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An Integrated Approach to Building Planning Using the Multi-Criteria Decision Method (MCDM) and BIM

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Abstract: The purpose of this study is to create a method based on an integrated multi-criteria decision-making—building information modelling (MCDM—BIM) approach, which will then be applied to two case studies at various stages of construction. For each case study, three options were developed based on the client's specifications. Dynamo was used as a Revit computational design tool. Based on the "principles of building planning," four important criteria were chosen. A questionnaire was developed for the subjective evaluation of possibilities based on the criteria that were chosen. Later, the ideal floor plan configuration was determined. The use of a combined MCDM-BIM technique enabled the ranking of each design option as well as 3D visualisation of all current and potential design options.

Keywords: Building planning, computational design, MCDM, BIM, and AHP

1. Introduction

Early decisions have a significant impact on how a project develops over its lifetime. This is true for all projects, whether they include building a simple house or a thermal power plant or a dam. The many phases of a construction project can be divided into conceptual, schematic, production, bidding, and building stages, according to Senay Atabay & Niyazi Galipogullari 2013 (Senay Atabay & Niyazi Galipogullari, 2013). One of the most crucial choices to be made during the conceptual design phase of a residential structure is probably to finalise the floor plan. There could be one, two, or more options available. The ultimate floor plan layout may be influenced by a variety of things. Finding the ideal floor plan design can be accomplished by taking into account the "principles of building planning." Building planning principles are "the idea of putting all the elements and units of a building in a methodical and practical manner to make the greatest and most efficient use of the available space, area, and facilities," according to the definition given by the American Institute of Architects. Conceptual, schematic design, production, bidding, and construction are the several phases that make up a construction project. One of the most crucial choices to be made during the conceptual design phase of a residential structure is probably to finalise the floor plan. The majority of the literature identifies 12 typical criteria that should be taken into account while applying the "principle of planning." (Ahuja, 2007; Mahajan, 2016) These elements may occasionally clash when choosing a floor plan layout. It can be said to satisfy a number of requirements. A "multiple criteria decision making" (MCDM) procedure can therefore be used to solve the challenge of setting a floor plan layout based on a "principle of planning). However, an examination of the literature reveals that not much prior work has taken the same into account.

Tan et al. (2021) stated that the integrated MCDM-BIM approach has received the least attention, and its effectiveness needs to be investigated. A common medium that ensures smooth data flow is required for such synergy

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to occur. Using computational design tools for this purpose is one solution. The "application of computational strategies to the design process" is the essence of computational design (CD). CD aims to improve problem-solving by encoding design decisions in a computer language. Only architects use the CD approach in the AEC industry. As a result, the goal of this research is to propose a methodology for connecting MCDM and BIM processes for building design planning based on "principles of building planning" and validate it using two case studies.

1.1 Phases of A Building Project

The phases of a construction project are classified in various ways. The following are various phases of a project from an architect's perspective, according to the American Institute of Architects (AIA) (Chintis, 2019). Pre-design: A data collection phase that serves as the foundation for subsequent design phases. The primary goal is to comprehend the client's objectives. Schematic design: The architecture team will complete the basic conceptual model during this phase of the design process. Design development: In this phase, further detailing of the architectural model, such as dimensioning, space finalisation, and material selection. At the end of this stage, a structural model must also be completed. Construction documentation: Design drawings are converted into a detailed set of construction documents that include all of the details needed to communicate the design to a general contractor. Building permit: The construction drawings are submitted to the jurisdiction for approval, along with any additional information required to obtain a building permit. Bidding and negotiating: The tendering process for selecting a contractor takes place at this stage. Construction administration phase: The stakeholders manage the work during the construction administration phase.

1.2 Principles of Building Planning

Building planning is "the methodical arrangement of various building components or pieces to produce a meaningful and consistent structure that serves its functional purpose," according to one definition (Mahajan, 2016). The basic goal of building planning is to arrange all of the structure's components on all floors at a specific level in accordance with their functional needs. This makes it possible to make the most of the building area. Ahuja (2007) outlined 12 planning principles for buildings, including orientation, aspect, prospect, furniture demand, roominess, grouping, circulation, sanitation, elegance, privacy, and adaptability (Ahuja, 2007). To guarantee that the building fulfils its function during the course of its lifespan, the aforementioned twelve planning principles must be taken into account during the building planning stage. These are considered during planning by architects. The literature review made it evident that there had never been any investigation into the potential effects of these principles on the BIM process for any kind of structure.

1.3 Multi Criteria Decision Making (MCDM)

With the use of the multi-criteria decision-making (MCDM) technique, it is possible to compare the merits of numerous options against a wide range of competing qualitative and/or quantitative criteria and arrive at a consensus-required conclusion (Kolios A, Mytilinou V, Lozano-Minguez E, 2016). Since the 1960s, MCDM techniques have been effectively created and applied in a variety of settings. Selecting an option from a list of selected possibilities or a single option that satisfies their requirements and validates their preferences is the aim of MCDM (Khan et al., 2018). AHP (Analytical Hierarchical Process), TOPSIS (Technique for Order of Preference by Similarity to an Ideal Solution), ANP (Analytical Network Process), DEA (Data Envelopment Analysis), and fuzzy decision-making are examples of popular MCDM methodologies. Each of these methods has benefits and drawbacks of its own. The use of MCDM is spreading across several fields and growing every year. It was discovered that researchers either employed the strategies alone or in combination. They also emphasised that TOPSIS-based and AHP-based models were the most widely employed techniques (Tan et al., 2021).

Process of the analytical hierarchy (AHP), Thomas L. Saaty founded it for the first time in the 1970s. It is a decision-making process that is based on linear algebra and uses pairwise comparisons to establish priority scales for challenging criteria and constraints (P.H. Dos Santos, S.M. Neves, D.O. Sant'Anna, C.H. de Oliveira, 2019). Analytic network procedure (ANP), this could be seen as an AHP generalisation. Both approaches use pairwise comparisons to dissect large multidimensional problems and identify trade-off solutions between several selection criteria. However, the decision issue is transformed into a network through ANP. Hybrid MCDM methods, including AHP and TOPSIS, the approach for ranking alternatives based on how far away they are from the ideal answer, known as TOPSIS, was developed. TOPSIS stands for "The Technique for Order Preference by Similarity to an Ideal Solution" (K. Yoon, 1981). Since "TOPSIS can list and identify possibilities in line with the reality scenario, and AHP can systematically weight the decision criteria," we may often discover the AHP-TOPSIS combo in the research. AHP and MAUT: "Multi Attribute Utility Theory (MAUT) is a method" for figuring out a decision-preferences maker's by weighing the utility values of several attributes and criteria in the face of uncertainty (J. Wallenius, J.S. Dyer, P.C. Fishburn, R.E. Steuer, S. Zionts, 2008). Fuzzy and TOPSIS: Fuzzy set theory helps decision-makers solve real-world issues more precisely by converting muddled qualitative or quantitative information into calculable equivalents (S. Nadaban, S. Dzitac, 2016).

