IMPLEMENTATION OF BUILDING INFORMATION MODELING BIM FOR ECONOMIC SUSTAINABLE CONSTRUCTION MINIMIZING MATERIAL WASTE IN TERMS OF VALUE ENGINEERING

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ABSTRACT: *The construction industry consumes a large amount of raw materials and produces large amounts of carbon dioxide emissions. However, studies have shown that philosophies alone are not efficient in solving problems in the construction industry. They must be supported by new tools and methodologies. Therefore, this study aimed to achieve a more sustainable building field by integrating BIM technology and value engineering principles in the management of building materials. to achieve the highest possible consumption of environmental resources and materials through value engineering. The methodology employed in this study was to develop a material waste management system for construction projects. Starting in the early design phase, develop a decision-making process for selecting the optimum floor tile size according to room dimensions. Some materials, such as floor tiles, wooden panels, and marble, can be used more efficiently using BIM and scheduling tools. Floor tiles are essential finishing materials in the AEC industry. The initial findings outline the benefits that can be obtained by using BIM tools to achieve waste minimization through value engineering principles by creating an automation process to choose the best floor tile size according to the space width and length and minimize the percentage of cut tiles to the total number of tiles that are used in the space. This provides a game-changing solution for construction stakeholders.*

KEYWORDS: *Building Information Modeling, Value Engineering, Sustainable Construction, Material Management, Construction Site Management, Architectural Engineering and Construction.*

1. INTRODUCTION

The construction industry is a critical sector in terms of economic sustainability. This enhances economic growth because it affects other economic areas. Appropriate building material selection and recommended construction details significantly affect the project cost. Moreover, their consumption value is approximately 40% of a project's total cost [3]. The designer ensures that the materials used in the proposed design are chosen accurately.

Floor tiles are major building materials widely used in the Architectural, Engineering, and Construction (AEC) industry. Moreover, it is used in every project with different materials and sizes. is also an essential material in architectural decoration, and its annual consumption worldwide has reached billions of square meters. For example, ceramic tiles, a type of floor tile, require high-temperature firing in factories to produce them, resulting in high energy consumption and significant pollutant emissions., thereby posing a serious threat to human health. The annual consumption of ceramic tiles reached 13 billion square meters by 2020, and more than half were used as floor tiles [6,7]. Improving the efficiency of floor tile application plays a critical role in promoting sustainable development in the AEC industry. Previous studies have shown that improving accuracy, effectiveness, and comprehensiveness may be an effective way to improve project benefits from the design perspective [6].

Compared with refined design, the waste rate difference of building materials caused by different design approaches can be as high as 41% in general architectural construction, and the difference in construction labor resource waste (e.g., rework) also shows a positive correlation [8].

In the architectural project, the architects chose the floor tiles according to the color and design, regardless of the size of the tiles and the wastage of cut tiles. Taking into consideration that Most tile producers and suppliers have different sizes for tiles of the same design and color. In theory, layout design requires architects to accurately plan the laying and cutting of materials. The design should include uncut and cut tiles and provide accurate graphics and figures for the following steps to achieve lean material management [9].

Referee List (DOI: 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Aya Ali Shihata, Mohamed Anwar Fekry, Wessam Hamdy Abbas, *Implementation of Building Information Modeling (BIM) for Economic Sustainable Construction Minimizing Material Waste in Terms of Value Engineering,* pp. 1033-1041, DOI 10.36253/979-12-215-0289-3.103

Therefore, the main objectives of this study were as follows:

- To optimize the waste of floor tiles in construction projects from the early design phase.
- Choose the best flooring tile size for the room dimensions to minimize the waste ratio of the flooring tiles.
- Create a practical method for selecting the optimum floor tiles.
- To reduce the time required for technical office engineers in the takeoff process.

The optimization process is performed through the integration of the Value Engineering (VE) principles with Building Information Management (BIM) as a tool to input the data and the dimension of the space as parameters, input the different optional sizes of floor tiles, and apply the VE principles and equations.

