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Flexible Design: An Innovative Approach for Achieving Sustainability in Primary Public Schools in Egypt

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Abstract: Public schools in Egypt are considered a valuable asset that should be preserved and sustained, as they play a paramount role for the development of a sustainable community. Whereas, currently, the schools in Egypt are not sustainable from social, economic and environmental perspective as they are generally heavy, fixed and normally irreversible once construction has been completed. This is due to the traditional construction method used in the construction of schools which consumes time and generates a vast amount of waste. In addition, the changing demands of the occupants may confront the need for future expansion or complete changeover. With the increase in labour costs, lack of skilled labours for different trades, demand for faster construction, increased considerations for safety and environment and above all meeting these demands at an economic and reasonable price requires us to change the approach used in construction. Hence, these faults could be sufficed with the introduction of green prefabrication methods as a flexible design approach for achieving sustainability for primary public schools in Egypt. Therefore, this paper aims to formulate a matrix that correlates the flexible design criteria with suistainability in order to achieve suistainability in Primary Public schools in Egypt.A research methodology consists of literature review to investigate the topics of primary public schools, flexible design, Green prefabrication and sustainability.

Keywords: Green prefabrication, Sustainability; Primary Public Schools; Egypt; Flexible Design; Matrix

1. Introduction

Public schools are considered one of the pillars of development in Egypt. Not only does a school provide students with foundational skills but also creates a sustainable community. Current status of schools in Egypt is not sustainable in terms of poor maintenance, increased costs and overpopulation. Subsequently, this negatively impacts the performance of schools, students and the educational process. Although there are around 6,000 public schools in Egypt, there is still a demand to build more schools in order to provide students with better education [1]. Consequently, Egypt was ranked 133rd out of 137th countries for the quality of the education in primary schools according to the World

Economic Forum Global Competitiveness Index [1]. Substantially, the traditional construction method of schools consumes time and produces a vast amount of waste [2]. Hence, flexible design is a proposed approach to achieve sustainability of primary public schools through green prefabrication. Prefabrication is defined as the offsite manufacturing of components or section of a building. These sections are then transported or delivered to the site for complete assembly [3]. However, there are some limitations for prefabrication .For instance, as the sections or the components are delivered from the manufacturing location to the onsite location, there is a restriction on the maximum tolerable proportions and sizes of these sections that rely on the ergonomics of the highway through which the components are transported. Consequently, a prefabricated structure cannot be constructed in one piece, and accordingly, they are fragmented into smaller sections or components that could be managed allows the execution of a building or a structure with higher quality and at a reasonable cost [3]. According to the Education Funding Agency (EFA), a school design is suggested to be green prefabricated as it is more environmentally friendly when compared with the traditional building method. Not only does the prefabrication reduces the maintenance costs but also reduces the construction time.

2. Literature Review

2.1 Public Schools in Egypt

The quality of education is an essential tool for achieving a sustainable environment [4]. Education for sustainable development (ESD) endorses the development of several aspects including knowledge, skills understanding, actions and values required to ensure environmental protection (environmental sustainability), to promote social equity (social sustainability), and encourage economic sustainability. The development of the concept of ESD was established from environmental education, which pursued to develop the knowledge, skills and values in people to maintain their environment. The goal of ESD is to enable people to carryout decisions and actions to enhance the quality of life. In addition, ESD also aims to assimilate the values of sustainable development into all levels of learning [4].

2.2 The General Authority for Educational Buildings (GAEB)

The general authority for educational buildings is a public building that is present in each governorate in Egypt. The authority is responsible for the planning of the educational buildings, developing the standards and specifications of the design of public schools and determining the building regulations and rules in the light of a scientific plan and taking into account the objectives of the development plan and the general policy of the state. The GAEB has typical designed prototypes of schools. These designed prototypes can be either a single linear form through which the floor encompasses four classrooms or an L-shape or U-Shape building with eight classrooms per floor [5].

2.3 Traditional Construction

2.3.1 Definition of traditional construction

The term traditional means conventional or customary. Forbes added that cast-in-situ is a commonly used term which is conventional method through which concrete is poured into a formwork on the site. This conventional method encompasses the use of common or traditional materials such as brick or concrete in the construction of buildings [6].

