DEVELOPMENT OF BIM-BASED TECHNIQUE FOR MODELING CONSTRUCTION WASTE IN DESIGN AND EARLY PLANNING PHASE OF CONSTRUCTION WASTE MANAGEMENT (CASE STUDY: TARTOUS HOUSING PROJECTS)

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Abstract. Construction waste poses significant environmental and resource challenges in the construction sector. Building Information Modeling (BIM) has become a promising tool to tackle these issues by enabling virtual project simulations that optimize material and resource use. This study investigates the practical application of BIM for modeling construction waste and its potential to minimize waste production, focusing on housing projects in Tartous, Syria. A BIM-driven methodology was applied during the design phase to model waste generation for 20 structural and finishing elements, including concrete, walls, flooring, and tiles. The approach collected detailed data on the volume and nature of waste linked to the project schedule. Results indicated that the model could shorten the construction timeline by 6.28% and lower costs by 3.85%, highlighting its value for waste management strategies and resource efficiency during project execution. By integrating BIM with project planning, stakeholders gain early insights into waste patterns, allowing proactive waste management. This alignment enhances sustainability by conserving resources and curbing waste, demonstrating BIM's potential to advance eco-friendly practices in the construction industry.

Keywords: construction waste, Building information modeling (BIM), sustainability, modeling construction waste.

Introduction

The construction industry is one of the most resource-intensive industries, consuming 15% of materials, 40% of energy, and 12-16% of fresh water [1]. Construction waste constitutes 27% of the total municipal waste and 75% of construction waste can be utilized [2].

Due to the increasing costs of construction projects and the environmental risks associated with them, engineers have resorted to using more efficient methods to conserve materials, especially with the United Nations seeking to make 2030 the year of creating sustainable cities and urban communities [3], and in recent years the use of Building Information Modeling (BIM) to manage construction processes has increased, as BIM is an information-rich model that contains large amounts of data of project elements and parties, which is a prerequisite for effective construction, operation and maintenance stages [3-4]. Over the past years, multiple studies have been conducted to understand the causes of construction waste formation, assess its impact, and propose methods and solutions to address the waste through recycling and reuse [5-6]. These studies have focused on developing models to estimate the amount of construction waste [7-8] in order to support designers with appropriate data and reports to make appropriate decisions in waste minimization strategies and steps, but few studies have predicted the amount of construction waste during the design phase.

This study aims to fill the research gap related to predicting the construction waste in Syria that can be formed in construction projects through BIM modeling using a questionnaire to know the percentages of construction waste formation for a number of construction elements and materials.

Objective of the research. The research aims to improve sustainability in the construction industry by reducing construction waste by using BIM modeling technology in the design phase and supporting designers with the necessary data to manage construction waste, improve site management, and reduce material consumption in the project during its implementation.

Research hypothesis. Our research hypothesis is that early prediction during the design phase of the expected amount of construction waste will contribute to improving the physical and temporal indicators of the project by relying on plans to reduce the expected waste or utilize it as an additional resource.

Review of previous studies

Many studies have been conducted to model construction waste, some of which relied on modeling some waste through the use of conversion codes such as the European Waste Code [9], and this method relies on modeling material waste from origin to the construction stage, and this method needs strict legislation and great control and control capabilities within the project, and it also needs continuous development due to the change in material specifications and construction methods.

In 2021 PhD thesis, [9] the researcher created a BIM 4D model by modeling the waste within Revit and linking it with the project timeline, but without presenting the timeline, but instead replaced it with visual representation of the waste as 3D models in parts of the building that represent a virtual time phase of the project.

One of the weaknesses of this model is that it represented the architectural elements of the building only, by modeling the walls without modeling its other components, and it did not present a study of the time plan and replaced it by representing the residues in the project elements that represent a phase of the project, and although it provided a clear visualization of the formation of some residues in the project phases, it did not study the impact of this model on the time and cost indicators of the project. Many researchers have also developed methods for estimating and evaluating construction waste using BIM tools [10-11], as all those interested in the construction industry agree on the ability of BIM techniques to improve design, coordination between parties and support quality requirements in the project. Some studies focused on identifying and modeling the waste of concrete elements and reducing reinforcing steel by modeling steel cutting processes to reduce waste [11], and some studies relied on modeling waste in walls and partitions in addition to concrete elements [12]. Despite the many researches that have been done to reduce waste and minimize the formation of waste by BIM, many researches recognize that BIM is not able to solve issues automatically [13-14], but needs the efforts of a team of specialists and the promotion of continuous monitoring and development according to the conditions and development of the work.