1.1 BIM and VE integration approach

A project's success and higher market value (fulfilling the owner's specifications) depend on controlling the construction schedule and costs. To reduce the overall costs, stakeholders have increasingly been used in construction projects. The early project phase offers a great opportunity to use BIM to streamline VE. A bibliometric analysis was performed by Baarimah et al. in 2022 to determine the benefits of combining BIM and VE. The findings demonstrate that VE and BIM support rising prominence as mainstream subjects related to the building industry and decision-making around cost-earned value. The evaluation of generated alternatives using predetermined criteria is the most important stage in VE applications. Stakeholders can use multi-attribute criteria to integrate created models by designing an automated method to assess and contrast these options.

1.2 Value Engineering (VE).

Value Engineering (VE) is a proven management approach in the (AEC) industry that is used to improve the functioning of projects and eliminate unnecessary costs. Because the construction industry has faced various challenges in reaching a project's high value on time and within budget, VE has been applied in numerous countries around the world for half a century [9]. VE has become an integral part of the development of many projects' development [10]. Surveys have reported that VE can save as much as 5–10% of construction project costs [11].

The VE study procedure called the VE job plan, is a systematic problem-solving technique comprising the following phases: information, function, creativity, evaluation, development, and implementation. Among these phases, the creativity phase, followed by function analysis, is the most crucial for generating innovative ideas that require existing information and experiential knowledge from past VE projects [12].

Value = Function + Quality/ Cost

Where:

Function = The specific work that a design/item must perform, which must be the same for all the options of floor tiles

Quality = owner’s need, which is the percentage of cut tiles.

Cost = life cycle cost of the product. Moreover, the additional cost of the wastage of the materials

Assuming that the materials are compared, they have the same quality of manufacturing with the same design, color, and materials of different sizes, for example, the same ceramic tile with different sizes only. In this case, the tiles have the same function and quality.

1.3 The current approaches to selectin floor tiles

In most cases, architects choose floor tiles in the conceptual phase of the design by focusing on the type, color, and texture based on design principles, without paying attention to the importance of the floor tile size in the waste management process in the early decision-making stage of the project. Subsequently, shop drawings were drawn without providing the exact tile requirements. Therefore, quantity surveyor engineers estimate the exact number of floor tiles, including uncut and cut tiles manually from shop drawings, which requires considerable effort and time.

For these procedures, it is difficult to produce a different shop drawing for each floor tile option to estimate the number of floor tiles with cut and uncut tiles, and to have a waste ratio to be able to choose the best floor tile size for each space.

As shown in Table 1, for two rooms with the same area and different dimensions, the default most commonly used ceramic floor tiles are 60 × 60 cm. There were different numbers of tiles used in the two rooms.

- The waste ratio for Room 1 was 14% and the total number of tiles used was 30.
- The waste ratio for Room 2 was 14% and the total number of tiles used was 40.

As shown in Fig. 1, the flooring tile layout plan for the default selection is 60x60 cm. There is a clear-cut tile in the two rooms, which can be avoided by using right-floor tiles.

Table 1: Parameters of default selection size.

	Area.	Length.	Width.	Long Ratio.	Total tiles.	Uncut Tiles.	Cut Tiles.	Waste Rate.
Room 1	120000cm2	400cm	300cm	1.3	35	30	5	14%
Room 2	120000cm2	600cm	200cm	3	40	30	10	25%

