 meters. The structural system of these buildings is a reinforced concrete which consists of columns and beams with monolithically cast solid slab. The buildings have been designed according to the Egyptian code. The permanent loads used in the design consist of self-weight of structural members, partitions and flooring (1500 N/m^2). The adopted live load for residential buildings is 2000 N/m^2 except for stairs load, which is 3000 N/ m^2. The lateral loads which are resisted by R.C frames. The masonry wall with 120 mm width is frequently used to infill reinforced concrete buildings, the masonry bricks with standard size of 250x120x60 mm are used. The isolated footings should be sized up according to geo-mechanical characteristics of the ground.



Case Study 1 (3 stories building mode l)



Case Study 2 (5 stories building model)

Figure 7. Layout of Case Studies

3.1 Case Study 1

For 3 stories model, the comparison between reinforced concrete, masonry and load bearing SIP systems was carried out. Beside to reinforced concrete system, the building is redesigned for masonry structure system and load bearing SIP system with the same architectural plan. The load bearing masonry building is designed according to Egyptian code for masonry structures. The width of masonry walls equals 250 mm. The floors are reinforced concrete solid slab and the foundation of building is a R.C. strip footing.

The insulating foam core sandwiched panel is considered to represent structural insulation panels. M2 is one type of insulating foam core panel products which has a section of polystyrene, steel and cement mortar used in the construction of floors, roofs and walls. M2 system applied in the Egyptian market showed flexibility to be used as independent construction system or to combine with reinforced concrete skeleton systems and act as isolated wall element (El-Alfy & Shalaby, 2011). The panel reinforcement consists of two electro-welded steel meshes formed by 2.5 mm diameter steel wires with horizontal space of 62 mm and longitudinal direction 3.5 mm with space 67 mm. The panel rigidity is gained by cross wires welded to the mesh on each side. Variation of dimensions of polystyrene core gives the thickness required of panel. The core is placed in position and shot-crete concrete is applied at both sides in order to create the average quantity of 30 mm plaster. The laying of wiring, plumbing, heat, sanitary fittings can be carried out after the complete assembling of the panels and before the spraying with concrete. Figure 8 illustrates the panel sections used in the design of case study. Walls panels have a 120 mm thickness with a 60 mm thick polystyrene core having density of 150 N/m^3 and the section of floor slab is ribbed to give more rigidity in order to reduce floor vibration. The thickness of slab is 200 mm and the distance between ribs is 570 mm with 2 ϕ 10 mm / rib. The dimensions of SIP slabs and walls are based on the tests carried out by manufacturer of panels

(Oscar, 2003) for purpose of comparison but the building system can be constructed on condition that it is proved by experimental tests.

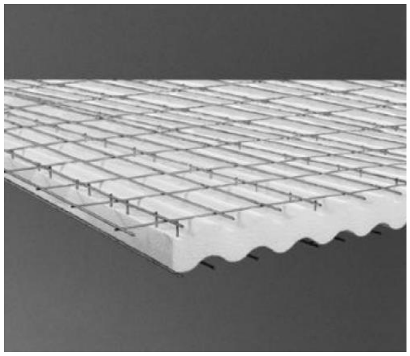


Figure 8. SIP Walls and Slabs

The selected parameters in comparison are the total vertical loads, the initial cost, the amounts of materials (reinforcement steel, cement, masonry, gravel and sand) of three structural systems of the case study as well as the total energy consumption in construction process of the building materials. Table 1 illustrates the initial cost of different systems of "build your home" model. The cost is calculated assuming that the prices of cement and reinforcement steel equal to 500, 4300 pounds per ton, respectively. Also, table 1 illustrates the amount of reinforcement steel, cement, bricks, sand and gravel of three structural system of case study which include all items of construction, plain and reinforced concrete, brick masonry, interior and exterior plaster and Flooring. In addition, table 1 shows the total energy consumption in construction process of the building materials (embodied energy) which is calculated by the product of the quantity of the material and the energy needed for producing a unit weight of the material. For example, the energy consumption of R.C. system = 10.4× 45 + 57.1×6.5 + 85× 5 + 423 × 0.5 = 1475 (Giga joule).

Table 1. Comparison between R.C., Masonry and SIP Systems for Case Study 1 Model

	R.C. system	Masonry system	SIP system
Initial cost (Pounds)	262598	236678	260150
Loads (t)	312	411	220
Rft. (t)	10.4	4.5	5.2
Cement (t)	57.1	50	38.6
Bricks (t)	85	193	20
Gravel & sand (t)	423	440	300
Energy consumed (Giga joule)	1475	1711	812

It can be noted from table (1) that the total initial cost of SIP system is approximately the same as the cost of R.C. system, while the total weight of SIP system decreases of about 30 % compared to R.C. system. The amounts of reinforcement steel and cement of SIP system decrease of about 50 % and 32 % respectively, if compared to R.C. system. Therefore, the energy consumption of SIP system is lower than energy consumption of traditional systems by more than 50%.

