DEVELOPING A BIM-BASED TECHNIQUE IN THE DESIGN PHASE TO ACHIEVE SUSTAINABILITY IN RESIDENTIAL BUILDING PROJECTS

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Abstract. The building construction industry is one of the industries that contribute most to waste production in the world. Therefore, the efforts of researchers focused on reducing construction waste (CW). The building design stage is a decisive factor in the formation of waste by determining the sizes and dimensions of the elements and the resulting formation of some remains (waste) that may become a resource added to the project resources if this process is planned in advance. The absence of this planning may lead to it becoming waste. In our research, we present a BIM-based model for reducing floor tile construction waste in multi-story residential buildings, which contributes significantly to achieving sustainability standards in construction projects. Tartous housing projects - in the Sheikh Saad complex project were chosen as a case study, which consists of 20 residential towers with 16 floors, each floor containing 8 residential apartments. The Revit program was used to model buildings, and Dynamo to design a technique to reduce CW in the design stage, by comparing different sizes of floor tiles using visual programming techniques. We chose the floor tile size that achieves the lowest value of waste throughout the entire project. High reduction rates were reached, amounting to 96.43% (of the actual waste in the project) compared to the current traditional design, which is a very promising percentage in the field of reducing the formation of construction waste and achieving sustainability standards.

Keywords: building information modeling, construction waste management, sustainability, construction waste reduction by BIM.

Introduction

With the development of human activity, the production of various wastes increases, which constitutes an important factor in lowering sustainability standards in environmental, economic and social terms. Every year, about 1.3 billion tons of solid waste (MSW) are produced worldwide, which is expected to rise to 2.2 billion tons by 2025 and to 3.4 billion tons by 2050 in the European Union according to the World Bank [1]. The construction industry in the European Union is considered the largest waste producer among all European industries, being responsible for 34% of total waste generation [2]. Design and rework errors constitute the most important causes of construction waste formation, according to the latest studies [3].

Although many studies have unanimously agreed on the effective role of the BIM technique in reducing construction waste in the design stage [4-6], studies related to reducing construction waste in the design stage are still in their infancy and require greater attention from specialists and engineers [7-8].

One study [9] estimated that 33% of construction waste is due to the failure of designer engineers to develop designs to reduce waste and losses through the creation of small pieces that are not usable in construction work, which some researchers consider the most important factor in the formation of waste in construction works [10].

Therefore, many researchers prefer to work on reducing and predicting construction waste through the design stage (preventive measures - inexpensive) rather than taking procedures and measures to treat waste (remedial measures - expensive) [11-13] because of the important role of this design process in reducing costs and giving a clear image of the amount of waste in the various stages of the project.

Recent studies in construction waste management (CWM) rely on predicting it before it occurs, and addressing this problem requires a strategic approach based on advance planning and careful study using appropriate design tools. CWM tools reveal fundamental design-based issues. Despite the knowledge that making the right decisions during design can reduce waste formation, none of the current tools have been fully integrated into the building design process. This makes the tools need more effort to reduce waste formation at the design stage, and thus it makes it difficult for architects and design engineers to use them. One of the most important gaps in CWM is its lack of reliance on BIM [15]. Therefore, in our current research, we focused on demonstrating the role of BIM techniques in reducing and managing construction waste for the floor tile component as a case study.

Various research studies have been conducted in an attempt to minimize waste in the production of floor tiles. One such study [16] focused on the use of industrial waste materials such as fly ash and silica fume in tile production. The results of this study showed a reduction in waste generation by up to 20% by incorporating these materials into the manufacturing process.

Other search results showed a waste reduction of up to 25% by incorporating these by-products into the production process [17]. Another way to minimize waste in floor tile production [18] by using BIM tools, simplified of a two-room building, was selected and the losses were compared for different tile sizes.

In our research we applied a practical example that compares the wastage of different sizes of floor tiles and supports the concept of guided implementation by arranging the work phases according to the wastage in the room.

Overall, these studies show that waste can be significantly reduced in floor tile production through the use of alternative materials and by-products. By incorporating industrial waste materials and recycled materials, the researchers were able to achieve waste reductions ranging from 14% to 25%, illustrating the importance of sustainable practices in the tile manufacturing industry.

Research objective

This research aims to improve sustainability in the construction industry by reducing construction waste at the design stage by developing effective strategies and interventions to reduce the amount of waste generated during the construction process for some building elements, which is floor tiles in our current study.