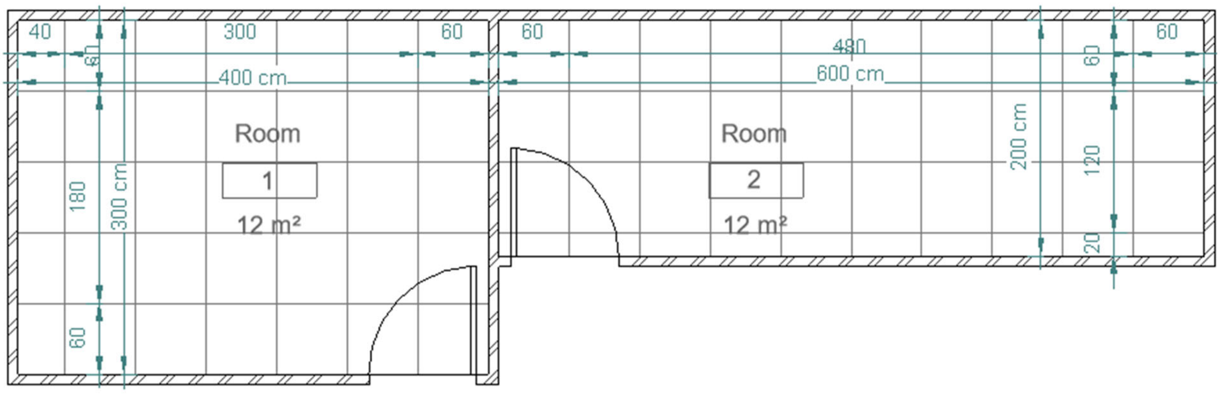

Fig. 1: Flooring tile layout plan for the default selection

2. RESEARCH METHODOLOGY

The purpose of this study is to develop material waste management for construction projects. Starting in the early design phase, develop a decision-making process for selecting the optimum floor tile size according to room dimensions.

As shown in Fig. 2, using a case study plan, this study focused on providing an automation framework according to the BIM model integrated with the VE job plan. The methodology focused on creating decision-making tools depending on the VE. The integration of the VE job plan and BIM into the framework through the optimization of the quantity of waste by applying the VE job plan through BIM tools to reach the optimum value by increasing the quality of the tile floor plan by decreasing the number of cut tiles to have as much space as possible with non-cut tiles, which is very visually comfortable, and decreasing the cost by choosing the optimum size of the tiles.

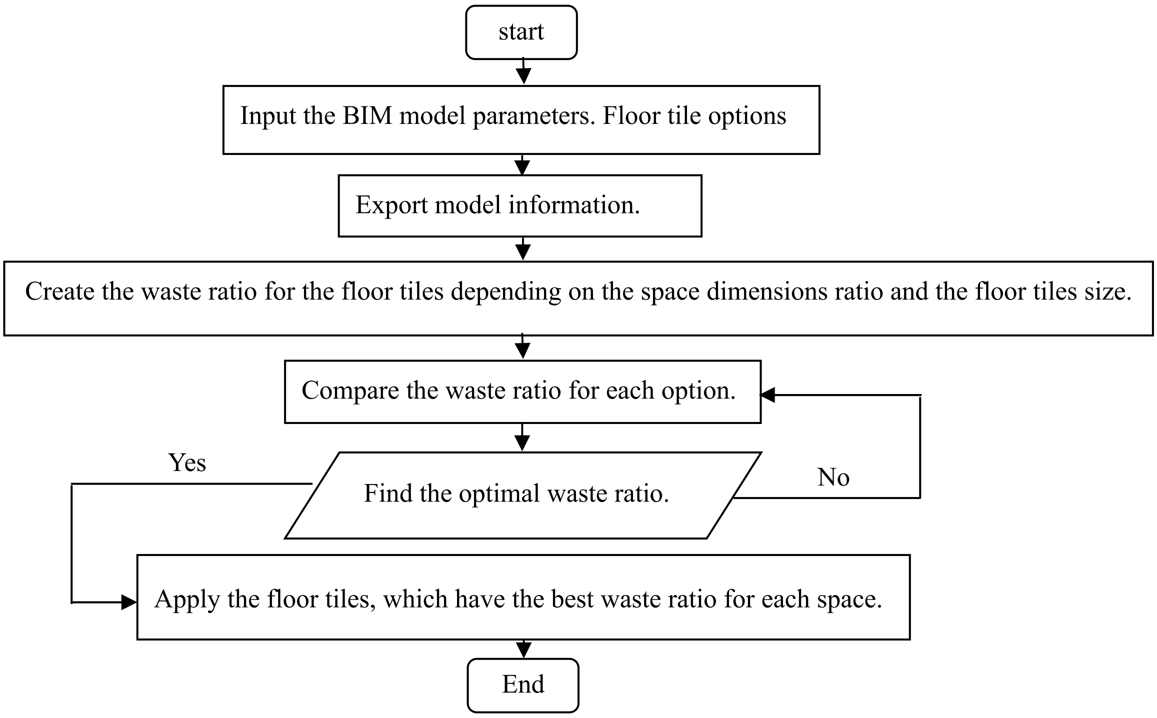

Fig. 2: The flowchart of the design decision-making tool

As shown in Fig. 3, the integration between the VE job plan and BIM optimization framework phase inputs the main parameters required for the floors.

