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MODULAR BUILDING UNITS AS A RAPID AND FLEXIBLE APPROACH FOR ADAPTABLE EDUCATIONAL BUILDINGS WITH AVAILABLE SITES

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Abstract: Education was and will remain an indispensable tool for the progress of nations. Therefore, strategies must focus on ensuring that children have access to education for all. However, as the demand for education continues to rise, it has become imperative to create schools with flexible building systems that meet the evolving needs of students and teachers. Not only do these buildings accommodate a larger number of students, but they also provide learning environments appropriate to pedagogical standards, considering factors such as rapid construction, flexibility, and sustainability. The study proposes the concept of a modular building unit, which allows its implementation in different building systems, to achieve flexibility, speed, and efficiency. To clarify the advantages of modular units, an illustrative model was proposed for the flexibility of designing school buildings in patterns that keep pace with the variables of most sites, or as in cases of expansion in existing schools. The study concludes that the advantages of using this method in buildings allow for providing an educational environment suitable for standards at an appropriate time.

Keywords: "modular design, inner-spaces standardization, Pre-manufacture ability, prefabricated system, Rapid Construction".

1. Introduction

Education is the key driver of progress in any society. It empowers individuals with knowledge, skills, and values that enable them to contribute effectively to their communities and economies and contribute to the stability and prosperity of a nation. In this context, the right of children to receive a quality education in an appropriate environment must be taken into account as described in the text of the United Nations Educational, Scientific and Cultural Organization (UNESCO) on the right to education as follows:

"We re-affirm the vision of the World Declaration on Education for All [1], supported by the Universal Declaration of Human Rights and the Convention on the Rights of the Child, that all children, young people, and adults have the human right to benefit from an education, that will meet their basic learning needs in the best and fullest sense of the term, an education that includes learning to know, to do, to live together and to be." [2]

The global demand for education is on the rise, driven by population growth, urbanization, and the recognition of education as a basic right. With societies striving to provide quality education for all, with the impact of the problem being exacerbated by long period of compulsory education of 9 years, the high rate of student density in classrooms, the phenomenon of multiple school periods, the lack of schools in many regions, and the deterioration of the education situation. Existing school buildings. [3]

It was necessary to establish a sufficient number of schools that could accommodate the increasing number of students. Traditional building systems may struggle to meet this increasing demand in the smallest amount of time possible, due to space, resource, and infrastructure constraints. Therefore, the establishment of schools with innovative building systems becomes necessary, to ensure that each student obtains an appropriate educational environment, quickly, efficiently, and at an appropriate economic cost, to keep pace with the modern development in education and achieve development plans in this sector. [4]

Modular construction is one of the prefabrication techniques, especially in regards to the speed of the construction process, the cost efficiency, and the reduction of negative impacts on the environment, i.e. sustainability. The study presents the concept of modular design as a flexible and effective tool for adapting school buildings to plots of different shapes, as well as in cases of expansion within the same site. By offering alternatives to form models, as a guideline, that shows the flexibility of design for building with modular units. This contributes to finding appropriate alternatives to provide educational buildings in the current situation and to provide school yards.

1.1 Research Goal

The research aims to take advantage of prefabricated modular construction techniques in providing educational buildings. To achieve rapid implementation and ensure compliance with standards. As an alternative to traditional building systems, and to keep pace with the growing demand for educational service needs; To give children their right to a quality education.

1.2 Research Methodology

The research approach is based on formulating a methodology through which the research objectives can be achieved on three levels:

First. Identify the problem of lack of educational buildings and its phenomena. Reviewing modular building systems for prefabricated buildings as a tool for providing educational buildings quickly, at an appropriate cost, and within the required standards.

Second. Provide a model to determine the dimensions of modular building units according to accepted standards, in compliance with many prefabricated building systems.

Third. Exploring the flexibility of localizing modular buildings according to available sites compared to the prevailing traditional building system. And then extrapolating the results and making appropriate recommendations.

Features of the shortage of school buildings and modular construction types

1.3 Increasing the Intensity of Students and Multiple School Periods Problem

The lack of school buildings is an ongoing problem along with the rapid pace of population growth, which leads to challenges in accommodating the growing number of students and affects the quality of education and the student experience in general. We address the development of this problem through two main indicators: increasing the density of students in classrooms and implementing partial school days that span multiple study periods. Hence the need to quickly meet the need for school buildings.

