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Modelling Design Standards for Iraqi Schools Using Building Information Modeling

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ABSTRACT

Schools are the functional type that includes several requirements and standards related to the conceptual, design, constructional and operational aspects. These standards consist of various factors with minimum and maximum values to which the design must adhere. In recent years, Iraqi schools suffer from overcrowding and insufficient facilities. The research problem has identified as the contradiction between the Iraqi standards for schools and the existing schools in terms of the capacity of students, number of classes, available facilities, etc. In addition, the existing school buildings ignore the differences in design specifications related to the student ages and their academic levels. In fact, the same design typology of school was used for different stages of study (primary, intermediate, and secondary), which led to the incompatibility with their requirements. Therefore, this paper seeks to present a methodology for modifying the design parameters of each school type to satisfy the minimum requirements of each study stage facilities. To achieve this aim, the paper adopts building information modelling (BIM) to represent a model for the design standards of educational facilities, and to facilitate the handling of different information, such as descriptive, quantitative, and qualitative values. The digital parametric model of school was built to represent the design constraints and the maximum and minimum limits of the Iraqi standards for school, and to provide the necessary flexibility to change the values within the permissible limits of the standard. This model was implemented using different software tools such as Revit, Planfinder and Grasshopper for Rhino to represent the information of schools in the Iraqi Standards. A methodology for adapting the typical school designs based on the concept of BIM and parametric programming was implemented to generate new designs by adding new spaces or changing the dimensions of existing spaces. The results proved the validity of this method in the derivation of feasible designs by adapting the typical school's designs approved by the Iraqi Ministry of Education.

1. INTRODUCTION

Several papers and UN organization reports such as UNESCO have referred to the lack of functional performance in many existing Iraqi school designs. These problems are attributed to the non-compliance with the Iraqi design standards, or even the lack of design standards for some important aspects. The paper aims to solve this problem by adopting a methodology for adapting the existing school designs to satisfy the maximum and minimum parameters of the Iraqi school standards. Many studies dealt with the application of BIM concepts in schools at different levels due to their advantages in representing information, the ease of sharing BIM between specialists, and the ease of modifying the parametric values within limited ranges. The levels of represented information in BIM include the conceptual, design, construction, operation, and reuse or demolition.

Di Giuda et al. [1] study sheds light on the capabilities of BIM in data and information management within an integrated approach between the various disciplines involved in the design, construction and operation during the life cycle of the building. Their study aimed to build a digital model for the development of the characteristics of educational spaces according to contemporary needs to achieve functional space characterized by flexibility and unity. Moreno et al. [2] seek to explore the role of BIM in educational facilities in the architectural, construction and engineering disciplines (ACE) within the standard-setting process.

Other studies used BIM for the creation of new high-tech buildings to meet the increasing demands for such facilities. This is done by improving and achieving sustainable factors in schools within BIM as an integrated and coordinated information database to support sustainable design [3].

Koutamanis et al. study [4] dealt with introducing Building Information Modelling approach (BIM) in the design process of educational buildings by involving users (students, teachers, and other participants) in the process of effective participatory design. The aim was to support functions that take place in the school through its life cycle which includes four phases: initiative, development, realization, and operation.

Some studies examined the application of BIM in the rehabilitation and maintenance of school buildings according to functional and environmental performance standards. The BIM system was used to represent and evaluate designs conformity with standards [5]. In addition, Le et al. [6] study examined values related to the renovation of educational buildings through BIM technologies. Their research dealt with the concept of sustainable renovation of schools due to adaptation to changing systems, which would extend the service life of buildings and focus on resource efficiency and user comfort.

Xiao et al. [7] addressed how to overcome some limitations in applying BIM at the landscape scope in education facilities, including technical, legal, educational, and social aspects by expanding the current standards and developing new ones. Buil on the studies, the importance of Building Information Modelling approach (BIM) in the design of new schools, and the development and renovation of existing school building is evident. Therefore, this paper adopts BIM for the improvement of school building types in Iraq by implementing Iraqi standards for school design in BIM model.

2. BUILDING INFORMATION MODELLING BIM

The definition of BIM varies according to its fields, including design, manufacturing, construction, maintenance and demolition [8]. BIM is a new system for approaching the design and documentation of construction projects [9]. The American Institute of Architects (AIA) defines BIM as a system for applying IT in construction based on models linked to a project information database [8]. BIM has created a new and innovative approach in architecture at the design, construction, and management level and in how specialists think about applying technology in architecture [10]. BIM is based on assembling the parametric objects that represent the components of the buildings in a virtual environment. These objects are described according to specific parameters that control the object's properties within the BIM system [11]. BIM provides a set of advantages and capabilities to users that distinguish them from other systems, including:

- **Clash Detection**: The presence of multiple disciplines with varying goals and requirements in one project is a problem facing engineers and project managers, which usually leads to clashes due to the overlap between the different disciplines. On the other hand, BIM can collect the specialists' data together and resolve the problem [12].
- **Constructability**: BIM can solve constructive problems accompanying management operations by providing information that reduces such problems [13].
- **Analysis**: BIM helps specialists conduct analyses and support better decision-making by linking BIM models with appropriate tools for analyzing energy consumption and thermal, mechanical and acoustic analyses [14].
- **Time & Cost Estimation:** It is one of the essential features of the BIM system, as it enables project managers and beneficiaries to visualize the different phases of the building, as well as providing an option to support the decision process in a short time [15].
- **Integration:** BIM models act as an information mediator between various disciplines due to the possibility of linking these models with other technologies to enhance communication between specialists, such as virtual reality (integrative, semi-integrative and augmented) to support design, analysis and maintenance processes [16].
- **Quantity Take-off:** This feature in BIM models is vital in studying different alternatives due to the integration between the BIM model and the database that enables the user to obtain an estimate of quantities quickly and accurately [17].
- **Element-Based Models**: BIM models consist of objects - not geometric elements such as lines and surfaces - so the model can be divided into several objects with a specific scope to facilitate their management, design and estimation [18].
- **Communication and Participation:** The unified model in BIM models improves communication and cooperation between all involved in the project, including project managers, architects, engineers, contractors, and others, during all processes associated with the building life cycle from data collection, design, construction, and management, which leads to Effective cooperation [11].

3. RESEARCH SCOPE

3.1 Research problem

Kazem and Al-Kazzaz [19] identified the absence of unified standards for schools in Iraq, as well as the non-compliance with these standards in existing types of school designs. These facts led to the inefficiency of current Iraqi school buildings and the inability of their typical designs to meet new requirements. Therefore, this study seeks to present a methodology for developing and adapting existing school designs to tackle problems such as overcrowding in Iraqi schools.

3.2 Research objectives

- Determine the deficiencies in the Iraqi standards of schools.
- Adoption of Building Information Modeling (BIM) for developing typical designs of school to meet design standards.

3.3 Research hypotheses

- The possibility of applying BIM in developing typical designs of Iraqi school buildings.
- BIM helps to meet the design standards for Iraqi school as design constraints.
- Adapting typical school designs can be done by changing dimensions and adding new spaces.

3.4 Research methodology

The research adopts an experimental approach in modelling and developing the existing typical designs of Iraqi schools using BIM to meet the updated design standards. The research method passes through the following stages as shown in Figure 1:

- Information collection includes determining the typical design layouts and their qualitative and quantitative requirements, approved by the Iraqi Ministry of Education. This Information and quantitative and qualitative data were collected from the records of Engineering Department at the Iraqi Ministry of Education by submitting an official request.
- Assessing the typical designs' inability to meet the Iraqi standard qualitatively and quantitatively.

- Modelling and representing the design information in a parametric model based on BIM using the Revit software
- Developing the generative design model by adapting typical design based on new requirements ahen evaluating its efficiency to meet the Iraqi standards.

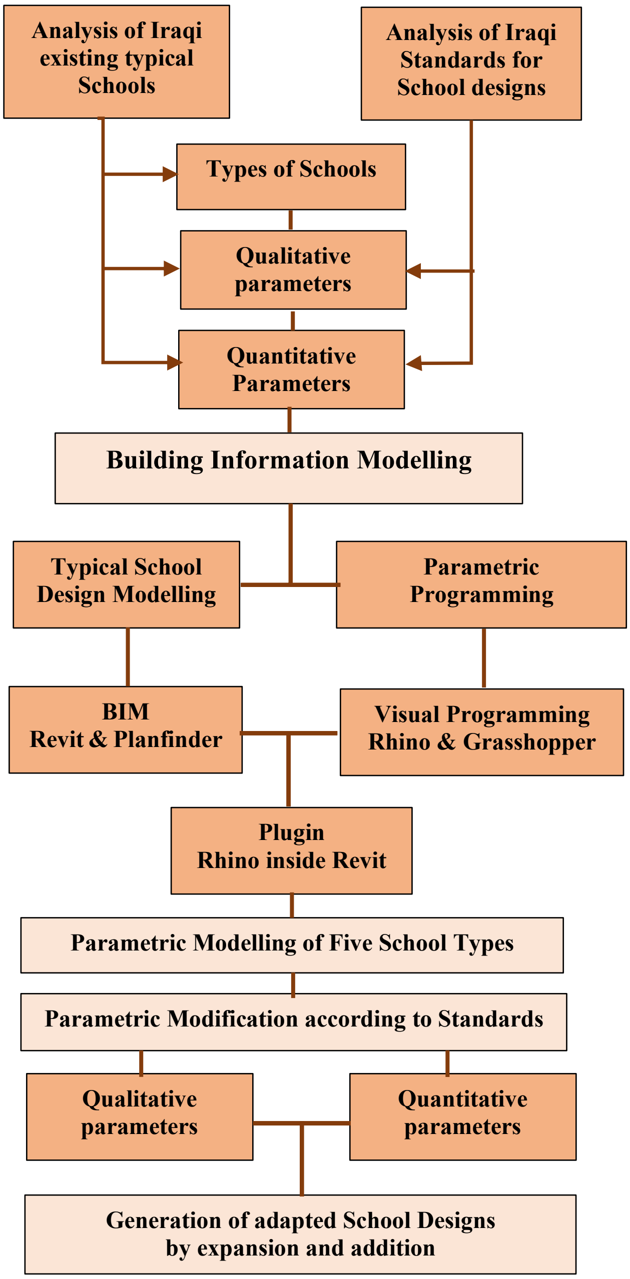


Figure 1. Proposed research methodology (source: researchers)