Literature review

Despite the benefits that the use of BIM can bring and the increased efforts and recommendations for its adoption, BIM is often neglected for construction waste management [19]. Although there are many studies that have contributed to supporting the use of BIM in construction waste management, no studies include clear instructions on how to use BIM in this field. Additionally, this lack of clear instructions raises serious concerns about how to integrate construction waste management into BIM environment. Some studies have provided a general framework only by identifying the factors that must be taken into account during design [20-21]. Among the most important factors that must be taken into account to reduce waste in the design stage are as follows.

- 1-Waste prevention strategies [22].

1. Identify potential waste sources and avoid them.
2. Applying lean construction methods.
3. Encouraging prefabrication and modular construction methods.

- 2-Material efficiency.

4. Efficient material selection.
5. Encouraging the use of recycled materials.
6. Designed for disassembly and easy material recovery/ retrieval [23].

- 3-Construction techniques.

7. Employing effective construction methods and techniques.
8. Reducing cuts and modifications on the site.
9. Applying advanced framing techniques [24].

- 4-Waste management practices.

10. Recycling and waste sorting on site.
11. Cooperation with waste management companies.
12. Developing effective waste management plans [25].

It is expressed in the form as shown in Fig. 1.

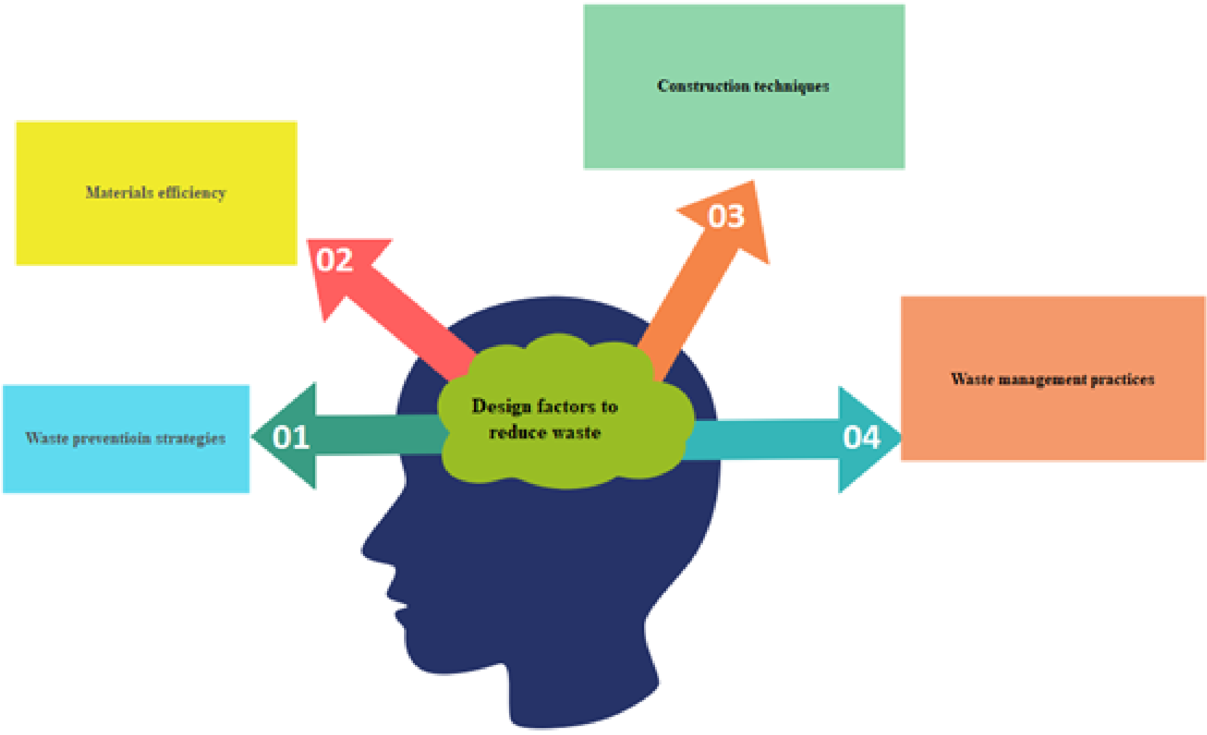

Fig. 1. **Design factors to reduce waste formation**

Therefore, this research provides a flexible and easy approach that can be easily linked to the labor market and enables project stakeholders to immediately measure its impact on the project cost and duration.