2.3.2 Characteristics of traditional construction

The traditional design and construction method are considered a waste generating process which uses materials that produce inordinate and excessive waste during the construction of a building [7]. In this context, bricks produce a vast amount of waste attributable to the broken units resulting from transportation [8]. Also, the wooden strips that are used in the traditional formwork to fit the required dimensions for the cast-in-situ could be ruined and eventually will not adapt to other uses. All these aspects can contribute to waste production which is detrimental to the environment. Unlike prefabrication, the traditional construction methods produce an inflexible building (Mahayuddin, 2016). A flexible building must be adaptable. However, the traditional construction method hinders the flexibility of building [6]. This means that the building is not adaptable with the user's changing requirements. Hence, future extensions of spaces in a building cannot be applied.

2.3.3 Traditional vs Prefabrication

Although both prefabrication and traditional construction commence the same way-planning, designing, approvals, site preparation and development, there are various differences between the two approaches in terms of quality, cost, required workers and machinery, construction time, environmental considerations, safety and flexibility [9]:

- Unlike traditional construction, quality in prefabrication construction can be controlled and maintained as the prefabricated elements or components are manufactured by using laser measured machines with precise code tolerances
- Although the maintenance cost of a traditional structure is less when compared to the prefabricated structure, the overall maintenance and lifecycle costs of the structure are decreased over the long term.
- The traditional construction involves massive number of workers using simple machinery. However, prefabrication requires less labor with heavy cranes and machinery for handling large prefabricated elements.
- The process of prefabrication is faster than the traditional construction as prefabricated units are produces in mass modules through which elements or components are easily assembled on the site. Apart from this, the prefabricated elements are delivered in few weeks after the drawings are verified as illustrated in figure 1.
- Prefabrication allows for recycling and reusing of materials, thus generating less waste. On the other hand, a traditionally constructed building produces waste as the remains of the building components are demolished and therefore the materials cannot be reused.
- In the traditional construction, workers may be exposed to severe weather conditions which may cause serious accidents and hinder the construction schedule. Conversely, in prefabrication constriction, an indoor controlled environment for workers is maintained. This indoor environment ensures that workers are manufacturing in a safe environment with reduced risk of accidents.
- Once traditional construction has been completed, a heavy, fixed and irreversible building is constructed Akin to this, flexibility is suppressed in traditional construction. However, a prefabricated building offers flexibility in two main ways: Firstly, the parts or components could be disassembled and reused in another location. Secondly, the building can adapt with the users' needs, thus allowing for future extension to occur in the building.

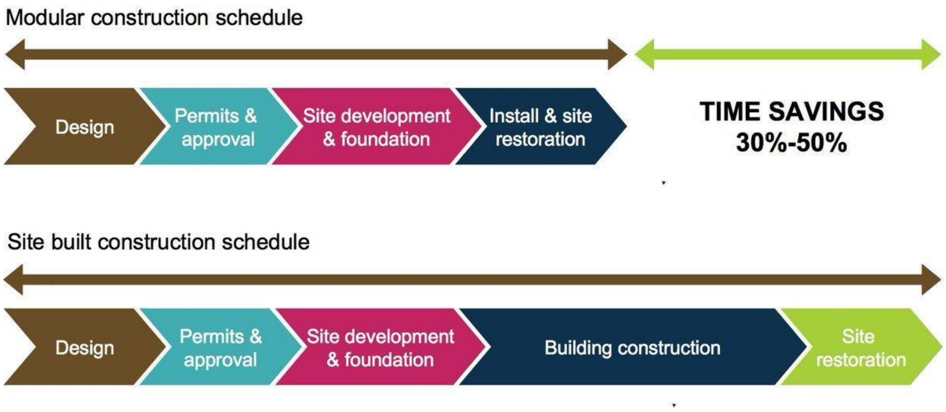

Fig.(1) Comparison between schedule of modular construction and traditional construction

2.4 Flexible Design

2.4.1 Definition of flexible design

The concept of flexible design was defined by researchers in different ways [10]. Flexibility was defined as the ability of buildings' features to adapt to the needs of the users. On the other hand, a flexible building must be adaptable which means the ability to change in order to meet the user's changing requirements as well as the physical environment [6]. These changes mean that the building is designed in a way to allow for modifications of a certain part without affecting other parts of the building. A balance between adaptability and durability while designing the building creates a flexible design [10].

2.4.2 Design for flexibility

There are three changes that can happen through the lifetime of the building. These changes or transformations could occur in the structure, the space and elements and material transformation [11]:

- Structural transformations occur when the capacity of the building changes. This means that the building components are reused, replaced or recycled.
- Spatial transformations occur due to changes in the function or the use of the building, thus requiring disassembly and adaptability in order to preserve the integrity of spaces.
- Spatial as well as elemental and material transformation occur due to changes in flow within the building.