4. THE CASE STUDY

The main building types of Iraqi public schools were evaluated taking into consideration the academic levels (primary, intermediate, and preparatory) adopted by the Ministry of Education. These existing types were analyzed to determine the extent of their conformity with the approved Iraqi standard and to set the variables that affect the school designs. The analysed schools include the following academic level types [20-23]:

- Primary schools: built on the analysis of data obtained from the directorates of the Ministry of Education in Mosul city, it was found that there are four design types of primary schools according to their size and the number of classrooms, including schools with six classrooms with a percentage of 56% (most of them are old construction and located in sub-urban), and 12 classrooms with a percentage of 28%, then school with 24 classrooms at a percentage of 16% (this building type of school has been converted into a primary school, which resulted in inadequacy to achieve the functional requirements).
- Intermediate schools: in this type, it is noted that schools with twelve classrooms are at a rate of 52%, followed by schools with eighteen and twenty-four classrooms at a rate of 24% each.
- Preparatory schools: this type of school has twelve or eighteen classrooms, at a rate of 50% for each, and most buildings in this type are relatively new schools.
- Secondary schools: this type incorporates both the intermediate and preparatory levels in one building. Therefore, their characteristics are shared with the two aforementioned types. Hence, schools with twelve classrooms are prevalent at a rate of up to 52%, followed by those with eighteen classrooms at a rate of 23%, and types with twelve and nine classrooms at a rate of 13% and 12%, respectively. This type is an old system, and now the Ministry of Education and its directorates are adopting the separation between the intermediate and preparatory levels.

4.1 The capacity of school types

In this part, the capacity of schools' design is assessed to point out their shortcomings. The paper seeks to propose the appropriate methodology for modifying the design to accommodate the real number of students within each school type in accordance with the restrictions and requirements of minimum and maximum numbers of students defined by the Iraqi standard. Based on the data of the Ministry of Education for Mosul city schools, the sample of the analyzed schools is 1650 cases distributed among primary, intermediate and preparatory schools and have five design typologies as shown in Table 1.

It is clear from the above assessment that there are considerable variations in the number of students in the school types of each academic level. There are overcrowding in many schools compared to what is planned. Therefore, the strategies for adapting the current schools' design are determined for each space and activity in the light of Iraqi school standards, taking into account the range between the maximum and minimum values for each design variable.

4.2 Comparison of primary, intermediate and preparatory school standards

In this part of the study, the differences between the standards of the three-academic levels are analysed to determine the minimum and maximum ranges of effective design variables in schools as shown in Table 2. In general, there are two types of differences between the standards and existing schools. The first is due to the non-compliance with standards in terms of facility provision in some school types (like the missing functional activities in some preparatory schools such as labs). The second one is regarding the inconsiderate of differences in some standard values among schools of different academic levels (like the allocated area for each student). Table 2 below shows the most important differences between the three levels of academic schools (including their similarities and differences This comparison is built on specific variables, considering the population density factor (this factor is crucial in determining the type of school and its built area).

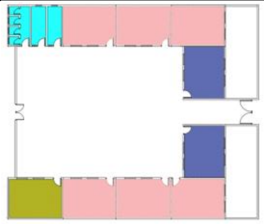
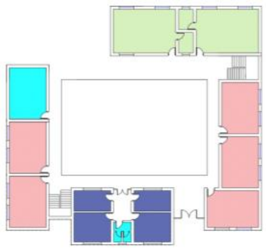
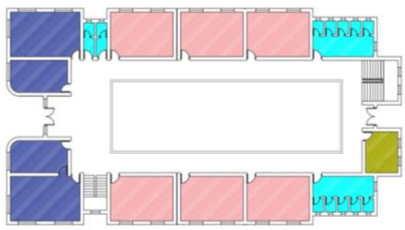
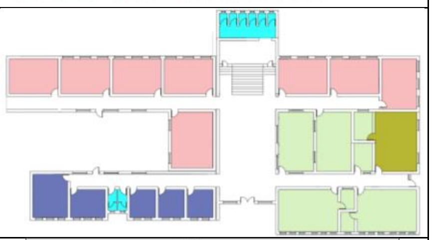
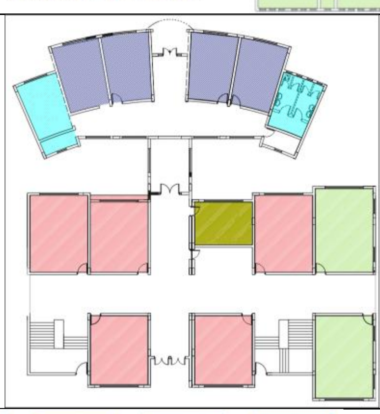
Table 1. Assessment of the capacity of schools for the study cases (source: researchers)