- Function analysis: All the floors that were selected in the process must meet all the function requirements.
- Creativity Phase: Alternative sizer selection options.
- Evaluation phase: start to comprise the alternatives which had been chosen to meet the best quality and assess the risk for each option.
- Development Phase: Finalize the cost and schedule impacts.
- Implementation Phase: Initiate applying the optimum selection choice per quality and cost.

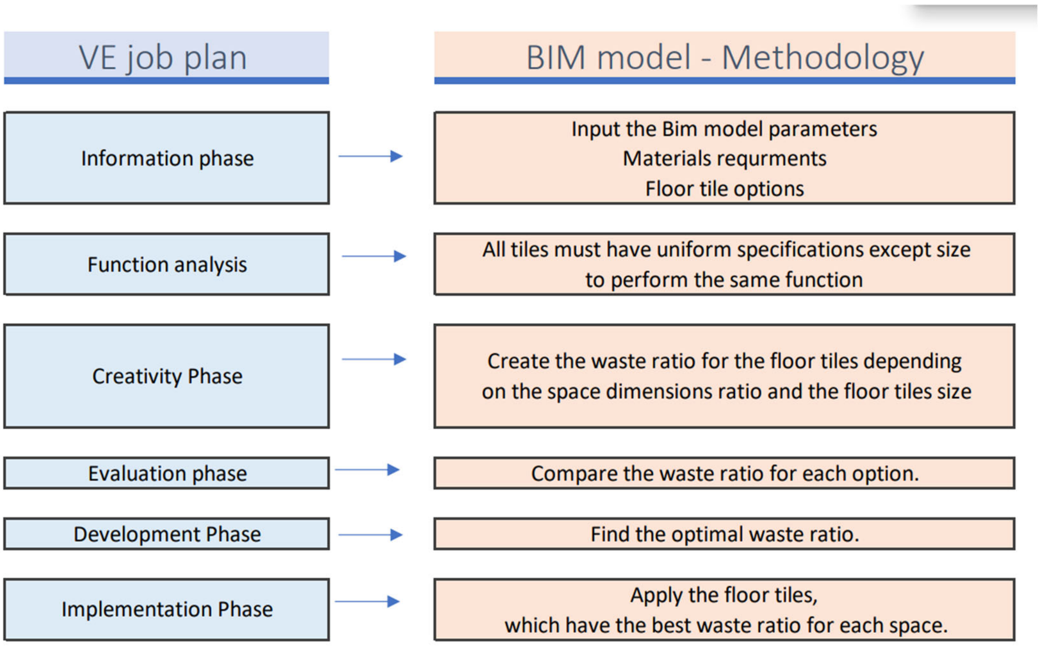

Fig. 3: The integration of the VE job plan and BIM into the optimization framework

3. CASE STUDY

Starting phase: Building the BIM model and inserting the floor tile options as parameters for each room, including the length, width, and dimensions of each floor tile option for each space in the model.

Fig. 4 shows a case study of two different rooms with the same area and different dimensions.