Research materials and methods:

The research is based on the quantitative estimation of construction waste through 3D modeling by Revit of construction elements, and the study of the time flow of waste according to the planning schedule of the project, and the project management software Premivera6 was used because many companies rely on it in the time planning of projects and as a step to show how to achieve its linkage with BIM technologies in a way that achieves the desired goal in the field of construction waste management.

Due to the lack of previous data on waste rates in local projects, it was calculated using methods used to measure waste in construction [15], such as waste audits [16], waste weighing [17], project data documentation [18], or waste tracking through BIM [19].

In this research, we adopted the questionnaire as a tool to determine the expected waste formation ratios, to be used as waste conversion factors in modeling 20 building elements/concrete elements - walls - floor tiles - clay -..../and other materials and elements, based on the results of a questionnaire for expected waste ratios in the conditions of projects in Syria.

The questionnaire included 52 engineers from several disciplines, 4 answers were canceled due to the presence of blank fields and 48 valid answers remained. The questionnaire also included a determination of the years of experience and scientific degree and the extent of his prior knowledge of topics related to construction waste and questions that include the ratios that each of them expects according to his experience for the waste that can arise in the elements of construction and the materials used in each of them and we subjected the questionnaire results to analysis and processing by SPSS22 program.

The reliability of the questionnaire was analyzed with regard to the answers regarding the proportions of construction waste and the calculation of the value of Cronbach's α, which gives an indication of the stability of the questionnaire and gives an indication of a significant correlation between the answers by statistical analysis programs spss22 and the Cronbach's α value was 0.701 and the number of questions was 24. The value of $\alpha = 0.701 \geq 0.701 \geq 0.7 \geq 0.8$, which means that the correlation between the responses is acceptable.

It is worth noting that many studies in the field of engineering sciences support the use of the Cronbach's alpha value above 0.7 as an acceptable threshold for assessing questionnaire reliability, for example, a study in the field of industrial engineering found that a reliability coefficient of 0.7 or higher is sufficient to ensure internal consistency within their survey instrument [20]. Similarly, research in information systems engineering also used a threshold of 0.7 or higher to assess questionnaire reliability [21]. As a result of the questionnaire, the percentages of waste and waste formation according to the questionnaire were as shown in Fig. 1.

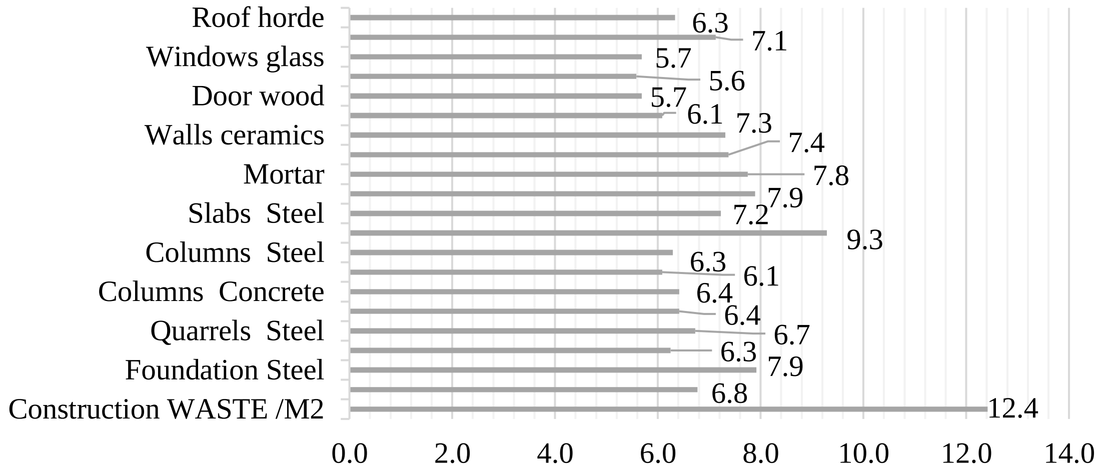

Fig. 1. **Percentages of construction waste according to the questionnaire results**

These percentages are considered an estimate and reflect the local conditions of the construction industry in Syria, noting the percentages of construction

according to the conditions, nature, location and technology of the projects [23]. In order to confirm the results of the questionnaire, we compared these ratios with some international ratios in a number of countries in the world, as shown in Table 1.