Fuzzy and PROMETHEE: Although the "Preference Ranking Organization Method for Enrichment of Evaluations" (PROMETHEE) does not assume that there is a single option that is always the best choice, it does assume that each option has some influence over the others and can therefore influence the best choice

1.4 Section Headings

Building Information Modeling (BIM) has proven to be extremely beneficial to the Architecture, Engineering, and Construction (AEC) industry because it aids in the integration of design and construction. It ensures that building quality is improved while also lowering construction costs and time (Eastman et al., 2011). The "National Building Information Modeling Standard (NBIMS) Committee of the National Institute of Building Sciences (NIBS) Facility Information Council (FIC)" defined BIM as "an improved planning, design, construction, operation, and maintenance process for each facility, new or old, that contains all appropriate information created or gathered about that facility in a format usable by all." (Eastman et al., 2011; VA BIM STANDARD, 2017). After analysing 32 major projects, Stanford University's Center for Integrated Facilities Engineering concluded the following are the main benefits of BIM: Unplanned change could be reduced by up to 40%. When compared to traditional estimates, cost estimation accuracy can be improved to within 3%. The time it takes to generate a cost estimate can be cut by up to 80%. Clash detection has the potential to save up to 10% of the contract value. Additionally, project time can be reduced by up to 7% (Salman Azhar, 2011).

1.5 General Guidelines

Several research studies show that MCDM can significantly help with the digitalization of the AEC industry. The researchers divided the main domains in which MCDM and BIM were used collaboratively into five categories: sustainability, retrofit, supplier selection chain, safety, and constructability (Tan et al., 2021). The research on sustainability had the highest percentage (37.78%) of the five domains. There were a few other instances where the combination was used. Data obtained from Tan et al. (2021) is represented in Table 1, which depicts the main domains, subdomains, and applications in percentage form.

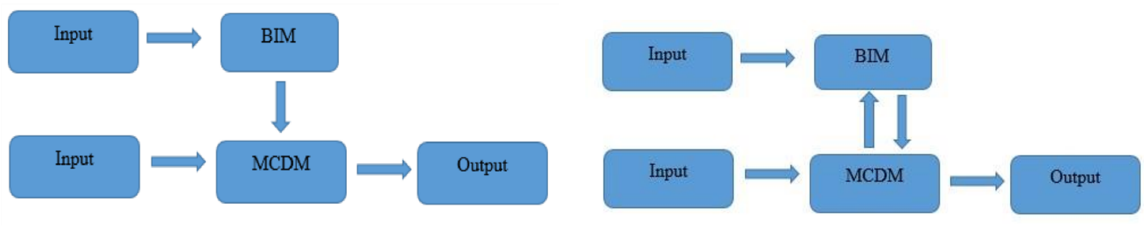
Table 1 - The primary domains of MCDM-BIM application

Domain	Sub domain
Sustainability (37.78%)	Sustainable building Sustainable component selection
Retrofit (15.56%)	Retrofit optioning Redevelopment assessment Compliance checking of retrofit
Supplier selection (9.49%)	Supplier selection
Safety (13.33%)	Evacuation simulation Building health evaluation Fall protection planning Safety pre-warning mechanism Fire risk assessment
Constructability (17.17%)	Constructability assessment Compliance checking Design for manufacture and assembly Value engineering
Others (6.67%)	Cost Construction network Dispute

A fuzzy TOPSIS approach for assessing supplier BIM competence was developed in this study. During the selection process, suppliers were prioritized based on their ability to provide BIM. In this case, the suppliers were consultants, subcontractors, and construction service providers hired to complete projects. Due to the complexity, uncertainty, and ambiguity involved with human decision-makers considering multiple options, the researchers stated that there are several constraints when selecting an MCDM technique. The Delphi technique was used to assign weights to the chosen criteria.

Synergy between MCDM and BIM: Tan et al. (2021) examined the framework used in 45 papers and concluded that BIM and MCDM had two synergetic relationships (Tan et al., 2021): a linear structure and an integrated structure. One-way workflow from BIM to MCDM platforms occurs in linear structures. The input for BIM included various building- or project-related data, whereas the input for MCDM included suggested multi-criteria and attributes of multi-criteria. The linear structure is depicted in Figure 1(a).

An integrated structure, on the other hand, had a two-way interaction. In the beginning, BIM served as a data foundation for MCDM processing, and then MCDM generated results, which were exported back to the BIM platform to present results and store performance evaluation results. The integrated structure is depicted in Figure 1(b). When compared to linear structures, the integrated structure, according to the research team, can properly illustrate how BIM and MCDM interact. However, only a few papers used the integrated structure; instead, they only used BIM as a database function to record the results of the MCDM process. As a result, the focus of this research is on identifying and documenting new design approaches for executing the integrated structure.



(a) (b)

Fig.1 - (a) Linear structure; (b) Integrated structure

1.6 Computational Design Practices in the Construction Industry

Because of advances in computer technology, computational design (CD) approaches have recently become very popular, particularly among architects (Caetano et al., 2020). CD design involves the use of computers. There are numerous approaches to CD, such as parametric design, generative design, and algorithmic design (Caetano et al., 2020). An extensive review of the literature revealed anomalies in the meanings of certain CD-related terminology, which were mostly due to their overlapping scopes. Taking important information from Caetano and Santos' work, the following section discusses three of the most commonly used CD terms: parametric design (PD), generative design (GD), and algorithmic design (AD). Parametric design, The term "parameter" is defined by the Oxford dictionary as "a numerical or other measurable factor forming one of a set that defines a system or sets the conditions of its operation" or "a limit which defines the scope of a particular process or activity." After reviewing numerous papers, the researchers arrived at the following definition of PD: "an approach that describes a design symbolically based on the use of parameters." Most BIM tools follow this approach, which is represented by the concept of a "family" or "object" that specifies groups of building parts.