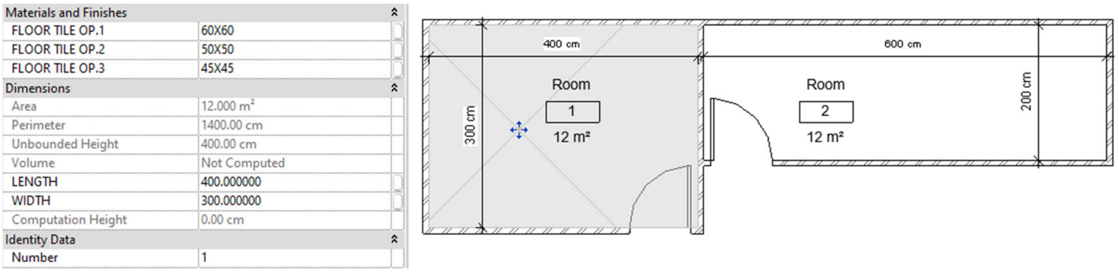

Fig. 4: the model instant parameter for each space

The next step is to create a Revit schedule for the instant parameter for each space, including the area of the room, length, width, and floor tile options. As shown in Fig. 5.

<FLOOR TILES OPTIONS>						
A	B	C	D	E	F	G
Name	Area	LR	WR	FLOOR TILE OP.1	FLOOR TILE OP.2	FLOOR TILE OP.3
Room1	12 m²	600	200	60X60	50X50	45X45
Room2	12 m²	400	300	60X60	50X50	45X45

Fig. 5: the model instant parameter for each space

Then export the Bim model schedule to an Excel sheet to apply the equations for each floor tile option, including the total tiles, uncut tiles, cuts tiles, and waste ratio.

The waste ratio was calculated according to the dimensions of the space and optional tiles, as shown in Fig. 6.

	A	B	C	E	F	H	I	J	K	L	M	O	P	Q	R
1		TILE SIZE		ROOM DIMENTIONS		TILES IN X DIMENTION			TILES IN Y DIMENTION			TOTAL TILES	UNCUT TILES	CUTS TILES	WASTE RATIO
2		LT=LENGTH OF TILE	WT=WIDTH OF TILE	LR=LENGTH OF ROOM	WR=WIDTH OF ROOM	UNCUT TILES	LR/LT	TOTAL TILES	UNCUT TILES	WR/WT	TOTAL TILES				
3		60	60	600	200	10	10	10	3	3.33333	4	40	30	10	25.00%
4	ROOM 1	50	50	600	200	12	12	12	4	4	4	48	48	0	0.00%
5		45	45	600	200	13	13.333333	14	4	4.44444	5	70	52	18	25.71%
6		60	60	400	300	6	6.6666667	7	5	5	5	35	30	5	14.29%
7	ROOM 2	50	50	400	300	8	8	8	6	6	6	48	48	0	0.00%
8		45	45	400	300	8	8.8888889	9	6	6.66667	7	63	48	15	23.81%

Fig. 6: the Excel sheet of the waste Ratio

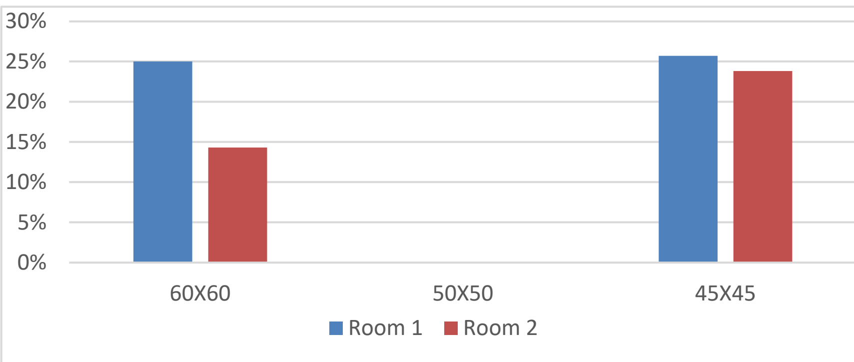

Fig. 7: Chart of waste ratio.

The schedule shows the results of the optional floor tiles, and the schedule shows the results for each space.

- The room 600 × 200 cm shows the following: the waste ratio of the tiling 60 × 60 cm is 25%, the waste ratio of the tiling, the waste ratio of the tiling 45 × 45 cm is 25.71%, and the best ratio is 0% for the flooring tiles 50 × 50.
- The room 400x300cm shows the following: the waste ratio of the tiling 60x60 cm is 14.29%, the waste ratio of the tiling, the waste ratio of the tiling 45x45 cm is 23.81%, and the best ratio is 0% for the flooring tiles 50x50.