NUMBER OF STUDENTS IN PRIMARY SCHOOLS IN MOSUL CITY - IRAQ							
	Type of School	Least Number of Students (L)	Highest Number of Students (H)	Mode Fuction*	Capacity of Design (CoD)	Maximum Capacity of Design (MCoD)	Increase = M-MCoD
1	6Classrooms	110	486	360	180	240	+120
2	9 Classrooms	198	571	511	270	360	+151
3	12 Classrooms A	387	645	645	370	480	+165
4	12 Classrooms B	387	645	645	370	480	+165
5	18 Classrooms	532	1018	777	558	720	+57
6	24 Classrooms	631	1175	924	720	960	-36
NUMBER OF STUDENTS IN INTERMEDIATE SCHOOLS							
	Type	Least Number	Highest Number	Mode	Capacity By Design	Maximum Capacity	Increase
1	6 Classrooms	75	125	112	-	-	-
2	9 Classrooms	135	388	320	285	290	+30
3	12 Classrooms A	245	667	540	324	432	+108
4	12 Classrooms B	245	667	540	324	432	+108
5	18 Classrooms	292	726	680	630	630	+50
6	24 Classrooms	628	1146	980	840	840	+140
NUMBER OF STUDENTS IN PREPARATORY SCHOOLS							
	Type	Least Number	Highest Number	Mode	Capacity By Design	Maximum Capacity	Increase
1	6 Classrooms	81	178	130	-	-	-
2	9 Classrooms	135	324	287	217	220	+67
3	12 Classrooms A	400	667	533	432	440	+93
4	12 Classrooms B	400	667	533	432	440	+93
5	18 Classrooms	292	822	758	630	630	+128
6	24 Classrooms	628	1146	980	840	840	+50
*** MODE FUNCTION IS THE MOST FREQUENTLY OCCURRING NUMBER IN A GROUP OF NUMBERS.**							

Table 2. Iraqi standards for school design (source: researchers)

Type	***Variables***	***Population Density***							
		1200	2400	3600	4800	7200	9600	14400	19200
Primary Schools *6 Years To 11 Years*	The number of children who go to primary school	184	370	554	740	+	+	+	+
	Number of classrooms (school size)	6	12	18	24	+	+	+	+
	The maximum capacity of the school	240	480	720	960	+	+	+	+
	The minimum net area of the primary school is (3.5-4.25 square meters) per pupil	850 M^2	1200 M^2	1700 M^2	2200 M^2	+	+	+	+
	The minimum built-up area of the primary school is (4.5-5.5 square meters) per pupil	1100 M^2	1500 M^2	2150 M^2	2750 M^2	+	+	+	+
	The minimum area of the school site (8.5-12.0 m^2) per pupil	2400 M^2	3000 M^2	4250 M^2	5000 M^2	+	+	+	+
Intermediate Schools *12 years to 14 years*	The number of children who go to primary school	-	-	107	143	214	285	428	+
	Number of classrooms (school size)	-	-	6	6	9	12	18	+
	The maximum capacity of the school	-	-	240	240	360	480	820	+
	The minimum net area of the school is (3.7-4.8 square meters) per pupil	-	-	1000 M^2	1000 M^2	1400 M^2	2000 M^2	3000 M^2	+
	The minimum built-up area of the school is (4.8-6.5 square meters) per pupil	-	-	1250 M^2	1250 M^2	2000 M^2	2500	3750 M^2	+
	The minimum area of the school site (9.0-14.0 m^2) per pupil	-	-	2800 M^2	2800 M^2	4200 M^2	5600 M^2	8400 M^2	+
Preparatory schools *15 years to 17 years*	The number of children who go to primary school	-	-	-	-	162	217	325	428
	Number of classrooms (school size)	-	-	-	-	6	6	9	12
	The maximum capacity of the school	-	-	-	-	216	216	324	432
	The minimum net area of the school is (3.7-4.8 square meters) per pupil	-	-	-	-	1100 M^2	1100 M^2	1400 M^2	1750 M^2
	The minimum built-up area of the school is (4.8-6.5 square meters) per pupil	-	-	-	-	1400 M^2	1400 M^2	1700 M^2	2100 M^2
	The minimum area of the school site (9.0-14.0 m^2) per pupil	-	-	-	-	3000 M^2	3000 M^2	4000 M^2	4500 M^2

Table 3. Plan and zoning of school types

	Type	Plans
1	**Opened courtyard type with six classrooms**	
2	**L-shape type with nine classrooms**	
3	**Closed courtyard type with twelve classrooms**	
	Type	**Plans**
4	**Opened courtyard type with twelve classrooms**	
5	**Linear axis type with eighteen classrooms**	
6	**Linear axis type with twenty-four classrooms**	
		

4.3 Analysis of space layout types of school designs

There are specific typical building plans for school designs accredited by the Iraqi Ministry of Education. The possibilities of adapting and modifying these plans will be examined through formal and spatial analysis. The effective parametric variables in each plan were determined using BIM models that allow the expansion by increasing existing dimensions or adding new spaces to accommodate more students. The examined space layout types are as follows in Table 3.