Data collection and research methodology

As a case study for applying the results of this research, we studied the youth housing buildings – the second phase (under construction), Syria, Tartous city, Sheikh Saad project. Fig. 2 shows the general location of the project and Fig. 3 – architectural facade of a building.

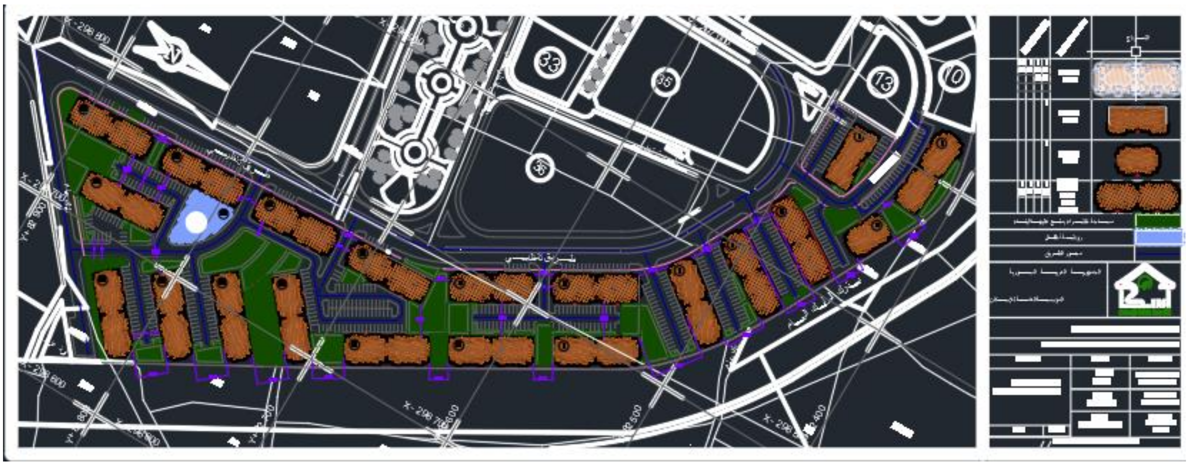

Fig. 2. **Project general site**

Since the project is still in its early stages, this gives our research the opportunity to provide a recommendation to the project management to benefit from the research outcomes and employ them in the project and in subsequent projects as well.

In our research, we will choose 20 towers. Each tower consists of 16 floors, excluding the basement floor, which is allocated for technical service. In it, floor tiles different from the rest of the floors will be used. Each floor consists of eight apartments according to the following figure (Fig. 4).