2.4.3 Design criteria for increasing building flexibility

There are two main indicators that should be considered in the initial phase of the building design in order to reach an optimal flexible design: design for durability and design for adaptability [6].

2.4.3.1 Design for durability

Durability is the ability of a building to fulfill its functions over a period of time [11]. Also, a building element will tolerate changes if they have a long life time. This ability entails a durable structure in order to allow for changes. A durable design increases the productivity of resources as the materials could be reused and optimized [11]. In addition, quality and lifetime of building components are important determinants for building durability [11].

2.4.3.2 Design for adaptability

Designing for adaptability means the ability of the building to adapt or change while fulfilling various functions during its lifetime [13]. Using modular systems and prefabricated components could simply increase a building's flexibility. In addition, modular systems or the use of prefabricated elements simplify the process of disassembly in order to change the function of a space. This paradigm reduces the construction time and energy consumption which produces an adaptable and sustainable building [13].

2.5 Prefabrication

2.5.1 Definition of prefabrication

Prefabrication or precast construction refers to the offsite manufacturing of components or segments of a structure. These segments are then transported or delivered to the site for complete assembly [9]. The components or the segments of the prefabricated structure can be fabricated of different materials such as steel, concrete, reinforced concrete, wood and Aluminum composite. Prefabrication can have several terms: off-site prefabrication (OSP), off-site manufacture (OSM) and as a modern method of construction (MMC)[9].

2.6 Types of Prefabrication

There are three main systems that are used in the prefabricated structural systems [9]: Modular prefabrication, panelized prefabrication and hybrid prefabrication as illustrated in figure 2. All the types are divided according to the used materials, methods and structural configuration.

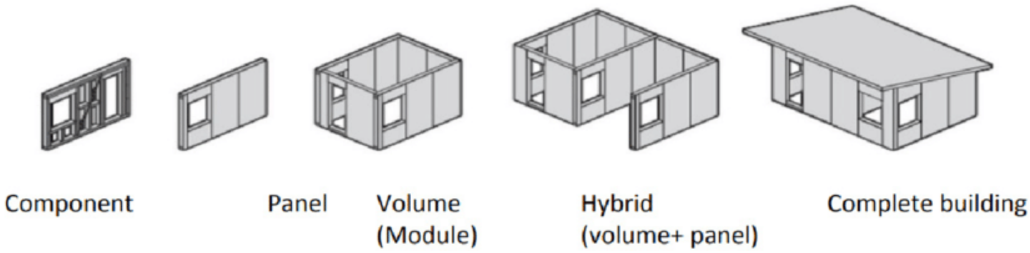

Fig. (2) Prefabrication systems (Dunlop, 2010)

Hence, Prefabricated systems are divided in three different types

- Modular Prefabrication (volumetric module)
- Panelized Prefabrication (component or panel)
- Hybrid Prefabrication (volumetric panel)

2.6.1 Modular Prefabrication

Modular buildings are volumetric 3d elements or components that are constructed entirely in a building facility and then transported to the final location for assembly [14]. These components are comprised of walls, ceiling and floor panels that are assembled to form the 3d volumetric module. The volumetric modules could be used for any building that with repetitive units such as hotels, hospitals, educational facilities and many other building uses.

2.6.2 Panelized Prefabrication

The panelized prefabricated system as a 2D-panel or components through which components are produced in masses and then delivered to the site for the three- dimensional assembly. These components or panels can be made of several materials including mainly concrete panels, timber panels or recycled timber[14].Furthermore, the panelized prefabricated system can be either an open-panel system in which panels are not fully insulated in the site or a closed-panel in which panels are insulated and completely manufactured in the factory.

2.6.3 Hybrid Prefabrication

The Hybrid prefabrication system is an integration of both the modular prefabrication system and the panelized prefabrication system. This means that some of the building components could be 2D panels or 3D volumetric modular construction [14].

2.7 Advantage of prefabrication

There are numerous advantages of Prefabrication [15]:

- Prefabrication reduces the construction time as the prefabricated units are delivered in few weeks after the approval of drawing.
- Prefabrication allows flexibility in the construction industry such that the prefabricated components can be easily dismantled and relocated to different sites. In addition, prefabrication units can blend in with any building type as the units can be used in different spaces. Moreover, prefabricated units offer future expansions in the building.
- The assembly process of the sections or components of prefabricated units are produced in a factory-controlled environment which creates a safer working

environment. This means that any complications associated with moisture and environmental hazard is reduced. In addition, an indoor construction environment ensures that workers are less likely to be exposed to accidents or other liabilities.