By examining the evolution of the increase in the number of classrooms over a period of five years from 2019 to 2023, it is clear that the number of classrooms built that operate on the part-time school system compared to those operating on the full-day system in 2020/2021 has increased. [5]. This means that there is a lack of keeping pace with the increasing number of students, as it is supposed to expand the scope of full-day classes, and not the other way around. Fig. 1

It is also clear that student densities exceed the maximum allowable, reaching 55.1 students/class [5]. With an increase of about 40%, even though these classes operate on a part-day system and the multiplicity of school periods as a double indicator expressing the urgent need for school buildings. Fig. 2

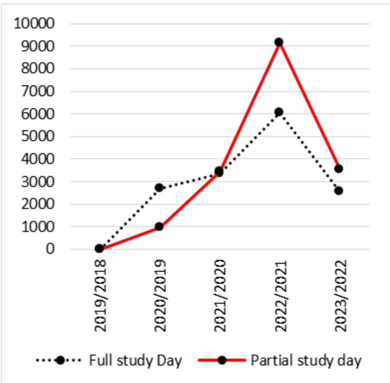


Fig. 1. Annual rate of classrooms growth (Full day-Partial day([5]

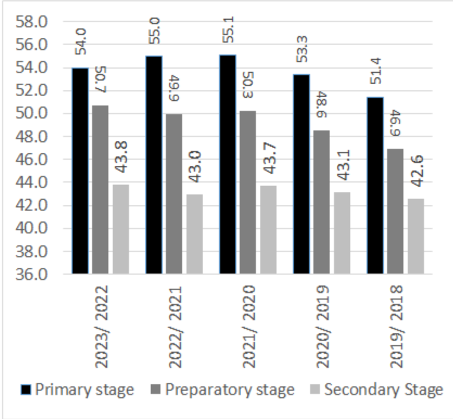


Fig. 2 Student intensity in classes [5]

1.4 Literature Review of the Concept of Modular Building

A modular building is a prefabricated building that consists of repeated sections called modules [6]. Modularity involves constructing sections away from the building site and then delivering them to the intended site. Installation of the prefabricated sections is completed on-site. Prefabricated sections are sometimes placed using a crane. The modules can be placed side-by-side, end-to-end, or stacked, allowing for a variety of configurations and styles. After placement, the modules are joined together using inter-module connections. The inter-connections tie the individual modules together to form the overall building structure [7]

Prefabricated buildings offer several advantages over traditional construction methods. These advantages make it a suitable choice for many applications, particularly ones where time, cost, quality, and sustainability are critical considerations, especially in educational buildings that feature modular and repetitive spaces. Some of the main advantages of modular buildings include: [8]

- Prefabricated buildings are constructed in a controlled factory environment in conjunction with site preparation. This greatly reduces construction time compared to traditional on-site construction.
- The total project cost can be lower due to reduced construction time, lower labor costs, and efficient use of materials. Additionally, due to the controlled manufacturing environment, unforeseen costs related to weather, labor shortages, or site conditions are minimized.
- Prefabricated buildings, by their very nature, are designed to be flexible and easily scalable. They can be expanded, replaced, or moved as needed, making them suitable for changing requirements or future growth
- Modular construction usually results in less construction waste and a more efficient use of resources than traditional construction. A controlled factory environment also allows for better management of energy consumption and material use.
- Ability to serve remote or hard-to-reach locations for building materials and trained labor. Especially in countries where construction sites may be in remote areas or crowded areas or random areas. [9]

- A controlled manufacturing process allows for the incorporation of energy-saving technologies and materials, resulting in reduced energy consumption and lower operating costs.

2. An overview of prefabricated systems

Prefabricated systems buildings. They balance speed and efficiency of construction, affordability, and ease of deployment while ensuring the integrity and performance of structures. The following is an overview of commonly constructed rapid school building systems.