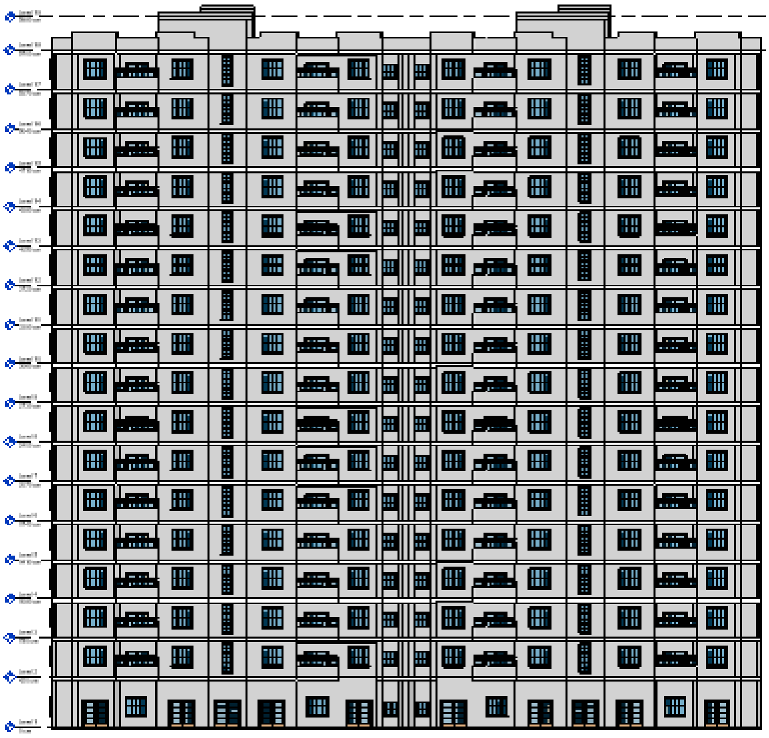

Fig. 3. **Architectural facade of a building in the project**

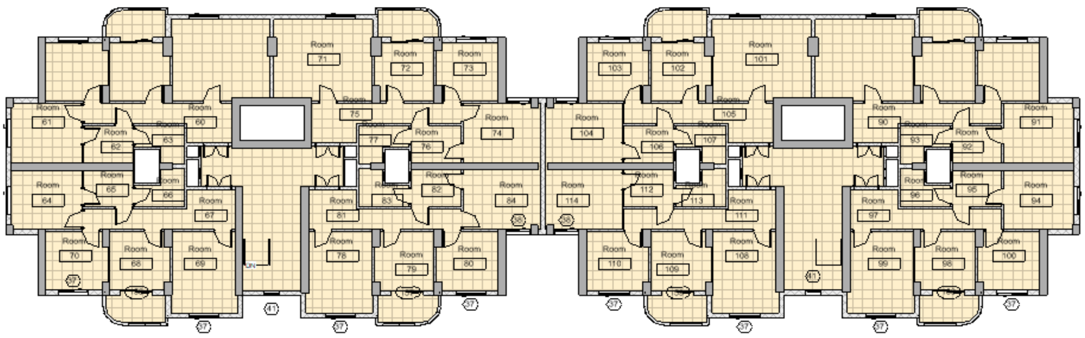

Fig. 4. **Horizontal layout of building floors**

Two cases of tile types were worked on, the first: tile sizes for bathroom and kitchen and the second: tile sizes for bedrooms and living rooms, due to the difference in the type of tiles used in each space, where the dimensions of floor tiles for bathrooms and rooms are determined according to what is available in the local market according to Table 1.

Table 1

Sizes of floor tiles used in residential buildings according to the type of rooms

No.	**Room tiles dim: cm x cm**	**Bathroom and kitchen tiles dim: cm x cm**
1	30*30	15*15
2	40*40	20*20
3	60*60	30*30
4	80*80	40*40
5	100*100	_–

The special platform for reducing CW that we will design will be provided by Dynamo with the previous sizes. By comparing the resulting waste, it is possible to choose the size that achieves the least waste. By comparing the resulting waste in the rooms, it is possible to determine in which room the tile work should be started before the other, which allows the use of the waste from the first room in the second room, and thus we have an additional reduction in waste. It also allows us to suggest a work plan regarding tile cutting methods/ fabrication/ in advance before starting tile works. This, in turn, allows us to reduce the duration of floor tiling activities. In this case, the amount of time reduction can be determined by comparing the time it takes workers to coordinate and cut tiles during work with pre-cutting according to the proposed methodology. This period ranges between 25-30% of the time for overall activity according to a poll of some technicians who work in tiling floor works. The time reduction period can be determined more accurately by calculating the total of units that can be cut in one apartment and the ratio of time that this process needs to the total duration of the apartment tiling. In general, we can determine the basic steps of the work methodology that we will use as follows.