Table 1

Waste formation rates in some countries

Maximum waste, %	Minimum waste, %	Article	Reference number	Country
10	7	Concrete	[23]	Nigeria
12	10	Steel		
7	5	Floor tiles		
5	3	Block		
8	5	Concrete	[24]	Germany
11	9	Steel		
6	4	Floor tiles		
4	2	Block		
12	8	Concrete	[25]	Spain
14	12	Steel		
8	6	Floor tiles		
6	4	Block		
9	6	Concrete	[26]	China
10	8	Steel		
7	4	Floor tiles		
5	2	Block		
13	9	Concrete	[27]	Nigeria
15	11	Steel		
9	7	Floor tiles		
7	5	Block		
11	7	Concrete	[28]	China
13	9	Steel		
8	5	Floor tiles		
6	3	Block		

Through comparison, we note that the ratios we obtained fall within the limits of international studies, which encouraged us to adopt these ratios initially to measure the amount of construction waste in construction projects in Syria, while leaving room to develop these ratios through more accurate methods by adopting construction waste management tools.

I: Use of Building Information Modeling (BIM) in construction waste modeling

Despite the benefits that BIM can bring and the breadth of recommendations and efforts to adopt it, BIM for construction waste management is often neglected [29], and although there are many studies that have contributed to support the use of BIM in construction waste management, none of these studies have provided clear instructions on how to use BIM in this field within a technical and legislative framework. Moreover, this lack of clear instructions raises serious concerns about how to integrate construction waste management into BIM, knowing that some studies only provided a general framework by identifying the factors that should be considered during design [30; 31]. Therefore, we developed a model for construction waste management in BIM by following the following steps:

1. 3D structural and architectural modeling using Revit software for residential buildings with general site modeling for the studied case.
2. Creating Dynamo nodes with the use of the programming language (Python) in order to model the various building residues of concrete, wall blocks, horde blocks, tiles, and ceramics.
3. Using phases in Revit to add a new dimension (time) to the 3D waste models.
4. Exporting the results to Excel and drawing diagrams.

Here is how to perform the steps for modeling construction debris using BIM techniques.

The first step: Modeling the building

Based on the collected data, Fig. 2 shows the results of modeling the residential building in Revit:

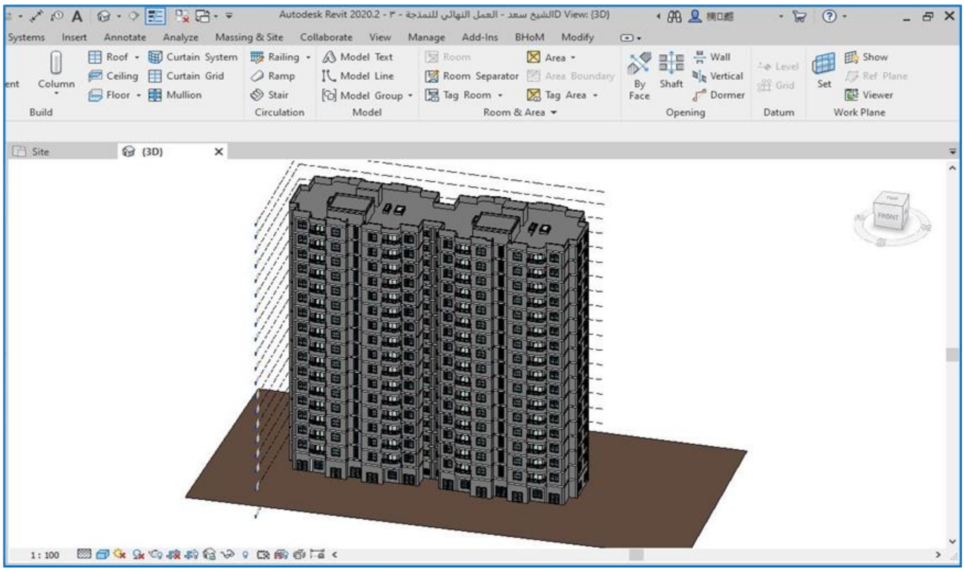

Fig. 2. **Interface of the project's construction model**

II: Using visual modeling to model waste

1. Based on the percentages of waste formation in the construction phase for each element of the building and using the Python programming language, the quantities of wasted materials were obtained for each element separately.
2. The amount of concrete in each of the columns, slabs and foundations was calculated using the Element node. (Get Parameter Value by Name). Element Get Parameter.
3. Using Python, the amount of wasted concrete was calculated for each of the foundations, columns and slabs.