Generative design, The Cambridge dictionary defines "generative" as "the ability to develop or create anything." According to I. Caetano and L. Santos, 2020, generative design is "a rules-driven iterative design process." Furthermore, GD employs algorithmic and parametric modelling to automatically explore, iterate, and optimise design options by establishing high-level constraints and goals. GD is also described as "a design paradigm that employs more independent algorithmic descriptions than PD." (Caetano et al., 2020) According to the findings of the study, Nagy, D.; Villaggi, 2020, GD uses algorithmic and parametric modelling to automatically explore, iterate, and optimise design options by establishing high-level constraints and goals (Nagy, D.; Villaggi, 2020). Furthermore, the authors argued that GD-based techniques could produce complex results even with simple algorithmic descriptions.

Algorithmic design, An algorithm, according to the Cambridge Dictionary, is "a set of mathematical instructions or rules that will help calculate an answer to a problem." As a result, distinguishing AD from GD becomes difficult. Based on the literature review, it is possible to conclude that the scope of the term AD overlaps with that of PD and GD, resulting in some inconsistencies in the definition of AD. AD, according to Terzidis (2004), is "an approach based on describing computer programmes that generate space and form from the rule-based logic inherent in architectural programmes, typologies, building codes, and language itself." (Terzidis, 2004). After reviewing various literatures, the researchers concluded that AD is "a design paradigm that uses algorithms to generate models" and can be considered generative. According to the above definition, AD is a subset of GD.

2. Research Methodology

As the first step, gather basic project information, such as the scope of work. The functional requirements of the building must be investigated. The site conditions must be thoroughly comprehended. The following step is to construct the various design alternatives. Any project can have multiple options. The ability for all stakeholders to see these alternatives equally in the early stages will ensure that the best decision is made. The 'Design options' feature in Revit software can be used for this purpose. Following the creation of design options or alternatives, the next step is to select the criteria for evaluating the design options based on building planning principles. The weights are then calculated with AHP. An expert (an architect) with sufficient experience will be required to assist in performing a pairwise comparison of criteria for this. As part of the Dynamo script, a questionnaire based on the criteria chosen for ranking alternatives will be created. Experts can be asked to rate each question (1-100). After obtaining the scores, they must be exported to MS Excel for TOPSIS. TOPSIS is used to select the best alternative based on scores. Using Dynamo, the ranking of alternative design options can be exported back to Revit and visualised in various charts. The resulting view can be saved as a proposal. The process can be repeated if any changes are made. The analysis can be repeated and the outcome updated. Once the outcome is determined, the chosen alternative can be designated as "primary," and additional information can be added. The methodology framework for the study is depicted in Figure 2.

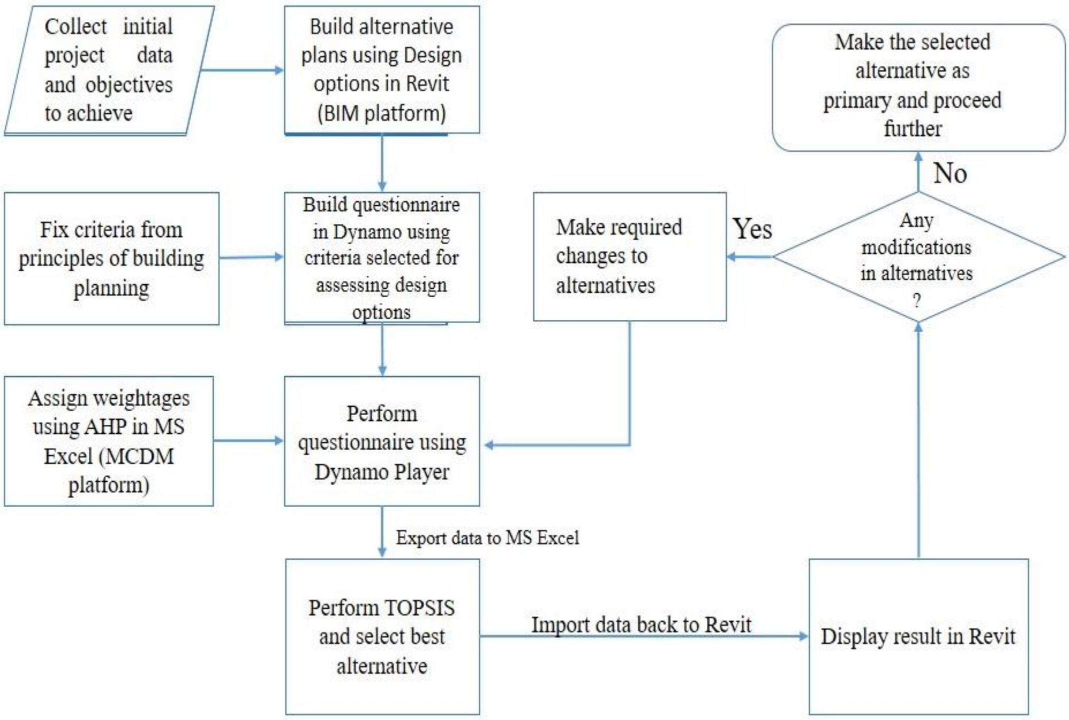
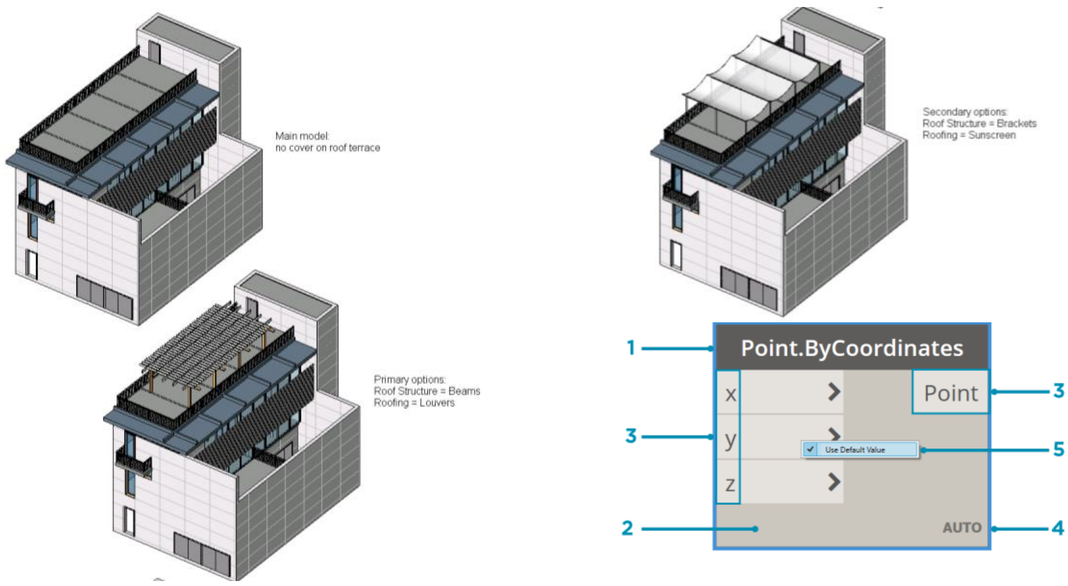