Therefore, the optimum selection of the floor tile for the two rooms according to the design approach is 50 × 50 cm, as shown in the chart in Fig. 7.

The next step is importing the sheet excel into Revit using a dynamo script. The minimum waste ratio values were selected. Then, the selected floor tiles were applied to each space.

4. RESULTS AND DISCUSSION

The proposed workflow and decision-making tool for choosing floor tile size by integrating BIM techniques and VE principles generates the waste ratio for alternative floor-tiling sizes.

Rooms 1 and 2 have the same area (12 m2), but different widths and heights, which is used as an example of the current approach to floor tiles. After applying the research methodology and selecting the minimum waste ratio of the floor tile options, the waste ratios for Room 1 and Room 2 were reduced from 14% to 0% and from 25% to 0%, respectively. The total number of cut tiles and unused tiles is clarified in Table 2.

Table 2: Comparison between the default design approach and the optimized selection

	The original design				The optimized selection			
	Total tiles.	Uncut Tiles.	Cut Tiles.	Waste Rate.	Total tiles.	Uncut Tiles.	Cut Tiles.	Waste Rate.
Room 1	35	30	5	14%	48	48	0	0%
Room 2	40	30	10	25%	48	48	0	0%

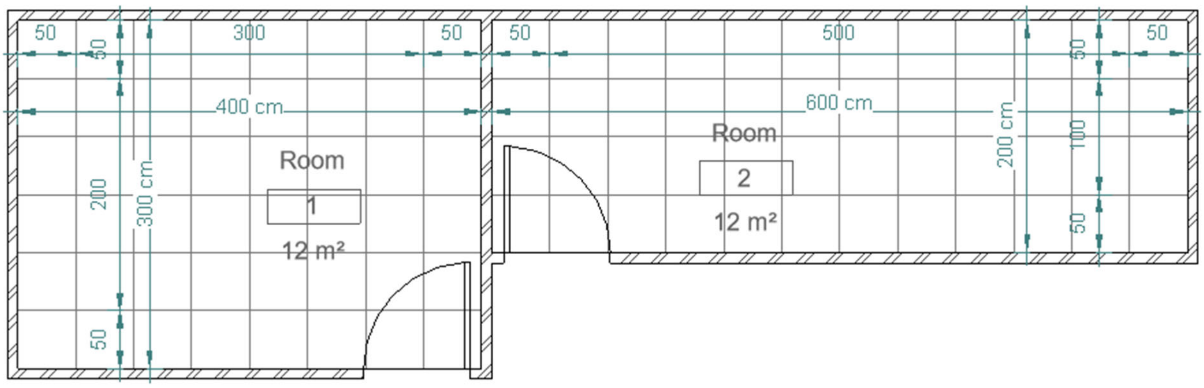

Table 2: Comparison between the default design approach and the optimized selection

As shown in Fig. 8, the floor tiling plan of the two spaces with the size of the selected tiles has a clear number of tiles with no cut tiles as a result of the proposed workflow, which is the optimum design of any space to have clear tiles with no cut tiles for multiple vectors, such as visual design-wise, sustainable to reduced waste ratio, and fast application.

Therefore, this design approach can be applied at different project scales with a large number of rooms to select the optimal floor tile size for each room and calculate the total waste ratio for all rooms that require the same floor tiles. Reducing the overall waste of flooring materials in the project eliminates the time required to apply value engineering principles in the project.

Selecting floor tiles in the AEC industry is a labor-intensive and time-consuming task. Architects often face difficulties in accurately creating shop drawings for floor tiles, owing to a lack of appropriate design tools. Consequently, they struggle to provide design support for subsequent stages, such as procurement and construction. This challenge becomes even more complex when architects need to incorporate waste reduction into their layout design. Consequently, the planning and cutting of floor tiles are typically performed extensively rather than precisely managed. This reliance on experience, rather than accurate calculations, leads to unnecessary material and labor wastage. To address this issue, we developed a workflow for generating accurate and comprehensive material waste rates.