- Opened courtyard type with six classrooms: this type has an open courtyard; on one of its sides, there is the entrance and the administrative part, while the classrooms are located on opposite sides, with three classrooms on each. The expansion is linear toward the free side, as well as changing the dimensions of the classrooms toward the outside to accommodate the maximum number of students.
- L-shape type with nine classrooms: this type is characterized by the side with four classrooms and two labs on the ground floor, while the first floor consists of 5 classrooms. The circulation of this design has two intersected corridors with a vertical circulation (stairs). On the other side, there is an administration and services. This zoning of activities facilitates the future expansion of the educational part by adding new classrooms and labs.
- Courtyard type with twelve classrooms, are comprised of the following:
  a. Closed courtyard type: a rectangular longitudinal closed courtyard on four sides; on each side, there are three classrooms on both the first and ground floor. The front side consists of the administration and its vertical circulation system, and the opposite side consists of laboratories and the student circulation system, in addition to water closets. Based on the plan analysis, it is clear that there is no chance to add any classrooms, but it is easy to expand the classrooms and labs to accommodate more students with the same proportions.
  b. Opened courtyard type: This courtyard is square, and the administrative part is on one of its sides, while the opposite includes the classrooms and laboratories. This type can be expanded, and the possibility of changing the spaces' dimensions while maintaining the same design characteristics.
- Linear axis type with eighteen classrooms: This type is characterized by being able to have addition to the open linear direction due to the zoning of the activities. This is because of its high-profile distinction, as the administrative wing is on one side with the laboratories, while the classrooms are on the other side, so it is expandable in both directions. The two wings connect the vertical circulation system.
- Linear axis type with twenty-four classrooms: This type appeared recently to meet the needs of schools to accommodate larger numbers of students, and this type is distinguished from the previous ones as the administrative part is separated from the laboratory and classroom spaces, which provides more ability to accommodate students through the strategy of adding or changing dimensions keeping the same design characteristics.

5. BIM FOR GENERATIVE DESIGNS OF SCHOOL

5.1 Building Information Modelling for school designs

BIM is effective in representing different types of values and data such as descriptive, quantitative, and analytical information, in a parametric model that is easy to deal with. Therefore, all the design characteristics associated with parameters in the Iraqi school standards are modelled. These characteristics affect the design of schools by representing the restrictions and the minimum and maximum values to conserve the feature of the school besides giving the flexibility to change the values within the permissible limits of the standard.

5.1.1 Preparing parametric data

This part determines the design data within two stages to be parametrically modelled. The first stage was concerned with choosing the types of parameters, and the second stage aimed to decide the range of values of each parameter in line with the Iraqi standard for schools. In this case, the modification is restricted according to the standards based on future needs. These parameters are interrelated within a digital model, and the modification of one of them will affect the rest by associated relations to make the modification and adaptation within the permissible limits. Below are the types of parameters that are implemented in the BIM model for school design:

- Numeric parameters are a numerical and mathematical range of some standard variables to represent for example: the number of classrooms, the area of spaces, the number of students, cost calculations, and others.
- Functional parameters: These parameters are concerned with the types of functions such as classrooms, labs, administration, etc. in the interior and exterior school spaces.
- Formal parameters: These parameters represent the formal aspects of architectural spaces in terms of the types of shapes and their proportions.
- Relational parameters: These parameters represent the relationships between the spaces in the space layout of school, such as the functional juxtaposition.
- Qualitative parameters represent the criterion's possible values, such as building materials, construction types and others.
- Composite parameters include two or more of the aforementioned parameters to represent one or several characteristics, such as movement paths that are represented by values and shapes (formal and numeric parameters) and school planning that represents formal, functional, numeric and relational parameters.

5.1.2 Digital information modelling

After preparing the design date and its values' range for the suitable parameters to be adopted in the modelling, this information is modelled parametrically using Revit and Rhino software and many plugins supporting information modelling systems. Modelling the information of Schools in the Iraqi Standards started with Revit software to represent the formal characteristics of spaces and set proportional constraints. Then, a plugin Rhino Inside Revit was used to connect Revit with Rhino to move to the plan's modelling stage. Then, Grasshopper for Rhino was used to represent the minimum and maximum values as parameters = using visual programming. After that the resulting model has linked again to Revit via Rhino Inside Revit plugin to be converted to another plugin Planfinder. The latter generates the designs by the addition of new spaces and modifying dimensions of existing spaces according to the capacity of school and considering the minimum and maximum values allowed by the Iraqi standards. The steps are as follows:

Representation of Formal and Numerical Characteristics. At this stage, the formal and numerical characteristics and the values range are represented to constrain the design types according to the Iraqi standard. Revit software operates the BIM system because it can enhance collaboration, coordination, efficient planning and scheduling, modelling accuracy, conflict detection, comprehensive facility management tool, and cloud-based capabilities [9].

So, various constraints will be adopted in the modelling process to restrict the design generation in accordance with the Iraqi school standard. Revit is characterized by being able to program many constraints. The following restrictions are used:

- Relational constraints establish the relationships between the elements and spaces in the school to prevent a clash. They are of two types, the first is related to dimensions to specify dimensional values for the spaces, and the other is spatial constraints, which determine the location of the administrative, educational, service and laboratories spaces with each other.
- Alignment constraints: These control the alignment of elements, such as walls, doors, and windows, with other elements in the project.
- Intrinsic constraints: These constraints connect the elements with each, and they are self-constraining and pre-activated in Revit, which determines the behaviour of the functional elements or spaces, such as circulation and others.
- Conditional constraints: These constraints are represented in the form of a rule and a condition to specify the range of values as parameters within the following types:
    a. minimum and maximum limits constraints: These constraints are used to represent the value ranges of the variables through parameters and the conditional IF statement formulate as follows:
    = if (tr54<condition>, <result-if-true>, <result-if-false>)
    = if (No_of _student <35, 50> , then use type 1)
    b. Linked Constraints: These constraints also use the IF conditional statement, to derive a series of constraints of applying rules with parameters, as follows:
    ;/= if (parameter a = 24", "result 1", if (parameter a = 48", "result 2", if (parameter a", "result 3", "type 1 not available: Please select a type 2 of either 5*7m for each classroom")))
    c. Related Constraints: This constraint is used when two interrelated conditions exist to achieve the state, so it uses IF and AND formulas.
    =if (and (no of students > 35, type =1), then dim 7*5)
    d. Conditional constraints, YES or NO, it also used IF conditional as follows:
    =IF with Yes/No condition =if (no of students, <35>, <without dim 7*5)
    e. Equations constraints are used in mathematical equations within a certain range.
    f. Visual constraints: this type will be used by Grasshopper (Grasshopper is a visual scripting platform for Rhino, a 3D modelling software. It is a plugin that allows users to create parametric designs and complex geometries using a node-based interface.

It is an algorithmic modelling tool that enables users to explore complex forms and shapes through a simple and intuitive interface without needing to write any code. Grasshopper allows users to create and manipulate 3D models using mathematical equations and logic, and it is widely used in fields such as architecture, product design, and industrial design. It can be used to create parametric models, data visualization, scripting, and generative design, among other things. It's a tool that allows users to easily create complex shapes and forms and explore and experiment with different design options in real-time [24, 25].) software as shown in Figures 2 and 3:

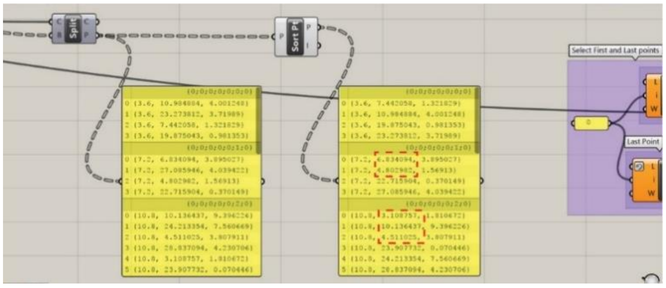


Figure 2. Visual constraints applied in the research (source: researchers)

Figure 3. Visual constraints applied in the research (source: researchers)

5.1.3 Programming parameters

After completing the representation of formal and numeric constraints as parameters, a plugin for Rhino is used in this stage of modelling Grasshopper. This software creates a parametric model of the school building that contains information about the school design standards, such as classroom size, number of students, number of windows, etc. This information can be stored in a database and linked to the 3D model of the building, allowing architects and builders to easily access and reference the design standards during the design and construction process.

Also, Grasshopper can be used to Code compliance to evaluate the design of new classrooms or reconfigured spaces against local building codes and regulations. In addition, it ensures that the design meets all necessary safety and accessibility requirements, according to the school design standards. These models can be linked to a database that contains information about the school design standards, and the building's performance, which can be used to track and analyse the building's performance over time as shown in Figures 4 and 5.

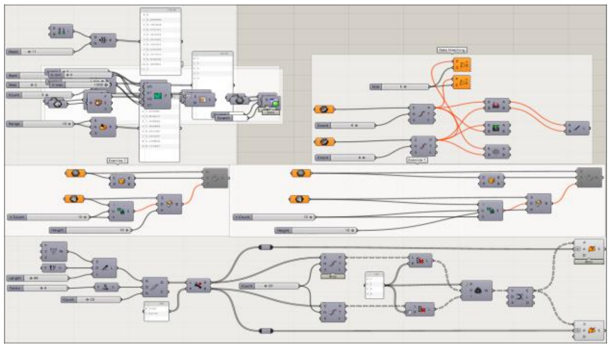


Figure 4. Visual programming of the school standards (the researcher)

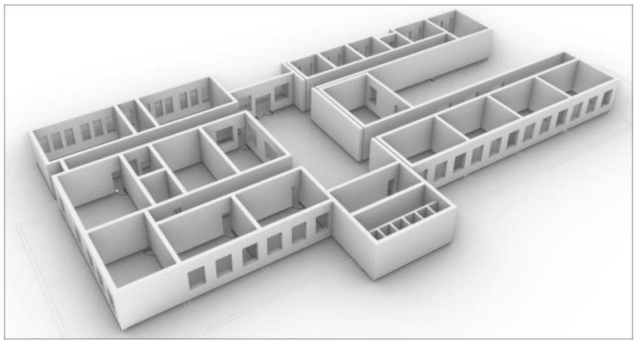


Figure 5. The generated 3D model via visual programming (the researcher)

5.1.4 Generating designs

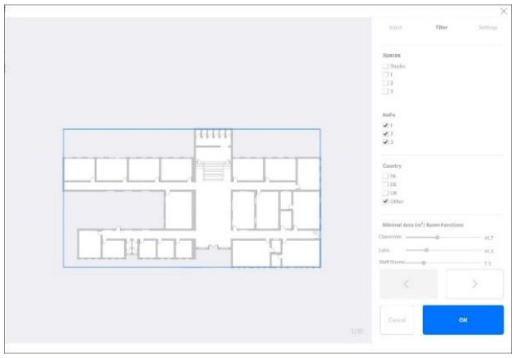


Figure 6. Generated Alternative A by Planfinder (the researcher)