- Not only does a controlled environment provides safety for workers but also produces units with consistent quality. Specific standards are followed to have assemblies constructed to a uniform quality. Moreover, precise machines are used to ensure adherence to building codes as well as quality control checks are made to monitor quality throughout the whole process.
- The technologies associated with prefabrication produces a building that is sustainable and environmentally friendly. Kumar asserts that the overall water saving was reduced by 70%, therefore enhancing energy efficiency by 20% per square meter of construction.
- Although the initial costs of capital and transportation costs from factory to the specified site may be high, the maintenance and life cycle costs of the building are reduced over the long term.
- Prefabrication produces a building that is flexible, safe, and environmentally friendly with a consistent quality, reasonable cost and reduced construction time.

2.7.1 Prefabrication offers flexibility

Prefabrication offers flexibility in terms of portability or movability, reprocessing or reusing components and expansions [6]. Portability or movability means that the prefabricated components could be easily disassembled and relocated to different sites. In addition, the elements also could be reused or repurposed for other functions. Moreover, a modular design allows for future expansions in the building [11].

2.8 Green prefabrication

2.8.1 Green prefabrication definition

The green prefabricated building as one which consumes less water, generates a reduced amount of waste, conserves or protects natural resources and enhances energy efficiency of a building [16]. Not only does a green prefabricated building provide a healthier environment for the occupants or the users of the building but also helps in using processes that are environmentally friendly. These processes aid the design, construction, operation and renovation of the building's life cycle by utilizing resources efficiently. Hence, green prefabrication expands the concerns of environmental, social and economic sustainability, thus creating a sustainable or "high performance building" [16].

2.8.2 Characteristics of green prefabrication

Green prefabrication incorporates a smart design that is energy efficient by using eco materials that are environmentally friendly while conserving water. High performance building focuses on sustainability [16]. Green prefabricated buildings consume less energy when compared to conventional or traditional buildings. This means that the amount of water, energy and raw materials used in the green prefabricated building during construction and operation supports the creation of a high- performance building. In addition, less emissions are generated due to the efficient use of resources. All these features create a better and healthy environment for users, reduced the cost of design and emphasizes the recycling and reusing of materials [11].

2.9 Sustainability

2.9.1Definition of Sustainability

Sustainability is defined as the efficient distribution of resources intra-generationally with the process of socio-economic activities within the borders or limitations of a finite ecosystem [17].On the other hand, sustainability is perceived as a dynamic process through which there is an interaction between the carrying capacity and the population of its environment such that the population expresses its full potential without creating or producing irretrievable impacts on the carrying capacity of the environment[18]. From this standpoint, sustainability emphasizes human actions or activities and their capabilities to meet the expectations, needs or desires of human in order to satisfy their needs and wants [18]. These needs and wants are sufficed without exhausting or diminishing the prolific resources at their disposal. This, consequently, incites thoughts on the manner through which people must lead their economic and social lives on the existing resources for human development.

2.9.2 Sustainability and sustainable development

The main concept of sustainability is to focus on the conditions of the environment in order to attain a designed product or output with maximum internal qualities of the environment such that it can reduce the undesirable features or aspects of these constructions [19]. Consequently, buildings must respond to the environment initially from the design stage and settling when they are to lessen or decrease confronting with nature. Sustainability was depicted as a three-legged stool through which the environment, the economy and the society are depicted as legs. Hence, the fundamental concept of the stool is that if any leg is missing or shorter (less important), the stool will be unbalanced. However, if these legs have the same dimension, this means that each pillar has an equal weight. Consequently, there would be a balanced stool that will support sustainable development [19].

2.9.3 The Three Pillars of Sustainability

There are three main attributes of sustainable development which are environmental protection, economic expansion and social integrity. Based on this, talyor,2016 stated that the idea of sustainable development rests, primarily, on three key pillars. These key pillars are “economic sustainability”, “social sustainability” and “environmental sustainability” [20].

2.9.4 Environmental Sustainability

The first pillar of sustainability by defining the concept of environmental sustainability such that it supports human life while remaining productive and resilient [8]. In addition, environmental sustainability recounts to the carrying capacity and ecosystem integrity of natural environment. This requires that the natural capital should be used sustainably as a source of economic input and as a disposal of waste [9]. As the earth systems have limitations or boundaries within which equilibrium is sustained, the process of regenerating and harvesting should be balanced. On the other hand, Kumar stated that the waste should be disposed in a way that the environment can maintain.