Fig.2 - Methodology framework

2.1 Tools and Techniques Used

Autodesk Revit: Revit software allows architecture, engineering, and construction (AEC) teams to design high-quality buildings and infrastructure. Revit software can be used to model forms, structures, and systems with parametric accuracy, precision, and convenience. Allowing real-time changes to plans, elevations, schedules, and sections as projects progress to streamline documentation work. Interdisciplinary teams are given specialized tool sets as well as a consistent project environment. Autodesk Revit "Design Options": A team can develop, assess, and remodel building components and rooms within a single project file by using design options. The difficulty level of design options varies. A designer, for example, may want to look into different entry designs or roof structural systems. As a result, design options become more focused and streamlined as a project progresses. Figure 3 (a) illustrates how to create design options in Revit.



(a) (b)

Fig. 3 - (a) Example for Design options (*Creating Design Options in Revit*, 2018); (b) Structure of nodes in Dynamo (Jezyk, 2016)

Dynamo: Dynamo is an open-source visual programming language for Revit developed by designers and construction experts. It is a programming language that allows users to enter code in lines and construct algorithms out of nodes. Dynamo can communicate with Revit's expanded BIM capabilities. Dynamo and Revit can work together to model and analyse complex geometries, automate tedious tasks, reduce human error, and export data to Excel and other file types that Revit frequently cannot handle. The design process can be sped up by utilising Dynamo's user-friendly interface and collection of ready-made scripting libraries. Dynamo's node structure The nodes are composed of scripts that perform specific tasks. It could be something as simple as storing a number in a list or something as complex as constructing intricate geometry. Python, a scripting language, is used to write Dynamo's code. Figure 3(b) depicts the Dynamo node structure. Almost all nodes, with a few exceptions, have five major components: name, main body, ports (in and out), lacing icon, and default value.

AHP (Analytic Hierarchy Process): The Analytic Hierarchy Process is a math and psychology-based strategy for organising and evaluating difficult decisions (AHP). It was created in the 1970s by Thomas L. Saaty and has since been improved. It is divided into three sections: the main objective or issue that must be resolved, all practical options, and the criteria used to evaluate the alternatives. By establishing its criteria and alternative alternatives and connecting those elements to the overall goal, AHP provides a solid foundation for a necessary conclusion. Table 2 shows the fundamental scale for comparison purposes, as mentioned by Saaty (1987). The procedure is as follows:

Table 2 - The fundamental scale (Saaty, 1987)

Intensity of Importance on an absolute scale	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance one over another	Experience and judgement strongly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed

Step 1: Create a model.
The first step is to define the problem and create a model by deciding which alternatives to compare and which criteria to evaluate.
For the sake of illustration, consider selecting the best project out of three options.
The evaluation criteria are denoted by the letters X1, X2, X3, and X4. Figure 4 shows how the model can be visualised.

Step 2: Perform pairwise comparisons using the previously mentioned fundamental scale. An example of such a pairwise comparison matrix is shown in Table 3.
It is necessary to check whether or not the pairwise comparison matrix is consistent.
As a result, the procedure follows. $[X_N]$ represents the geometric mean of each row in a pairwise comparison matrix.

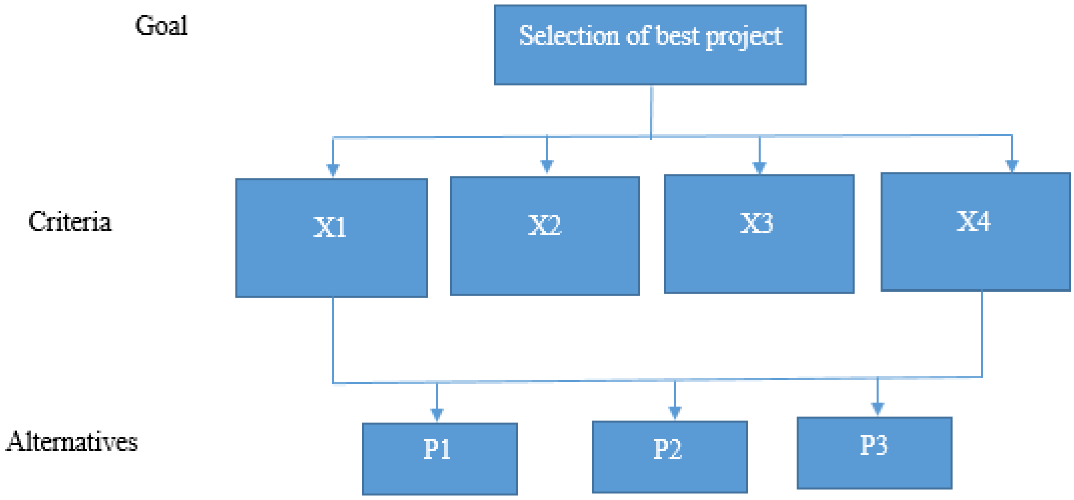


Fig. 4 - The model's visual representation

$[X_1]= (1* 1/7* 1/5* 1/3)^{1/4} = 0.31239$
$[X_2]= (7* 1* 2* 3)^{1/4} = 2.5457$
$[X_3]= (5* 1/2* 1* 3)^{1/4} = 1.6549$
$[X_4]= (3* 1/3* 1/3* 1)^{1/4} = 0.75984$
Sum (S) = $\sum [X_N] = 5.2728$
Weightage of X_N (included in A2 matrix), represented by $W_{Xn}= [X_N] / (S)$.Therefore,
$W_{X1}= 0.059246$
$W_{X2}= 0.4828$
$W_{X3}= 0.31385$
$W_{X4}= 0.144$