It can be concluded that SIP systems are suitable for additional stories above existing buildings due to light weight and the buildings required saving energy, after the checking the precautions required for this type of construction

Table (1) illustrates that the initial cost of masonry system is lower than the R.C building system by 11 % , while the total weight of masonry system is greater than the weight of R.C. system of about 32 %, the increase is due to the wall thickness equals 250 mm in masonry system while the wall thickness equals 120 mm in R.C. system. The amounts of reinforcement steel and cement of masonry system decrease of about 57 % and 12 % respectively, when compared to R.C. system. The total energy consumed of masonry system is higher than energy consumed of R.C system of about 14 % due to the amount of bricks increase more than double.

The initial cost of one story masonry system of case study 1 is lower than the R.C. system by about 20 %. With increasing the number of stories, the difference of cost between the masonry and R.C. systems decreases. The cost of 5 stories masonry system is approximately the same as the cost of R.C. system (El-Betar & Metwally, 2010). But, the thickness of masonry walls is equal to 250 mm except for the thickness of interior walls in lower stories for 5 stories buildings which increases to 370 mm to overcome the tensile stress of walls under lateral loads. This causes reduction of the interior area of rooms by 8 - 18% compared to R.C. buildings whose walls thickness is equal to 120 mm. The thickness of load bearing walls increases in cases of bricks with low compressive strength such as mud or rammed earth. In addition, the masonry structures are vulnerability during earthquakes as well as inability to remove walls or modifying their places after its creation. Therefore, load bearing walls system becomes unsuitable for 5 stories buildings or more.

It can be concluded that load-bearing walls system is suitable for one or two stories buildings in the desert areas or low-dense villages due to decreasing the cost, the materials may be extracted and manufactured locally, to minimize the energy embodied in their transportation. On the other hand, reinforced concrete system is preferable in cities and dense populated villages to achieve the best use of the land area to reach the maximum height to streets width and possibility of using the basement as a garage.

3.2 Case Study 2

Based on the results of case 1 study, reinforced concrete system is suitable for residential buildings (for 5 stories or more). The masonry wall width is equal to 120 mm which is frequently used to infill reinforced concrete buildings. But, it is recommended to use the partitions walls from materials with light weight and high thermal resistance. To illustrate this objective, the comparison was conducted between different types of partition walls in the selected typical residential building (case study 2). In addition to ordinary bricks (hollow shale), several types of bricks were studied. The types of bricks are light sand lime bricks, shale bricks and cement bricks with thickness equals 120 mm and 250 mm. Also, SIPs were used as partition walls. The insulating foam core sandwiched panel was selected to represent structural insulation panels, 120 mm thickness with a 60 mm thick polystyrene core, as mentioned in Figure 8.

3.2.1 Weight of Walls

Table 2 illustrates the weight of walls per square meter and the total weight of floor per square meter for the case study 2 model for different types of partition walls. The total weight includes the walls weight, the own weight of structural members, floorings and the live loads. It is evident from table (2) that the weight of walls (120 mm thickness) is equal to 30-35% of the total weight of the building due to low area of the rooms of the model. For walls with 250 mm thickness, the weight of walls is up to 47 % of the total weight. It also shows that the use of SIPs rather than hollow shale bricks walls in building model reduces the total weight by 14%, while the building weight with light-weight bricks walls decreases by 11%. On the other hand, the use of solid cement bricks increase the building weight by 8% compared to ordinary bricks.

Table 2. Weight of Floor /m^2 of Case Study 2 Model for Different Types Walls

Wall type	Density of bricks (N/m^3)	Wall thickness= 120 mm		Wall thickness= 250 mm	
		Weight of floor walls (KN) / m^2	Weight of floor (KN)/ m^2	Weight of floor walls (KN) / m^2	Weight of floor (KN)/ m^2
SIP panels		2	10	-----	
Light sand lime bricks	6000	2.4	10.35	3.41	12.4
Hollow shale bricks	14000	3.65	11.65	6	15
Shale bricks	18000	4.28	12.2	7.36	16.4
Cement bricks	20000	4.6	12.6	8	17

3.2.2 Thermal Resistance of Walls

Some studies indicate that the leaked heat ratio of walls and floors attained 60-70% in desert areas, while the rest percentage comes through the windows and doors openings. This indicates the importance of thermal insulation to reduce electricity consumption in air-conditioning. Another study in one of the Gulf countries indicates that the use of thermal insulation could lead to save the energy up to 30-50% (Mohamed, 2002). The thermal insulation of walls depends on the type of bricks. The thermal insulation of material is measured by thermal conductivity k, where (k) is the amount of heat through the unit of thickness per the unit area of material per the unit time when there is a change of one degree in temperature between the two sides. The thermal resistance (R) is calculated by $R = L / k$, where L is the thickness of the layer. The increase of the thermal resistance indicates the increase of resistance to the heat transfer.