2.9.5 Social Sustainability

The second pillar is social sustainability which represents any aspect that is related to human rights. In this context, social sustainability is not only about ensuring that human needs are met but also aiming at providing conditions for humans to have the capacity to realize their needs. This means that anything that impedes or hinders this capacity is considered a barrier [19]. However, if human needs are met, a socially sustainable environment will exist.

2.9.6 Economic Sustainability

The third pillar of sustainability is economic sustainability which requires the use of resources efficiently [21]. The economic sustainability is used to outline strategies that promote the consumption of socio-economic resources to their maximum benefit. In addition, there should be an efficient allocation of resources as well as an equitable distribution in order for the economy to operate in s sustainable manner [21]. However, during the design and construction phase, for example, aspects such as building materials should be considered in terms of their cost effectiveness. This means that using recycled materials during the design phase and construction phase can help lower the costs, leading to a long-term cost efficiency.

2.9.7 Relationship between Environmental, Social and Economic Sustainability

In order to achieve sustainability, there must be a balance of economic, social and environmental factors in equal harmony [22]. As shown in figure (3) there are three main aspects of sustainability which include environmental, social and economic. The interaction between these aspects created three new aspects, specifically: Social- Environmental, Environmental-Economic and Economic-Social, which explains that each individual has a right or share of natural resources of the environment at both national and international levels. This ensures that resources are not consumed by a portion of the society leaving the of the society with needs that cannot be met by remaining resources [22].