2.1 Prefabricated Concrete Units

Prefabricated concrete units are structures that are manufactured off-site in a factory in a controlled environment and then transported for assembly Fig 3. This method reduces construction time, ensures consistent quality standards, and allows for the fulfilment of standard design requirements and functional needs in line with educational goals. Fig 4. It achieves cost savings compared to traditional construction methods. A simplified manufacturing process, bulk purchasing of materials, and reduced labour costs contribute to reduce overall costs. [10]

Fig. 3. Prefabricated linear walls [17]

Fig. 4. Prefabricated units [16]

2.2 Standard and lightweight structures

Buildings with lightweight modular structures. Allows for easy on-site fabrication and assembly. It can also be manufactured in specialized factories off-site and transported, which reduces construction time. It has several types, including: [11]

- The steel frame structure as a lightweight and strong structural system. Fig 5. Or the wooden frame. It is characterized by easy assembly and quick disassembly. Fig 6. It is also resistant to earthquakes and strong winds.
- Prefabricated insulated panels are lightweight, thermally efficient, and provide quick assembly. They can be made with insulating materials such as EPS, polyurethane foam, or mineral wool.
- Truss systems of lightweight steel or engineered wood structure. Trusses provide stability, allow for longer spans, and reduce the overall weight of the roof.

Fig. 5. Lightweight metal structures sample. [18]

Fig. 6. Lightweight wooden structures sample. [19]

2.3 Insulated Concrete Formwork (ICF) and expanded polystyrene system (EPS)

Insulated concrete formwork (ICF) is a construction technique that involves using interlocking foam boards or blocks as formwork for pouring concrete walls. The foam acts as both insulation and temporary formwork, providing a quick and efficient way to build solid, reinforced concrete walls as shown in Fig 7. [12]

Expanded Polystyrene (EPS) core board system is a modern, efficient, safe, and economical building system for building construction. These panels can be used as load-bearing elements as well as non-bearing elements as shown in Fig 8. The EPS core panel is a three-dimensional panel consisting of a three-dimensional welded wire space frame with an insulating polystyrene core. The panel is set in position and the shotcrete is on both sides. EPS panels use the truss concept to impart pressure and rigidity, including welded reinforcing meshes of high-strength wire, and diagonal wire, and then shotcrete is applied to the assembled panel at the construction site. [13]. Here are some of the key features and benefits of reinforced polyurethane panels:

The combination of concrete and foam insulation in the building is characterized by good thermal and acoustic insulation capabilities, where walls provide high strength durability, and resistance to shocks, fires, and harsh weather conditions.

Interlocking foam panels or blocks are easily assembled on-site to form the desired wall shape. Thus providing flexibility in design.

Fig. 7. Insulated Concrete Formwork (ICF [12]

Fig. 8. EPS core panel detail [13]

3. Determine the modular design unit dimensions

Modular units allow standardization according to design processes. This standardization not only ensures consistent quality but also simplifies the construction process. Schools can choose from pre-designed, modular configurations that fit their needs, reducing the time required for custom design and planning.

To determine the dimensions of the appropriate modular unit, the standards for educational spaces applied by the EPGA must be reviewed as it is the accredited authority. It is noticed that an area of 38.0 m^2 is repeated for each of (classrooms, laboratories, activity rooms), and by taking the square root, we get a side length of 6.2 m, and adding a wall thickness of 0.25 m it can be deduced that the dimensions of the educational space are about 6.5 m * 6.5 m with an area of about 39.1 m^2. Which can be formed by using four modular units.

Accordingly, we can conclude that the dimensions of the standard unit are within the range of 3.25 m * 3.25 m, as shown in Table 1. It is also suitable for the corridor width, which is supposed to be 3.0 m in the case of double loading. These dimensions are also commensurate with the different spaces of the educational spaces. Table 2

TABLE 1: Axis dimensions and net areas of the combined modular units [14]

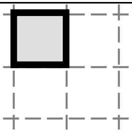
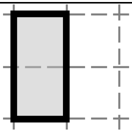
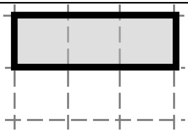
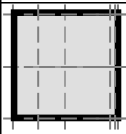
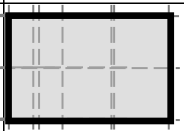
	1 Unit	2 Units	3 Units	4 Units	5 Units	6 Units
Unit Shape						
Axis Dim.	3.25*3.25	3.25*6.50	3.25*9.75	6.50*6.50	6.50*9.75	3.25*3.25
Clear areas	9.0 m2	19.3 m2	28.50 m2	39.1 m2	59.40 m2	82.2 m2