The same mechanism in step (1) and (2) will be applied to all elements with the modification of the coefficient of waste formation and some materials such as concrete, which is present in multiple elements in the building, the total waste can be modeled according to step (3) using visual programming so that we have the expected total waste in addition to the waste in each element.

Thus, we were able to obtain the amount of waste expected to be formed from the different materials that were modeled using Revit22 and the results were according to Table 2.

Table 2

Quantities of materials wasted in the project

Item	Unit	The amount of waste
Total waste in wall clay	m^3	9.171
Total wastage in column's concrete	m^3	51.61
Total wastage in mortar under cladding units	m^3	14.73
Total waste in floor tiles	m^2	371
Total waste in block walls	m^3	19
Total waste in the Al-Hurdi Block	m^3	0.65
Total wastage in flooring concrete	m^3	150.67
Total waste in wall ceramics	m^2	192
Total wastage in base concrete	m^3	88.55
Total waste in window glass	m^2	61.185
Total waste in door wood	m^3	5.138
Total wastage in rebar	ton	107.7

To achieve the spatial correlation of the generated waste with the elements from which it was formed, each type of waste was modeled using the model in place in a three-dimensional form, this method helps in creating a three-dimensional visualization, thus the waste generated on the project site evolves with the development of the work stages.

Third: Adding a time dimension to the 3D residue models

By adding the construction waste stage within Revit, the model displays the waste in 3D, and once the cursor is clicked on any part of this waste in Fig. 6 below, a dashed line appears that connects the waste to the part of the 3D model of the building in Fig. 3.

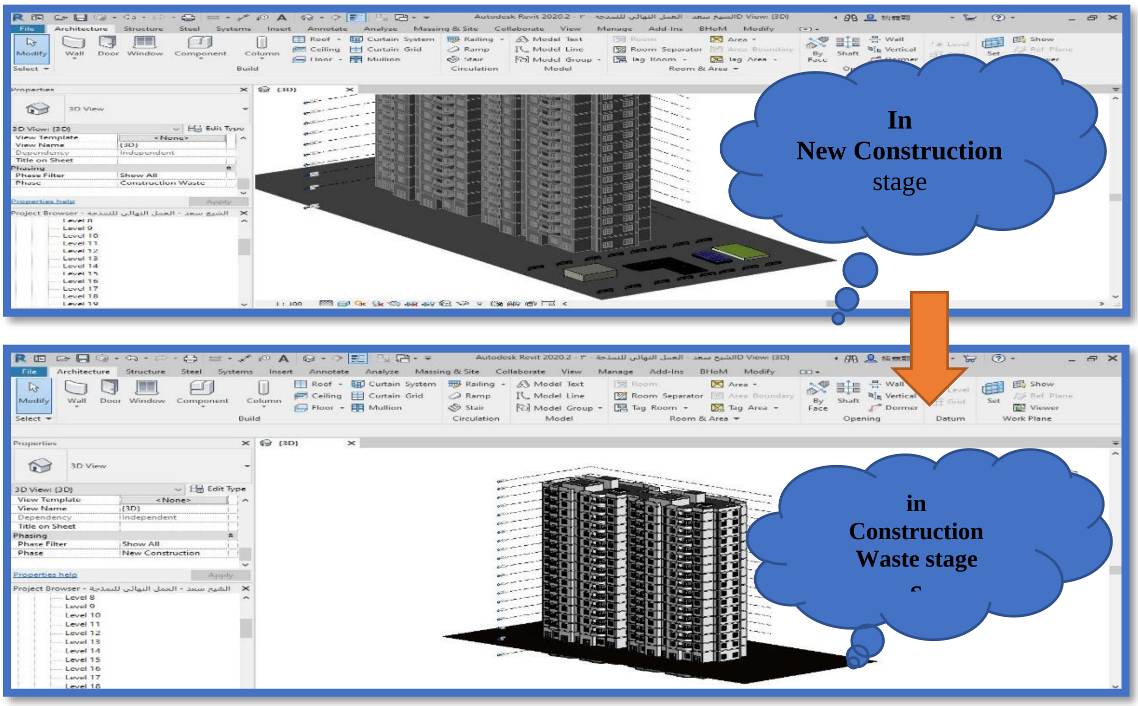

Fig. 3. **Construction waste by BIM model overview**

The following Fig. 4 shows how the residue can be 3D mapped to the element from which it is formed and is shown in the form of a dashed line.