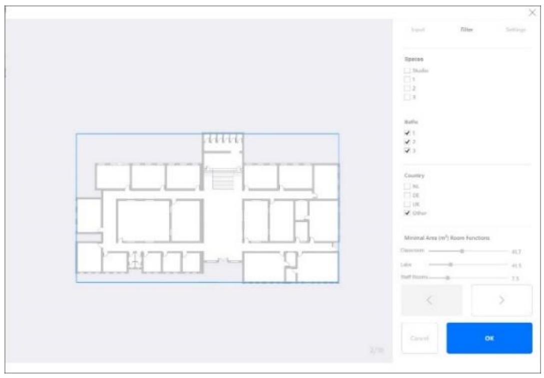


Figure 7. Generated Alternative B by Planfinder (the researcher)

Planfinder (Planfinder is a BIM-based plugin (Building Information Modelling) application that can be used for space planning, design, and construction of buildings. It is software that helps architects, engineers, and builders to plan and design buildings more efficiently. It can create detailed 3D models of a building, including its layout, structure, and systems such as HVAC, plumbing, and electrical. Planfinder can be used in various types of buildings, including schools, hospitals, and commercial and residential buildings; it can be used to design and plan additions, expansions, and new construction, as well as for facility management, maintenance, and future expansions) is used to generate plans as a plug-in Revit for schools by creating parametric models that can be easily modified and optimized based on different design criteria. Grasshopper can be used to generate plans for schools through:

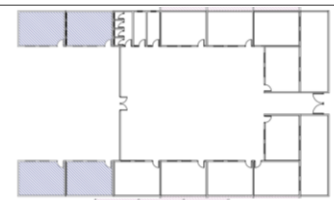
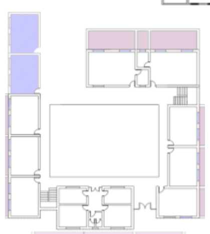
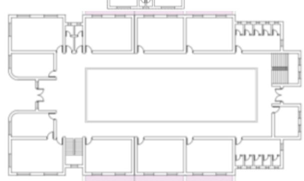
Space planning: Planfinder can be used to create parametric models of the school building, which can be used to analyse the current space utilization and identify opportunities for adding new classrooms or reconfiguring existing spaces. This can include evaluating the size and layout of the existing classrooms and determining the optimal locations for new classrooms based on factors such as natural light and access to outdoor spaces.

Design generation: Planfinder can generate multiple design options for new classrooms or reconfigured spaces, which can be evaluated and compared based on factors such as functionality, cost, and energy efficiency. This can include creating floor plans, elevations, and 3D models of the new classrooms or reconfigured spaces Figures 6 and 7.

6. RESULTS AND DISCUSSION

In Table 4, expansion and addition to the design types were applied.

Table 4. Expansion and addition to the design types to accommodate students

	Type Of School Layout		Adapted Plans	Expansion	Addition	Academic Level	Existing Capacity	Before Adaptation	After Adaptation	Improvement Rate
1	Opened Courtyard Type With Six Classrooms			Yes	Yes	Primary	360	240	380	100%
						Intermediate	320	240	380	100%
						Preparatory	315	240	380	100%
2	L-Shape Type With Nine Classrooms			Yes	Yes	Primary	511	360	430	84.2%
						Intermediate	320	360	430	100%
						Preparatory	287	360	430	100%
3	Courtyard Type With Twelve Classrooms	A		Yes	Yes	Primary	645	480	550	85.2%
						Intermediate	540	480	550	100%
						Preparatory	685	480	550	86.13%
		B		Yes	No	Primary	645	480	528	81.86%
						Intermediate	540	480	528	97.7%
						Preparatory	685	480	528	77%
4	Linear Axis Type With Eighteen Classrooms			Yes	No	Primary	777	720	755	97.1%
						Intermediate	680	720	755	100%
						Preparatory	758	960	755	99.3%

5	Linear Axis Type With Twenty-Four Classrooms		Yes	No	Primary	924	960	1100	100%

6.1 Comparison of school types standards

- The significance of this study lies in its ability to determine a suitable methodology for adapting an ordinary or pre-existing school design to accommodate changes that address problems such as the number of classrooms, the maximum capacity, the minimum area of the school, in addition to the conversion of the school academic stage from a primary school to an intermediate or preparatory school without allocating the necessary space for each student.
- Comparing the standards of primary, intermediate and preparatory schools reveal significant differences in the area of spaces allocated to each student. In addition, the significant impact of the school's location and the population density of the school's serviced area is also noted.
- The differences in the values of design standards among primary, intermediate and preparatory school types are evident. It is the fundamental reason for the inappropriateness of school designs. whose type is transformed and changed without considering these differences leading to an unsuitable environment for education that does not meet the minimum requirements. Therefore, the presented methodology is suitable for modelling the standards as parameters with a specific range of values applied using building information modelling for each design type. The digital model of each type can be adopted at the three academic levels incorporating future changes while preserving the general characteristics of the type within the pre-defined criteria.
- Based on the comparison of school design types focusing on the future expansion possibilities of each type, it is clear that:
  - The Opened courtyard type with six classrooms has the limitation of linear expansion on one side only.
  - The L-shape type with nine classrooms allows for future expansion of the educational part by adding new classrooms and labs.
  - The Courtyard type with twelve classrooms has two variations: closed courtyard type which has no chance of adding any classrooms. Still, expanding the classrooms and labs to accommodate more students with the same proportions is easy. on the other hand, the open courtyard type can be expanded, and it's possible to expand the dimensions of the classrooms and labs.
  - The Linear axis type with eighteen classrooms allows for expansion in both directions. The administrative wing is on one side, while the classrooms are on the other, allowing for easy expansion.
  - The Linear axis type with twenty-four classrooms provides more ability to accommodate students by adding or changing dimensions with the same design characteristics.
  - Overall, the L-shape type with nine classrooms and the linear axis type with eighteen and twenty-four classrooms have the most potential for future expansion. In comparison, the open courtyard type with twelve classrooms and the Linear axis type with twenty-four classrooms have more flexibility in changing the dimensions of classrooms and labs.