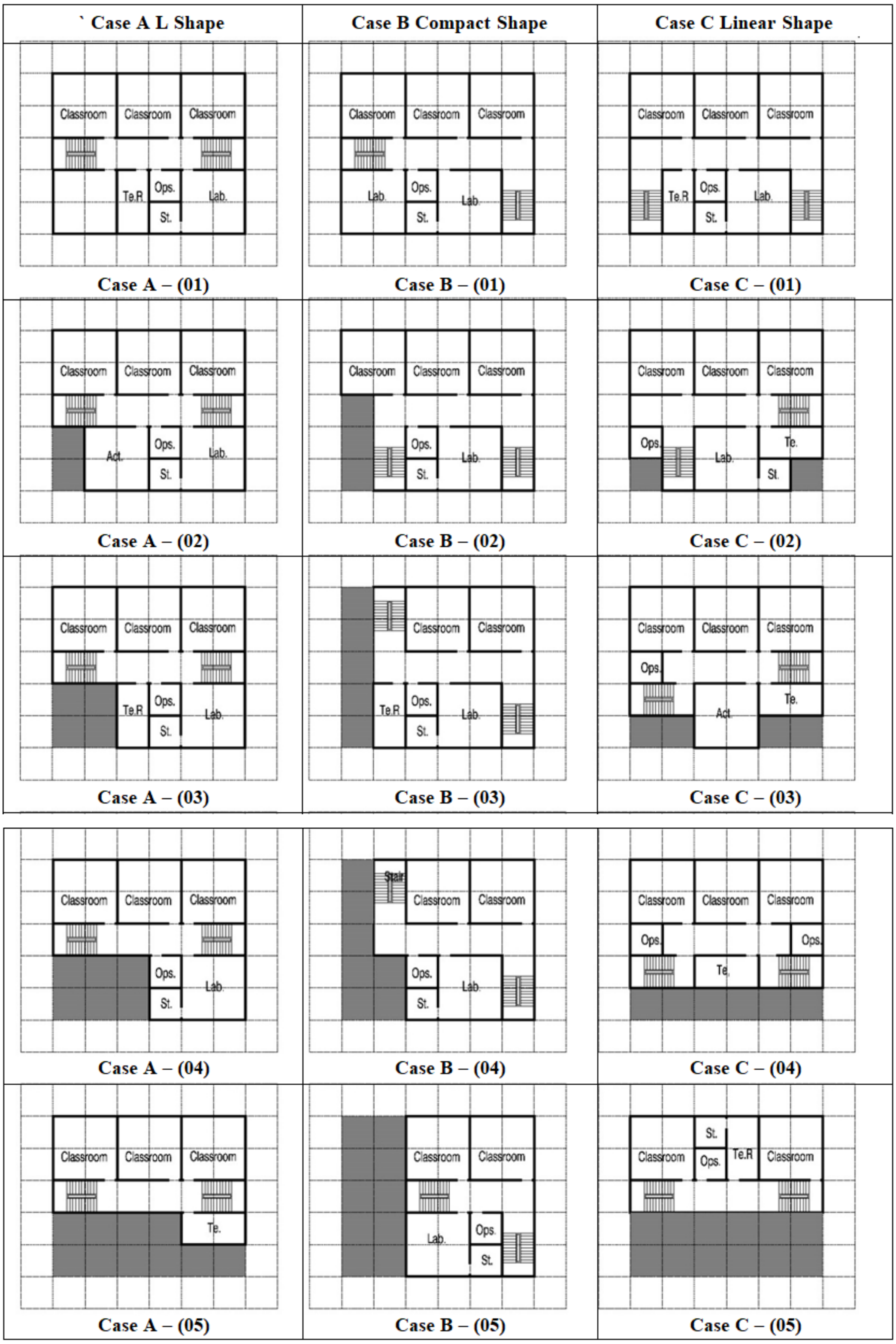
TABLE 2: Academic and service spaces suitability requirements for building schools. [15]