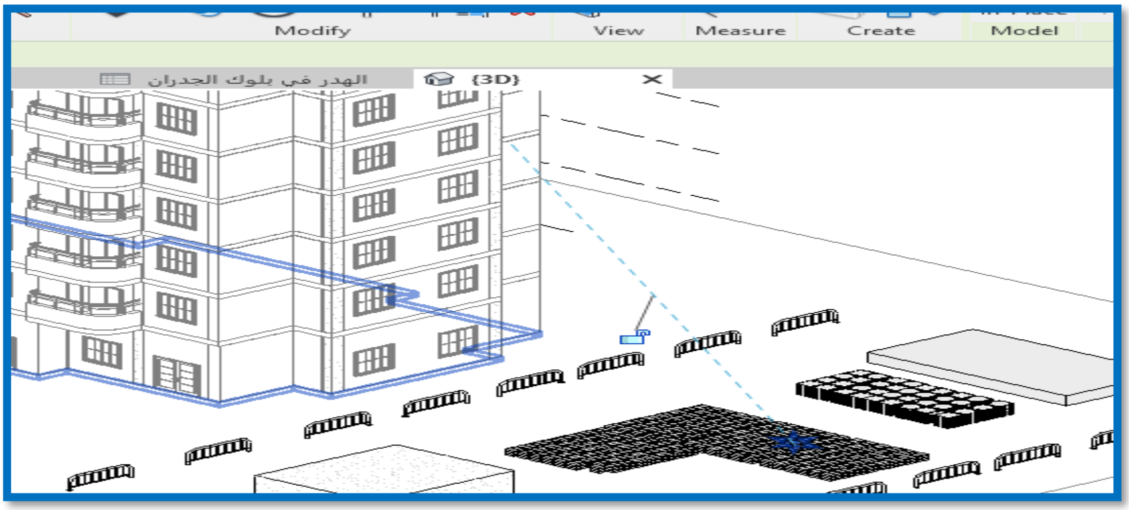

Fig. 4. **Mechanism for linking residues to their constituent elements**

This new step helps in forming an actual pre-visualization of the waste at the site during construction, obtaining the expected amount of construction waste according to the proposed model and linking it with the project execution plan through a standardized ID between Revit & Primavera allows us to know when the waste is formed at any stage of the project and form a waste flow chart linked to the activities.

Results and discussion

The proposed methodology, using the new model of Construction Waste by BIM, allows us to predict the amount of waste that can be generated in the project during its various stages, and determine the 3D link between the elements and the waste generated from them, and this technology will support waste management plans and methods of waste reduction through the design phase to reduce waste more effectively. Fig. 5 shows some waste flow diagrams during the stages of project implementation.

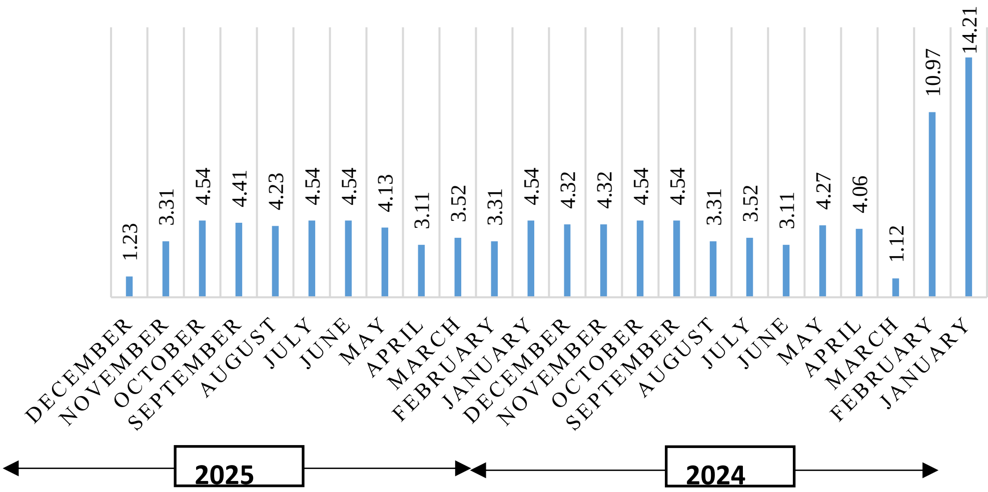

Fig. 5. **Rebar Tailings Flow Chart for the project**

The modeling of waste within the project timeline allows us to reduce costs and time in the project by controlling waste and following waste reduction methodologies, as confirmed by a study in this field. The possibility of reducing the formation of waste in floor tiles reaches 86% [32], where waste control will be reflected on both the time and cost of the project as the formed waste is a phase of the activity (part of the activity) that needs time and cost, and reducing its formation contributes to reducing both time and cost.