Step 3: Verify consistency. By computing the consistency ratio, AHP offers the benefit of determining whether the weights acquired are consistent or not.To do this, the computation shown below must be done:

$$\text{Matrix, A3 = A1 x A2} = \begin{bmatrix} 1 & \frac{1}{7} & \frac{1}{5} & \frac{1}{3} \\ 7 & 1 & 2 & 3 \\ 5 & \frac{1}{2} & 1 & 3 \\ 3 & \frac{1}{3} & \frac{1}{3} & 1 \end{bmatrix} \times \begin{bmatrix} 0.059246 \\ 0.4828 \\ 0.31385 \\ 0.1441 \end{bmatrix} = \begin{bmatrix} 0.23902 \\ 1.9575 \\ 1.2838 \\ 0.58739 \end{bmatrix}$$

$$A4 = \frac{A3}{A2} = \begin{bmatrix} 0.23902 \\ 1.9575 \\ 1.2838 \\ 0.58739 \end{bmatrix} / \begin{bmatrix} 0.059246 \\ 0.4828 \\ 0.31385 \\ 0.1441 \end{bmatrix} = \begin{bmatrix} 4.0344 \\ 4.0545 \\ 4.0905 \\ 4.0762 \end{bmatrix}$$

Measurement of Inconsistency: Equation represents the consistency index, or CI

$$Consisency\ Index = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

where λ_{max} represents the A4 matrix's average value and "n" represents the number of criteria.
For the given case, λ_{max} = 4.0639 and n =4.
Hence, $Consistency\ Index,\ CI = \frac{4.0639-4}{4-1}$ = 0.0213
After calculating CI, the consistency ratio, CR, is calculated using eqn.

$$CR = \frac{Consistency\ Index}{Random\ Index} \quad (2)$$

The Random Index, or RI, is the average of the CI. values from comparison matrices of various sizes Table 4 depicts the RI for the various n values given in Table 3. As a result, CR = 0.02393. The consistency ratio should be less than 0.1 for the pairwise comparison to be satisfactory. The value for the given case is less than 0.1, so the weights obtained in the A2 matrix can be accepted.

Table 3 - Pairwise comparison matrix

	X1	X2	X3	X4
X1	1	1/7	1/5	1/3
X2	7	1	2	3
X3	5	1/2	1	3
X4	3	1/3	1/3	1

Table 4 - Random index

Attributes	3	4	5	6	7	8	9	10
RI	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

TOPSIS: It is a multi-criteria decision-making process invented in the 1980s. The alternative with the shortest Euclidean distance from the ideal solution and the greatest distance from the negative ideal solution is chosen by this method. The theoretical portion of the step-by-step procedure is described further below.

Step 1: Scores are assigned to alternatives based on various criteria.
Let alternative, a= 1, 2, 3,…. n. Criteria, i = 1,2,3….m. Decision matrix, X= (x_{ai})

Step 2: The performance scores are normalised.
The criteria chosen may be based on various units. There is also a chance that the scores assigned will be on different scales or ranges. As a result, it is necessary to normalise the matrix before proceeding with the calculations. This is accomplished by dividing the scores by the square root of the sum of each squared element in a column (the criterion), as represented by equation (3).

$$r_{ai} = \frac{x_{ai}}{\sqrt{\sum_{a=1}^{n} x_{ai}^2}}, \text{where } a = 1,2,\ldots,n \text{ and } i = 1,2,\ldots,m \quad (3)$$

Step 3: Create a weighted normalised decision matrix.
Normalised scores must be multiplied by the weight assigned to each criterion. Weightage can be calculated using a variety of methods, including AHP. Assume that the criteria weights Wxi are normalised scores rai. The weighted scores obtained shall be given by equation (4).

$$v_{ai} = w_{xi} * r_{ai} \quad (4)$$

Step 4: Determine the distances between ideal and non-ideal locations.
Using the weighted normalised score from the previous stage, each alternative is compared to the virtual ideal and anti-ideal alternatives.
Using the highest ratings for each criterion, create a virtual ideal alternative (v_n+).
If you want to maximise criterion i use Max (v_{ai}). If you want to minimise criterion i, use Min (v_{ai}).
Using the lowest ratings for each criterion, create a virtual anti-ideal alternative (v_n-).
If you want to maximise criterion i use Min (v_{ai}). If you want to minimise criterion i, use Max (v_{ai}).
For each alternative, the Euclidian distance between ideal (Sn+) and anti-ideal (S_n-) points must be calculated. Equation (5) gives the formula for distance from the ideal point (S_n+).

$$s_n^+ = \sqrt{\sum (v_{bi} - v_{ai})}, where\ a = 1,2,..,m\ and\ i = 1,2,\dots,n \quad (5)$$

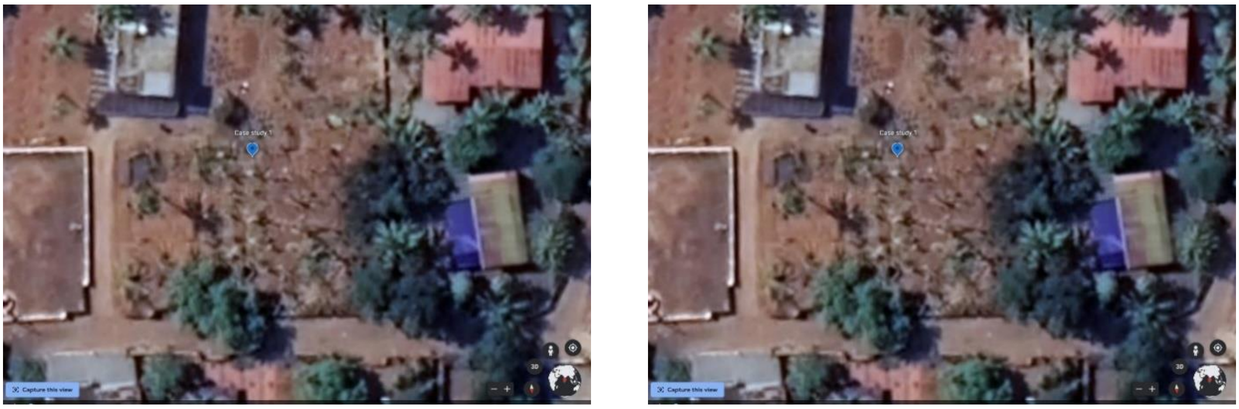
Step 5: Determine the closeness ratio for each alternative.
The equation (6) can be used to calculate the closeness ratio. The closeness ratio ranges from 0 to 1. Among the alternatives, the one with the highest value is the best.

$$p_i = \frac{s_n^-}{s_n^+ + s_n^-} \quad (6)$$

Two projects were chosen to validate the aforementioned methodology. The first project was in "predesign," while the second was in "operation and maintenance."

3. Experimental Program

This research entails creating various design alternatives and selecting the best design options. Two case study buildings were chosen to obtain this. Case study project 1 (8.9172773° Latitude and 76.6369787° Longitude) is currently in the design phase, with only the ground floor finalised and various design alternatives considered. Case study project 2 (8.9159834° Latitude and 76.6378281° Longitude) is a G+1 building with the requirement of an additional bedroom on the first floor, for which different design alternatives were considered.