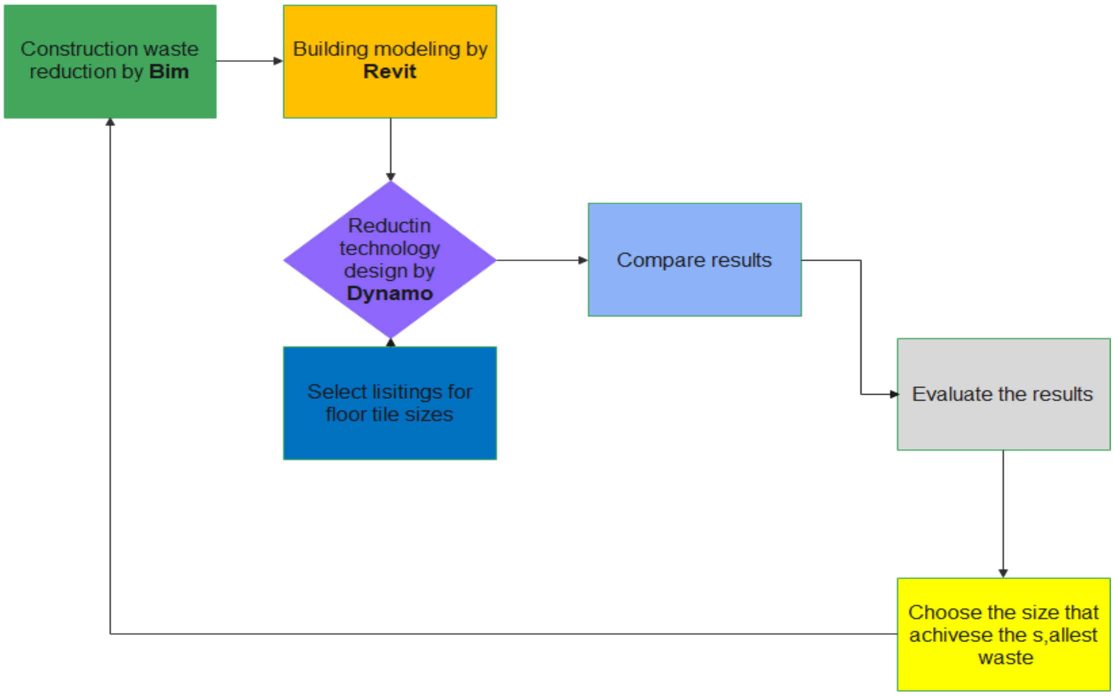

Fig. 5. **Methodology for reducing waste using BIM techniques**

The quantity of floor tiles allocated to the aforementioned towers was compared according to the bill of quantity -BoQ of 10 towers approved by the Public Housing Corporation, which owns the project and the model designed by us using Revit according to Table 2.

Table 2

Variances in tile area between the traditional(study) and the proposed/ Revit method

No. of buildings	Bathroom tile area (by Revit) A_1, m_2	Room tile area (by Revit) A_2, m^2	Room tile area (by traditional study) A_3, m^2	Bathroom tile area (by traditional study A_4, m^2	Variances, m^2 $A_5 = A_1 - A_4$	Variances, m^2 $A_6 = A_2 - A_3$	Variance percentage% $A_5/A_1\%$ $A_6/A_2\%$	
10	70304	23444	70000	25000	304	1555.5	6.6	2.2

Table 1 also shows the difference between the quantities of floor tiles according to the design using Revit and the current -CAD design, the quantities of which were calculated using traditional methods-CAD. The results showed that the difference is (+2.2%) for room floors and (-6.6%) for kitchen and bathroom floors. This difference is expressed according to Fig. 6.

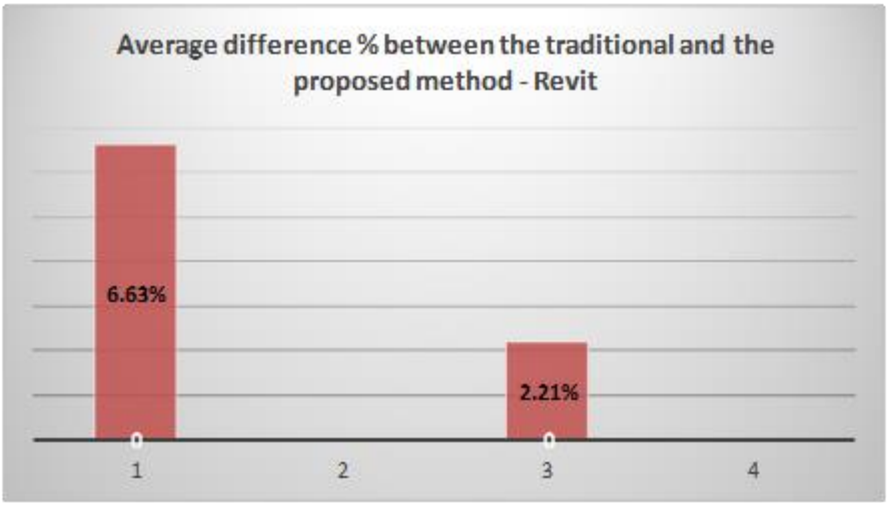

Fig. 6. **Percentage variances between the tile area studied in the project and the quantities after Revit modeling**

Below are the main steps to determine the quantity of wasted materials from ceramic tiles using Revit2020 (Fig. 7-8).