6.2 Modelling process

- In the modelling process, various constraints are adopted to restrict the design generation and ensure its compliance with the standards. These include relational constraints, alignment constraints, intrinsic constraints, and conditional constraints. The conditional constraints, in particular, are used to specify the range of parametric values including the minimum and maximum limits as the value ranges of the variables. These constraints work together to create a detailed and accurate school design model that adheres to the standards and can be modified and expanded as needed.
- Regarding the use of Visual programming via Grasshopper, it can be noted that:
  - using Grasshopper to represent school design standards can benefit architects, builders, and other stakeholders. The ability to easily access and reference the school design standards, and to analyse the building's performance according to these standards, can help to ensure that the building meets the necessary regulations and standards. Additionally, collaborating and sharing information using Grasshopper can help minimize confusion and misunderstandings and ensure that all stakeholders are working towards the same goal.
  - Furthermore, using Grasshopper to create detailed models of the finished new classrooms or reconfigured spaces, which can be used for maintenance, facility management and future expansion, can help to ensure that the building is well-maintained and can be easily expanded upon in the future.
  - However, it is important to note that Grasshopper is a tool whose effectiveness depends on the user's skill. It's important to have a clear understanding of the school design standards and regulations and a good understanding of the Grasshopper's capabilities to represent them effectively.
  - Overall, it can be concluded that Grasshopper is a powerful tool for representing school design standards and can provide many benefits for architects, builders, and other stakeholders.

However, it's important to use it properly to achieve the best results.

- Planfinder, a plugin for Revit, allows for the efficient generation of school plans based on the standards modelled using BIM and constraints. It can quickly generate various design options that adhere to the standards and can be easily modified to suit a school's specific requirements. other benefits are:
  - Automation in the plan generation process reduces the time and effort required to create a design that meets the standards.
  - Flexibility: Planfinder is a flexible tool that allows for creating a wide range of design options that can be modified to suit the specific needs of a school. It also allows for easy adjustments to be made to the design to meet changing requirements in the future.
  - Collaboration: Planfinder enables collaboration between stakeholders, such as architects, engineers, and construction professionals, which facilitates the coordination and communication of the design process.
  - Improved Quality: The use of Planfinder can lead to improved quality in the final design as it ensures that the design adheres to the standards and regulations, which can help to improve the overall functionality and safety of the school.

7. CONCLUSIONS

BIM (Building Information Modelling) is a powerful tool that can be used to model and represent information related to school design standards. BIM such as Revit software in conjunction with Grasshopper and Planfinder, can effectively address the problems in Iraqi existing school designs. By combining Revit with both Grasshopper, a visual scripting parametric tool, and Planfinder, a space planning software, it is possible to model the characteristics associated with school design standards and identify the restrictions and minimum and maximum values of the standard. These tools built a parametric model representing different types of values and information, such as descriptive, quantitative, and analytical information, making it easy to deal with.

This parametric model can be used to set constraints and parameters, such as the number of classrooms, areas, number of students, and cost calculations. It allows for the easy modification of existing design within the permissible limits of the Iraqi standards and to make changes according to future needs.

This approach allows designers, builders and operators to work within the restrictions of design standards while providing the necessary flexibility to change the parametric values within the permissible limits. It also allows for efficiently optimising space and resources, addressing the overcrowding issue in Iraqi schools. Using BIM, Grasshopper and Planfinder, the architects, engineers, and builders can ensure that school buildings are designed to meet the users' needs and provide a safe and comfortable learning environment for the students.

This paper presents a methodology for adapting existing school designs to accommodate changes using building information modelling (BIM) with Grasshopper and Planfinder as tools to model the design standards and generate school plans efficiently. The study concludes that using these tools properly can improve design quality, flexibility, collaboration, and automation, resulting in better school functionality.

The limitations of this study can be attributed to the fact that it is based on Iraqi school design standards and may need to be generalizable to other countries.

Several areas of future research can build upon the findings of this study including:

- The investigation of the impact of adapting other factors of class design such as the window sizes and location, on improving daylight in the learning environment of typical Iraqi schools, and the integration of these factors into the presented methodology and modelling process.

The development of a comprehensive database of school design standards, regulations, and best practices in BIM models that can be used as a reference for architects, builders, and other stakeholders involved in the school design process.

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