(a) (b)

Fig. 5 - Location – satellite image (a) Case study 1; (b) Case study 2

Case Study Project 1&2 is described in Table 5, and Figure 5 depicts the location (satellite image) for (a) Case Study 1 and (b) Case Study 2. Following an examination of the site layout, topography, and client requirements, three different design alternatives were created within a single ".rvt" file using Revit's "Design options" feature. In that order, the options were dubbed "Model 1," "Model 2," and "Model 3." The setbacks from the plot line were determined in accordance with the Kerala Municipal Building Rules (KMBR) (Government of Kerala, 2019).

As a result, the following constraints were shared by all three proposed plans: 3 m front setback, 1 m side offset, 1.5 m rear end. 147 m^2 total floor area (140 m^2). Three proposed models were developed using the aforementioned constraints. Figure 6 (a) depicts the floor plans of the Model 1, Model 2, and Model 3

(a)

(b)

Fig. 6 - Design options of (a) Case study 1 - Ground Floor plan of Model 1, Model 2 and Model 3; (b) Case study 2 - First floor plan of Option 1, Option2 and Option 3

With the assistance of an expert, four of the twelve building planning principles were chosen to best fit the existing case study: aspect, prospect, grouping, and flexibility. The experts have ten years of combined experience in architecture and planning. The weights were calculated, and the consistency ratio was calculated. If the consistency ratio is less than 0.1, the weight obtained may be acceptable. After a few trials, the weights were fixed because the consistency ratio obtained was 0.0381, which was within the acceptable range. The following are the criteria and their weights: Aspect is 0.5465, Prospect is 0.2335, Grouping is 0.1313 and Flexibility is 0.0887.

Table 5 - Base details regarding case study 1 & 2

	Case Study 1	Case study 2
Type of building	Residential house (Single storey)	Residential house (G+1)
Location	Karicode, Kerala	Karicode, Kerala
Coordinates	8.9172773 ^{o} Latitude & 76.6369787 ^{o} Longitude	8.9159834^{o}Latitude & 76.6378281^{o} Longitude

Client	Asif Alam	Nizam
Budgeted cost	2.4 Million Rupees	
Area of plot	283.22 m^2	323.74851 m^2 (108.89 m^2 existed floor area)

As part of the Dynamo script, a questionnaire was created for each of the three developed alternatives to assign a score based on selected criteria. Figure 7 depicts the Dynamo script for Case Study 1. The following describes how to use the Dynamo script: The set of nodes was created to collect expert scores via Dynamo Player. This group organises the individual numerical scores into a matrix format for use in MS Excel. This node group exports the data from the previous step into the specified MS Excel file's required cells. TOPSIS will be performed using the data transferred. When the process is finished, the MS Excel sheet will contain information about ranking in the specified order. When the ranking is finished, this node will return the ranking data to Revit. This set of nodes (from the "Data shapes" package) will display the results as a bar chart, with alternative names on the x-axis and rankings on the y-axis.

The number sliders that will contain the scores must be labelled as "inputs" while building the script in order to be displayed in Dynamo Player. BIM has the advantage of allowing for precise visualisation and comparison of alternatives. The "camera view" option, for example, can precisely produce the view from the entrance of all three options. When considering privacy, this aids in comparing alternatives. This can also aid in visualising the exterior view through doors and windows (prospect). Wherever possible, the expert was provided with adequate information to aid in scoring. Following that, as shown in Figure 8, the expert-assisted questionnaire was run in "Dynamo Player" to obtain the scores. After entering the scores and running the programme in Dynamo player, the data was exported to predefined cells in MS Excel and the analysis was performed using TOPSIS. Figure 9 depicts the computations used to rank the models.