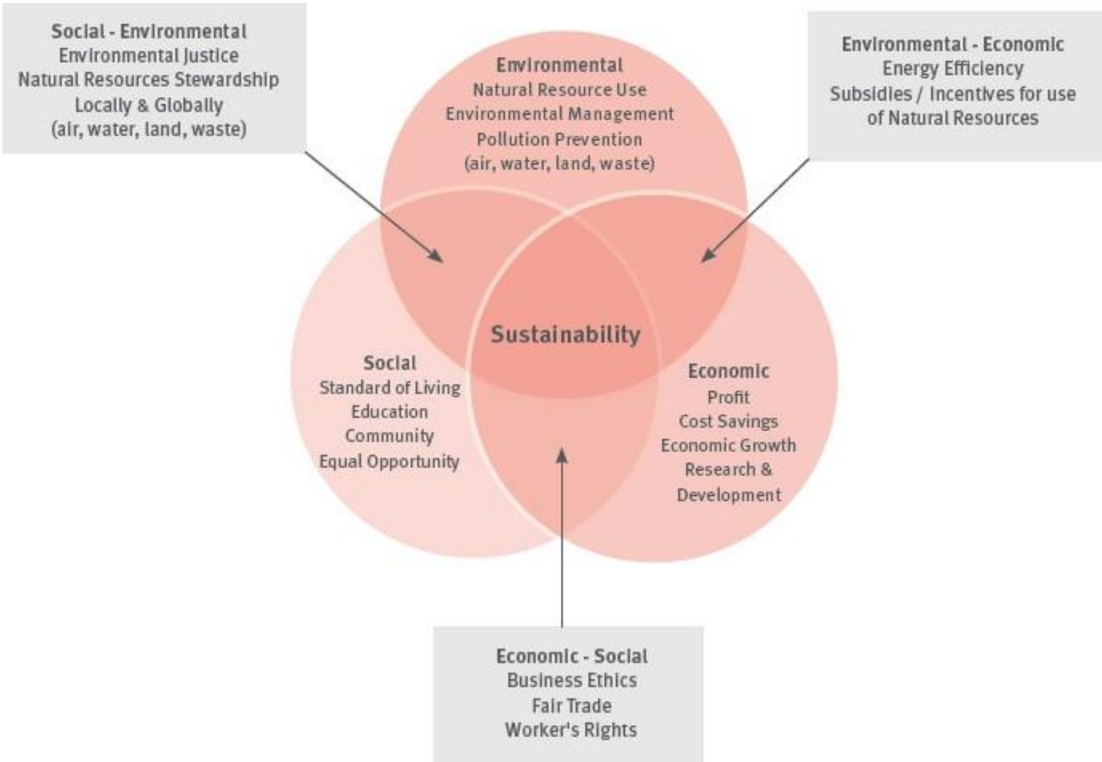

Fig. (3) Aspects of Sustainability

2.9.8 Benefits of Sustainability

The application of sustainability in construction is reflected in every aspect of the construction process. It includes, for instance, sustainable design, sustainable planning, sustainable architecture, sustainable landscaping and sustainable construction. By applying the concepts of sustainability in the construction industry, a number of benefits will be achieved. Environmentally, sustainability helps reducing the use of non-renewable resources, minimizing environmental risk and uncertainty, reducing waste and pollution, and increasing the reuse and recycling of building materials [22]. Socially, sustainability focuses on identifying stakeholders' requirements and ensuring that the developed project fulfils their needs and meets their expectations. Moreover, it encourages the involvement and getting feedback from all parties affected by the built environment, ensures health and safety requirements are achieved, considers people with special needs and provides support and adding value to communities and the supply chain. Economically, sustainability supports growth in the construction industry through increasing gross domestic product (GDP), providing more job opportunities, raising the client's profit and investment return [22].

3. Conclusion

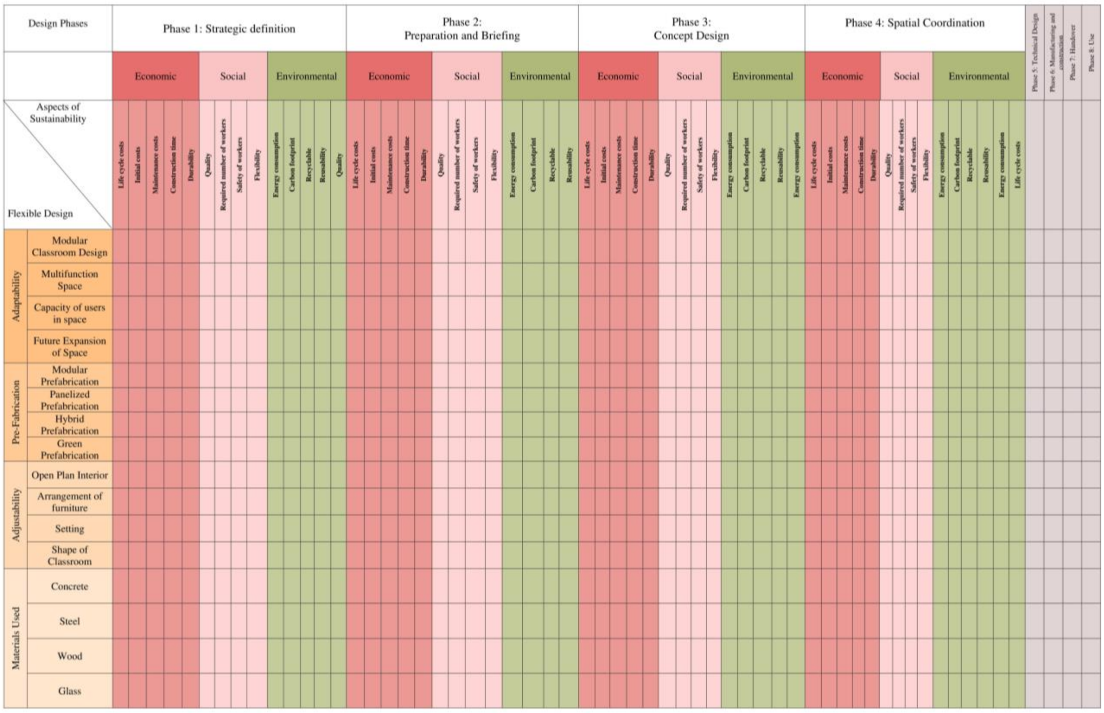

Fig. (4) Matrix showing correlation between Flexible design criteria and sustainability

Primary Public schools have a vital role towards developing a sustainable community. Despite its important role, the inflexibility of the traditional methods used in construction create social, economic and environmental challenges that makes the school unsustainable. Hence, flexible design is a proposed approach to achieve sustainability in Primary Public schools. The paper's methodology consists of qualitative data gathered from several reliable and valid sources in order to formulate a comprehensive literature review that would help to investigate the role of flexible design for achieving sustainability in primary public schools in Egypt through Green Prefabrication. Finally, the output is formulated in the form of a matrix which shows the correlation between flexible design criteria and the three pillars of sustainability as illustrated in figure (4).

Recommendation

Implementing green prefabrication in Primary Public schools in Egypt entails the creation of flexibility which includes both adaptability and durability in order to suffice the future needs of the users. Both green prefabrication and flexibility are essential tools that, if applied in schools, will help in shaping an environmental-friendly and sustainable community.

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