By comparing the time and cost we can see that controlling waste can reduce cost and time, as Table 3 shows the change in the total cost and time of the project if measures are taken to reduce waste.

By comparing the cost and time in the two cases, we find that the percentage of cost and time reduction gives an important indication of the need to give special importance to construction waste management that BIM technology provides effective tools to achieve the required goals in this field, which was obtained by calculating the difference between the cost and time in the two cases listed in Table 3, and by the percentage of If we symbolize the cost of the project in the traditional case as Ct and in the case of applying waste management techniques as Cwm, and the time of the project in the traditional case as Tt and in the case of applying waste management techniques as Twm, the indicators of the application of construction waste management techniques on both the time and cost of the project appear in Table 3.

Table 3

Comparison of cost and project time changes with waste control measures

Tt-Twm/ Tt, %	Ct-Cwm/ Ct, %	Cwm, billion sp	Ct, billion sp	Twm, day	Tt, day
6.28	3.85	40.39	42.01	687	733

It is certain that the cost and time reduction will be of great value, especially in large construction projects such as suburban reconstruction projects in particular, and the reconstruction of Syria in general, especially due to the scarcity of resources and the high prices of building materials. These results will also encourage the adoption of policies to minimize the formation of waste in construction projects by applying modern construction waste management principles.

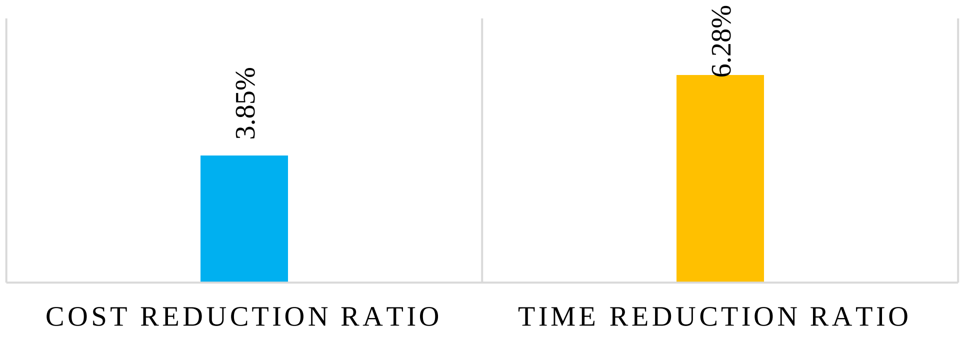

Fig. 6. **Cost and time indicators through construction waste management**

Conclusions

Through the proposed methodology and using the new technology Construction Waste by BIM (CWB), we achieved the following results:

1. We were able to determine the amount of waste that will be generated from the various elements of the project studied with the possibility of predicting it during the design phase.
2. Knowing the stages of waste formation by linking it to the project timeline, where the waste appears with the stages of the project within time according to the associated elements it can be visualized and quantified accurately in time.
3. The proposed BIM construction waste management technique allows us to reduce the cost by 3. 85% of the project cost through the waste reduction plan for the floor tile element only.
4. Reduced time by up to 6.28% of the project time.

It also shows that the new technology will be a crucial element in the field of construction waste management, through the possibility of predicting the amount, type and sources of waste at the design stage, and will provide a greater possibility to support waste minimization options by proposing different plans and scenarios to minimize waste by integrating them into the project implementation plan. In addition to this, the new technology will enable us to support waste treatment options by developing a construction waste management plan in advance of the implementation phase, which leads to a reduction in cost and time for the project, in addition to the possibility of categorizing waste into the basic options available (Reuse, Recycle, Disposal), which in turn gives a great opportunity for project parties to control it to achieve the required sustainability standards always.

Recommendations

The research results showed the importance of using BIM techniques in the design phase as a key factor in predicting the amount of construction waste in advance before the implementation phase, which allows effective management to achieve sustainability standards, but it is clear that research in the field of developing construction waste management still needs further steps in the field of control and control during project implementation, and looking for ways to integrate treatment options within the project implementation plan, and this requires additional research to know the treatment options for each waste material and propose legal legislation to develop project management so that sustainability standards related to waste reduction and preservation become a reality.

Author contributions

Both authors have contributed equally to the study and preparation of this publication. Authors have read and agreed to the published version of the manuscript.

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