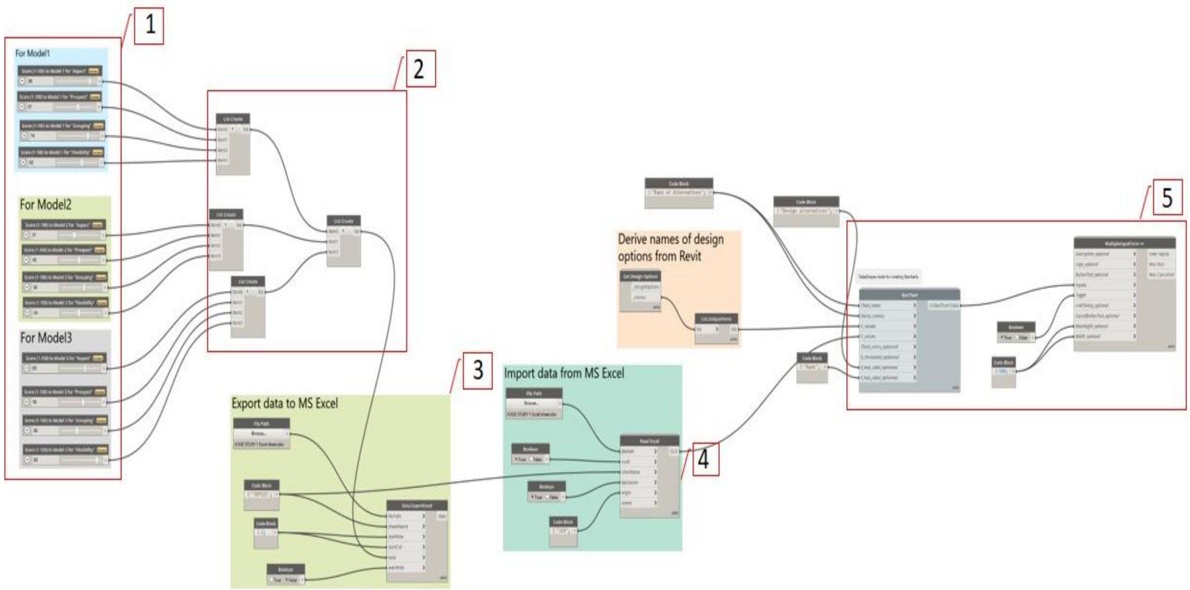


Fig. 7 - Dynamo script for case study 1

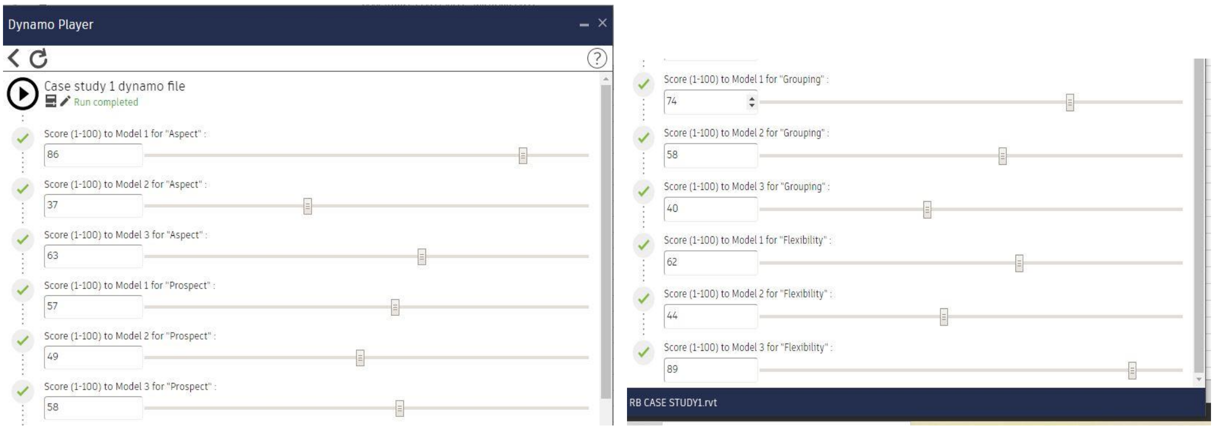


Fig. 8 - Allotment of scores to alternatives

	A	B	C	D	E	F	G	H	I	J
1			Aspect	Prospect	Grouping	Flexibility				
2		Wxn	0.546	0.233	0.131	0.089		TOPSIS for Case study 1		
3		Model1	86	57	74	62				
4		Model2	37	49	58	44				
5		Model3	63	58	40	89				
6										
7										
8			Calculation of Normalized matrix rai							
9			Aspect	Prospect	Grouping	Flexibility				
10		Wxn	0.546	0.233	0.131	0.089				
11		Model1	0.762107	0.600365986	0.72423827	0.529682417				
12		Model2	0.327883	0.516104093	0.56764621	0.375903651				
13		Model3	0.558288	0.610898722	0.39148015	0.760350566				
14										
15										
16			Calculate weighted normalized matrix Vai							
17			Aspect	Prospect	Grouping	Flexibility	Si+	Si-	Pi	Rank
18		Wxn	0.546	0.233	0.131	0.089				
19		Model1	0.41611	0.139885275	0.09487521	0.047141735	0.020676	0.242245	0.921362	1
20		Model2	0.179024	0.120252254	0.07436165	0.033455425	0.241432	0.023078	0.087247	3
21		Model3	0.304825	0.142339402	0.0512839	0.0676712	0.119518	0.132229	0.525244	2
22										
23			Calculate ideal best and ideal worst value							
24		V+	0.41611	0.142339402	0.09487521	0.0676712				
25		V-	0.179024	0.120252254	0.0512839	0.033455425				

Fig. 9 - Computation of rank using TOPSIS

Similarly, three different layouts were proposed for case study project 2 as "Option 1," "Option 2," and "Option 3," with the best one chosen. The floor plans for Options 1, 2, and 3 are shown in Figure 6 (b). By relocating the bedroom to the northwest, Option 1 increased its size by 14.07 m^2. Option 2 includes an additional room and toilet on the ground floor, next to bedroom #1. This makes structural and other detailing easier. Furthermore, the proposed common hall can be used for a variety of purposes, making it a more versatile option. Option 3 adds a new toilet room to the north-east side. This adds 13.193 m^2 to the available floor space.

The weights assigned to the four building planning principles of aspect, prospect, flexibility, and elegance were 0.5450, 0.2328, 0.1385, and 0.0837, respectively. The questionnaire was built as part of the Dynamo script for the evaluation of three alternatives in Dynamo Player, as shown in Figure 10. Dynamo Player was used to assign scores to all of the options. The Dynamo player's collected scores were processed in an Excel spreadsheet using the TOPSIS method, and the final ranking of the alternative options was extracted. Figure 15 depicts the TOPSIS ranking of alternatives.