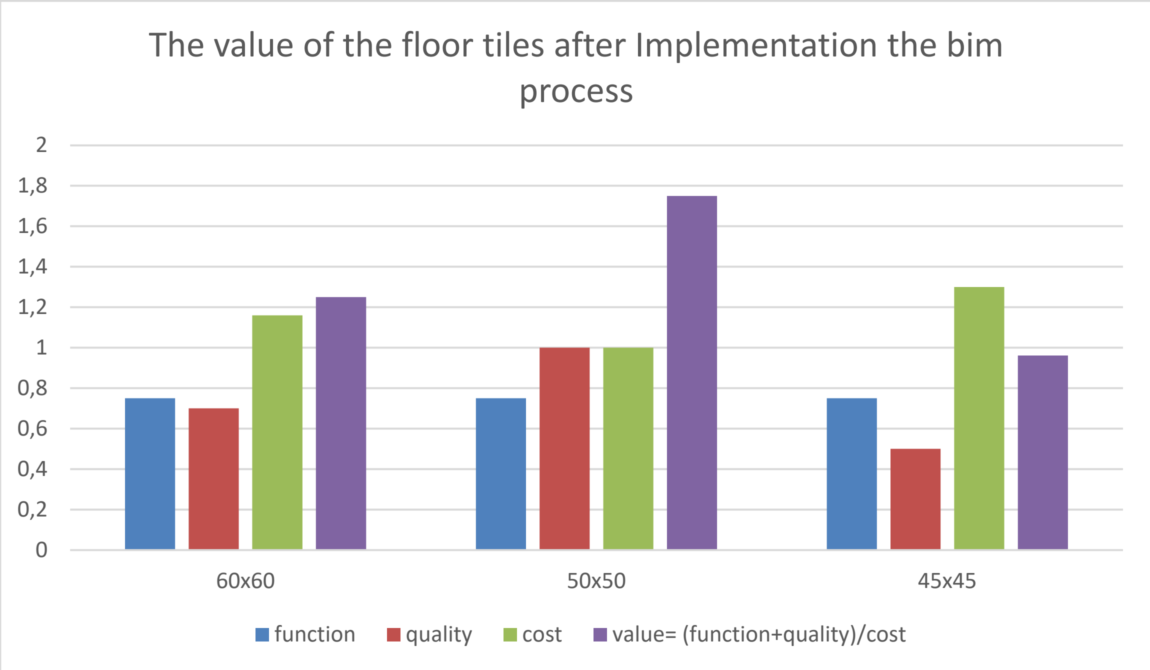

Fig. 9. The Result of the value engineering according to the integration of the Bim framework

5. CONCLUSIONS

This research proposes a workflow for selecting the optimized floor-tile size according to space percentage. The work limitation is on spaces with rectangular shapes with perpendicular angles, which is the most applicable space for material optimization in the VE process. All tiles must have uniform specifications except for size. The automation equation could be updated in future studies for application to regular spaces that are confirmed to have more than one rectangular shape by dividing the spaces into smaller rectangles.

The workflow integrates BIM and VE equations, enabling architects in the early decision-making phase of the project to automatically calculate the waste ratio of each floor tile size option by inserting the optional sizes, outputting the floor selection by the minimum waste ratio for each space individually, which significantly reduces the material waste, minimizing the time wastage of the quantity surveyor engineer surveying the quantity of tiles manually from the shop drawings, and calculating the exact number of uncut and cut tiles to enable the procurement engineer to order the correct amount of flooring tiles. This methodology is a step in waste management research to reduce the material-waste ratio and help technical office engineers to enhance the process of selecting and using flooring materials.

To enhance the entire tile design process, researchers proposed a workflow in the optimization process of floor tile planning to automatically generate the layout design of floor tiles, including uncut and cut tiles, after choosing the best tile size. [28]. Additionally, the two studies can be combined to form an integrated optimization process for the best tile planning.

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