Table 3 presents the thermal resistance of different types of walls. The thermal resistance of the walls is calculated by summation of R of bricks, plaster and exterior and interior surface thermal resistance according to the Egyptian Code.

$$R = R_{so} + L_1/k_1 + L_2/k_2 + R_{si}$$

Where, R_{so} and R_{si} are the values of exterior and interior surface thermal resistance. L_1 and L_2 are the thickness of plaster and brick layers. K_1 and K_2 are the thermal conductivity of layers. For example, R for hollow shale bricks wall = 0.055 + 0.05 / 1 + 0.12/ 0.6 + 0.123 = 0.428 (m^2 ºC /W), where 0.055, 0.123 are the values of exterior and interior surface thermal resistance, 0.05 and 0.12 are the thickness of plaster for both sides and bricks, in meters. K_1 and K_2 are equal to 1 and 0.6 for plaster and shale bricks, respectively.

Table 3. Thermal Resistance for Different Types of Walls

Wall type	Thermal conductivity (k)	Thermal resistance (R) (m^2 ºC /W)	
		Wall thickness	
		120 mm	250 mm
SIP panels	0.035	1.95	-------
Light sand lime bricks	0.2	0.828	1.48
Hollow shale bricks	0.6	0.428	0.65
Shale bricks	1	0.35	0.48
Cement bricks	1.25	0.33	0.43

Table 3 illustrates that the panel of core foam is perfect material for insulation, the thermal resistance of a SIP (120 mm thickness with a 60mm thickness of polystyrene core) is 4 times greater than thermal resistance of the ordinary (hollow shale brick) wall. The thermal resistance of walls with Light weight sand lime bricks increases by about twice over than the ordinary walls, while the use of solid cement bricks reduces the thermal resistance of the walls compared to ordinary bricks.

It can be concluded that the use of partition walls with lightweight bricks or SIPs decreases the weight of building and increases the thermal resistance of building that are recommended in hot regions. Although SIPs and light weight bricks have a higher initial cost than traditional materials, saving will be achieved in the long run due to reducing of energy for heating and air conditioning. In addition, the houses become more comfortable. On the other hand, the use of solid cement bricks reduces the thermal resistance of the walls and increase the building weight compared to ordinary bricks. In addition to the negative effect of the cement industry on the environment, it is recommended to reduce using the cement bricks.

4. Conclusions

1- Reinforced concrete is the most suitable structural system for buildings in cities and dense populated villages in Egypt, for achieving the best use of the land area to reach the maximum height to the streets width. The weight of walls is equal to 30% - 35% of the total R.C. building weight. Therefore, low weight and high thermal insulation walls such as SIP or light weight bricks walls are recommended, especially in hot regions.

2- Load-bearing walls system is suitable for one or two stories buildings in the desert areas or low-dense villages due to decreasing the cost. The materials may be extracted and manufactured locally, to minimize the energy embodied in their transportation.

3- Structural insulated panel system is suitable for additional stories above existing buildings due to light weight of panels as well as the buildings required saving energy, after the checking the precautions required for this type of construction.

REFERENCES

Adrian, P., 2004. Planning and design strategies for sustainability and profit: Pragmatic sustainable design on building and urban scales. Elsevier Ltd, The boulevard, Langtord Lane, Kidlington, England.

Chales J. Kibert, 2008. Sustainability construction green building design and delivery. Second Edition, John Wiley& Sons.

El-Alfy, A., & Shalaby, A., 2011. A Comparative Study between Wall Bearing Steel Reinforced Expanded Polystyrene Composite Wall System and Insulated Concrete Forms. *Australian Journal of Basic and Applied Sciences*, 5(10): 296-305.

El-Betar, A. S., & Metwally, I. M., 2010. Sustainability of Unreinforced Masonry Buildings. 1st Arab Housing Conference, Building Sustainability in Arab Region especially in Desert Environment, Cairo, Egypt.

HBRC, 2011. Conference of National Vision for Engineering Sciences Council. Housing and Building Research Center (HBRC), Egypt.

Kassiani, T., Marco, L., & Paolo, N., 2014. Building design for safety and sustainability. Luxembourg: Publications Office of the European Union, from https://ec.europa.eu/jrc

Katab, M. H., 2007. Poor Building - New Vision. *Magazine of Engineers Association*, No. 621, Egypt.

Mohamed, A. H., 2002. The Importance of Thermal Insulation and Energy Saving in the Buildings of the Desert", Seminar of Urban Development in Regions Desert, Saudi Arabia.

Mohamed, R. A., 2013. Inspiration of the Architectural Heritage from Cloning to Rooting and Sustainability of Architecture and Local Urbanism. The Conference of Hosting Major International Events Innovation, Creativity and Impact Assessment, Cairo, Egypt.

Paulay, T., & Priestly, M. J. N., 1990. Seismic design of reinforced concrete and masonry buildings. John Wiley & Sons, Inc.

Ramirez, O. M., 2003. Experimental tests on sample of panel system from M2. Technology University Engineering Experiment Centre, Panama.

ToolBase Services 2008. The Home Building Industry's Technical Information Resources. NAHB Research Center.

U.S. Environmental Protection Agency, 2010. Green Building Home. Retrieved November 28, 2009, from http://www.epa.gov/greenbuilding/pubs/components.htm