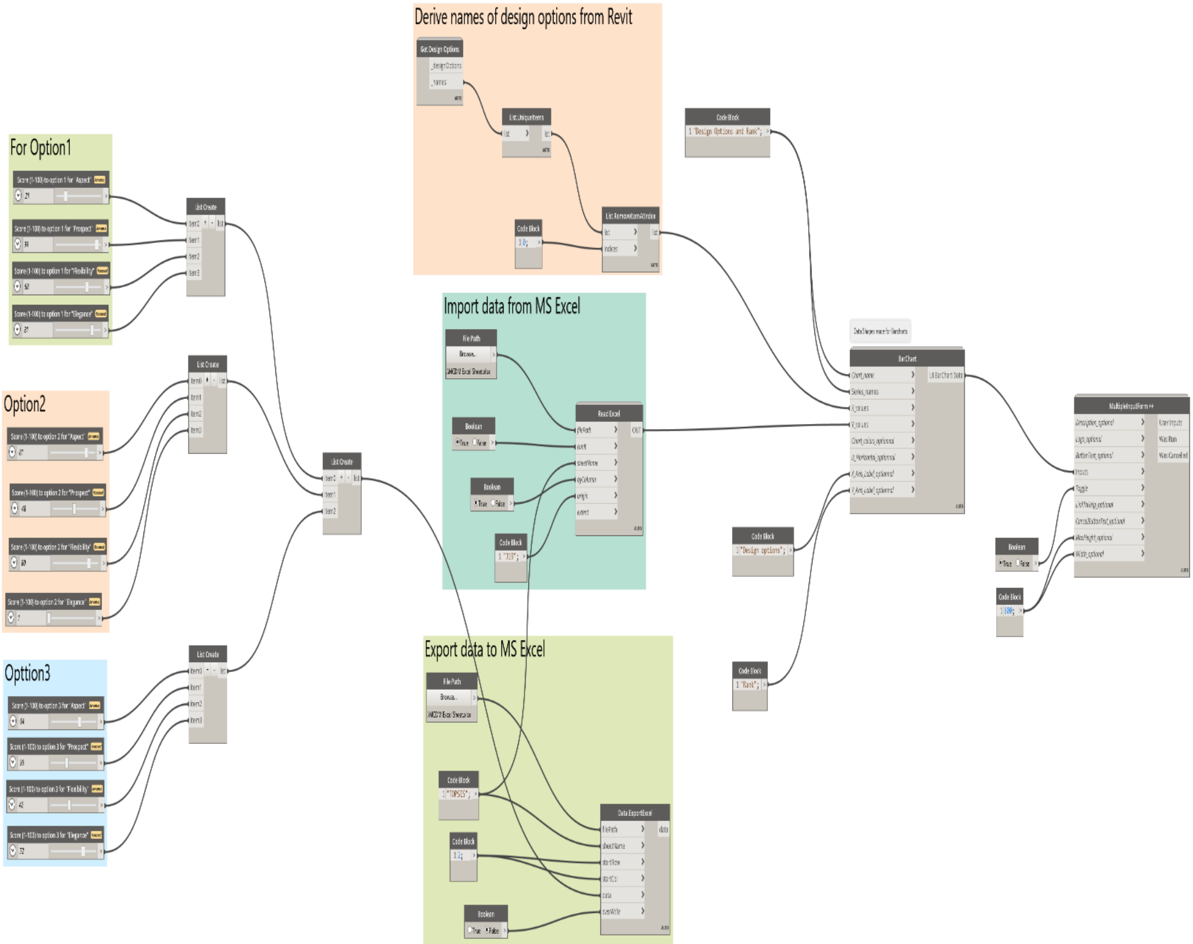


Fig. 10 - Dynamo script

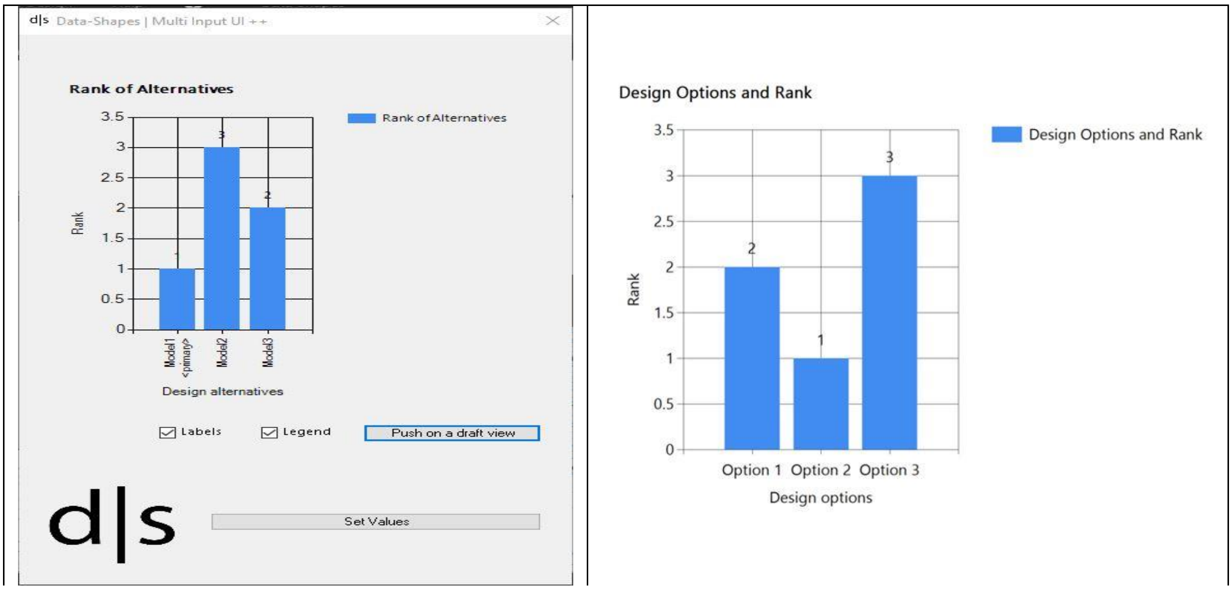
4. Result and Discussion

4.1 Case Study 1

In the Dynamo script, the Data Shapes node was used to import the required data from MS Excel back to Revit in the form of a bar chart. Model 1 was chosen as the best alternative among the three models for the current study, and it is ranked first, followed by Model 3 and Model 2, which are ranked second and third, respectively. Figure 11 (a) shows the output displayed as a pop-up window in Revit after the script is successfully run. The outcome was communicated to the client, and the proposed alternative was chosen for further detailing and development.

4.2 Case Study 2

In the second case study, option 2 was ranked first, followed by option 1, and option 3 was ranked second and third, respectively. The script was successfully run, and the output is shown in Figure 11 (b). The client was informed of the outcome and agreed to proceed with it. The two case studies indicate that the proposed methodology was successful in selecting the optimal floor plan when multiple criteria were required to be considered.



(a) (b)

Fig. 11 - Ranking of alternatives for (a) case study 1 &; (b) Case study 2

The principles of building planning take into account all factors when determining a floor plan and thus provide proper guidance in arriving at the best solution. In addition, the "Design Option" in Revit aided in the conduct of this research and served as an important component of the methodology framework. Integration of MCDM and BIM aids in working with large amounts of data when computation must be automated and decisions must be made quickly but accurately and reasonably. The research work demonstrated that it is possible to combine MCDM and BIM for optimal building planning. Another important conclusion from this study is that the computational design tool can be extremely useful when data transfer between Revit and other platforms is required. According to the research of Abrishami et al. (Abrishami et al., 2021), the use of computational design during the early conceptual stage is extremely beneficial.

Students, researchers, and practitioners were polled via questionnaire. A question was asked about integrating BIM and computational design to overcome challenges during the early design stage and in designing complicated shapes. 32% said they were unsure, 2.6% said no, and 65.4% said yes. This confirms that the computational method will be extremely useful in modelling future buildings with complicated designs that require accuracy and precision.

5. Conclusion

As part of this research, a methodology for determining the best design alternative using BIM and MCDM techniques was developed. The BIM platform was Revit, and the MCDM method was a combination of AHP and TOPSIS that best fit the objectives to be achieved. A medium was required to act as a link between Revit and MS Excel in order for an integrated synergy to occur (the MCDM platform). Dynamo, a computational design tool, was used for this purpose.

The models were ranked, and the data was exported to Revit. Two case study buildings in various stages of construction are used to test the proposed solution. Following the analysis, "Model 1" was chosen as the best alternative among three models of case study building 1. It was discovered that "option 2" was chosen as the best alternative among the three options of case study building 2. It was discovered that 65.4% of stakeholders are aware of the use of BIM and computational design to help overcome early design stage challenges, while 32% are unaware. Designers, particularly structural engineers, use a variety of design alternatives to achieve a sustainable design. However, combining BIM and MCDM will help to make the sustainable mantra a reality, particularly in terms of design that saves energy.

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