Space name	Limits	Basic requirements	Units rea	Number of units
Classroom	Min. area	38.0 m^2	39.1 m^2	4 Units
	Max. length	8.5 m	6.25 m	
	Min. area/student	1.0 m^2	1.0 m^2	
Science Lab	Min. area	38.0 m^2	39.1 m^2	4 Units
	Min. Lab. Prep. room area	12.5 m^2	18.75 m^2	2 Units
	Min. doors number for each	2	2	
Activity room	Min. area	38.0 m^2	39.1 m^2	4 Units
Computer lab.	Min. area	38.0 m^2	39.1 m^2	4 Units
Admin. room	Min. area	10.0 m^2	9.0 m^2	1 Unit
Multi-purpose hall	Min. area	80.0 m_2	82.2 m^2	8 Units
Single loaded corridors	Min. width	2.4 m	3.0 m	1 Unit/m
Double loaded corridors	Min. width	3.0 m	3.0 m	1 Unit/m
Door opening	Min. width	1.0 m	1.0 m	-
Windows area	Min. as a ratio of space area	18.0 %	18.0 %	-
M. Toilets	Min. One toilet/student + urinal	40	40	-
F. Toilets	Min. One toilet/student	30	30	-

4. Flexibility of Modular Buildings Design

Alternative building shapes, such as L-shaped, compact, and linear designs, offer unique advantages to suit different plot shapes and accommodate the expansion of existing schools. It is the most suitable form for building with modular units, achieves simplicity in formation provides the possibility of speedy construction while achieving educational spaces according to the standard rates. And by assembling standard units all the spaces required for the educational spaces can be achieved exactly Table 3.

TABLE 3: Study and service spaces suitability requirements for building schools [14]



Three commonly used types of educational buildings were reviewed in the previous table, and how to extract and add parts to the building to adapt to the shape of the site:

- Case 1: The L-shaped building configuration involves two wings. This design is well-suited for corner plots or irregularly shaped sites. It maximizes the use of corner spaces, providing opportunities for open areas. Each wing can be designated for specific functions, allowing for efficient space organization.
- Case 2: The compact building contains minimal internal corridors and wasted spaces. The goal is to create a more efficient layout that maximizes usable areas. It optimizes the use of available space, resulting in more efficient circulation and reduced construction costs per square meter. This configuration can enhance accessibility and minimize energy consumption for lighting and climate control.
- Case 3: The extended longitudinal design configuration is particularly useful for sites with elongated shapes. It can make the most of a narrow plot by maximizing the linear footprint. They often provide flexibility for future expansion along the same axis. This design can also create clear zoning within the building, with different sections serving specific functions.

5. Conclusions

In conclusion, modular construction plays a crucial role in achieving standard rates and speed of construction in school buildings. The benefits of faster construction, standardized designs, quality control, reduced disruptions, and cost predictability make modular construction an effective choice for educational institutions looking for efficient and timely building solutions.

Determining the dimensions of a standard design unit contributes significantly to unifying the standards of educational spaces in line with the standards approved by the Educational Buildings Authority, the accredited authority, which reduces the margin of excesses in design, achieves flexibility and speed in implementation and opens the way for choosing many prefabricated commonly used school building systems (Prefabricated Concrete Units, Standard and lightweight structures, insulated Concrete Formwork (ICF) & Expanded polystyrene system (EPS), etc.).

It can also adapt to many locations of plots of land in a flexible manner in addition to determining of the minimum educational spaces accurately, and thus the margin of error in the suitability of standards is reduced, and the cost and timing of construction can be determined as it is easily calculated due to being modular repeated units.

Building configurations such as longitudinal, L-shaped, compact and extended designs provide adaptable solutions to the various plot shapes and expansion needs of existing schools. Educational institutions can create functional, efficient and visually appealing buildings that align with their spatial requirements and growth plans.

The research concludes that modular building units offer a rapid, flexible, and adaptable approach to creating educational facilities on available sites. The study underscores the significance of embracing innovative construction methods to meet evolving educational needs sustainably and effectively that takes into account educational standards, to save time, cost, and effort.

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