Determine the type of room, whether it is a bathroom or a bedroom, and then obtain the area of the space using the following contract diagram:

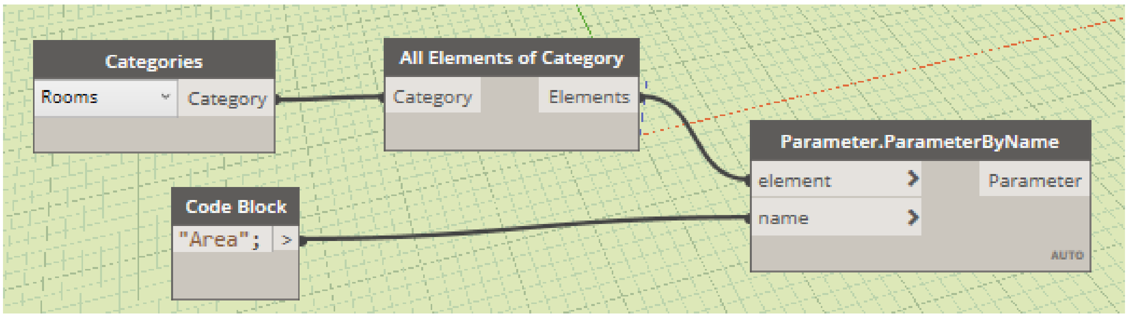

Fig. 7. **Determining the space to be tiled/implemented**

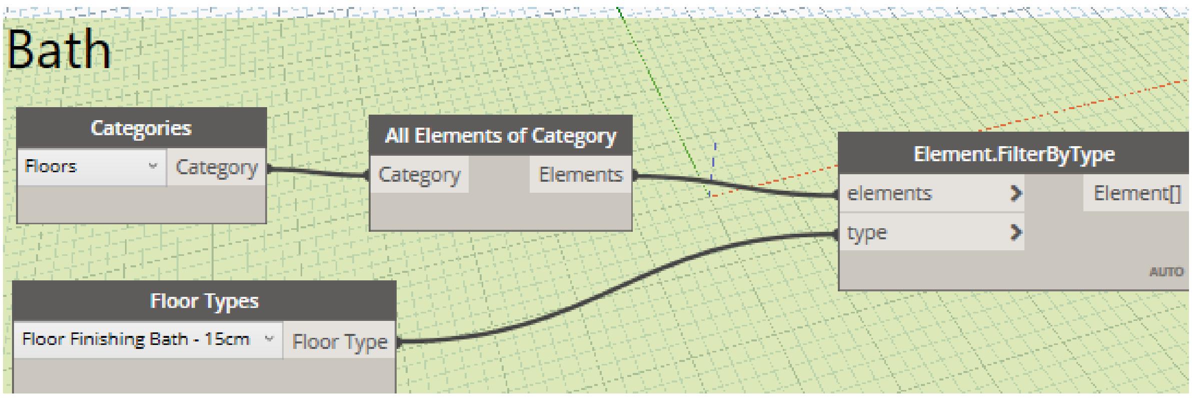

Fig. 8. **Determining the type of room, whether it is a bathroom or a bedroom, then obtaining the area of the space**

The Python language will be used to find the area of ceramic tiles, since the Revit software gives us the total area of the cladding tiles (ceramic with mortar and sand) by taking advantage of ID of each cladding material (Fig. 9).

Python Script

```python
import clr
clr.AddReference('ProtoGeometry')
from Autodesk.DesignScript.Geometry import *
clr.AddReference("DSCoreNodes")
import DSCore
from DSCore import *
clr.AddReference("RevitAPI")
import Autodesk
from Autodesk.Revit.DB import *
# Import RevitAPI
clr.AddReference("RevitAPIUI")
import Autodesk
from Autodesk.Revit.UI import *
clr.AddReference("RevitNodes")
import Revit
from Revit import Elements
clr.AddReference("RevitServices")
import RevitServices
from RevitServices.Persistence import DocumentManager
from RevitServices.Transactions import TransactionManager
#The inputs to this node will be stored as a list in the IN variables.
dataEnteringNode = IN
#mat=UnwrapElement(IN[0])
ele=UnwrapElement(IN[0])
doc = DocumentManager.Instance.CurrentDBDocument
v=[]
for j in ele:
    s = ElementId(559734)
    #vol=j.GetMaterialVolume(s)
    area=j.GetMaterialArea(s,False)
    v.append(area)
#*********************************************************************

#************************************************************************

#************************************************************************

#************************************************************************

#Assign your output to the OUT variable.
OUT =v
```

Fig. 9. **Using the Python language to enable Dynamo to determine the tile area**

Input the ceramic tile dimensions (length and width) in order to know the required quantity of tiles used (Fig. 10, 11).

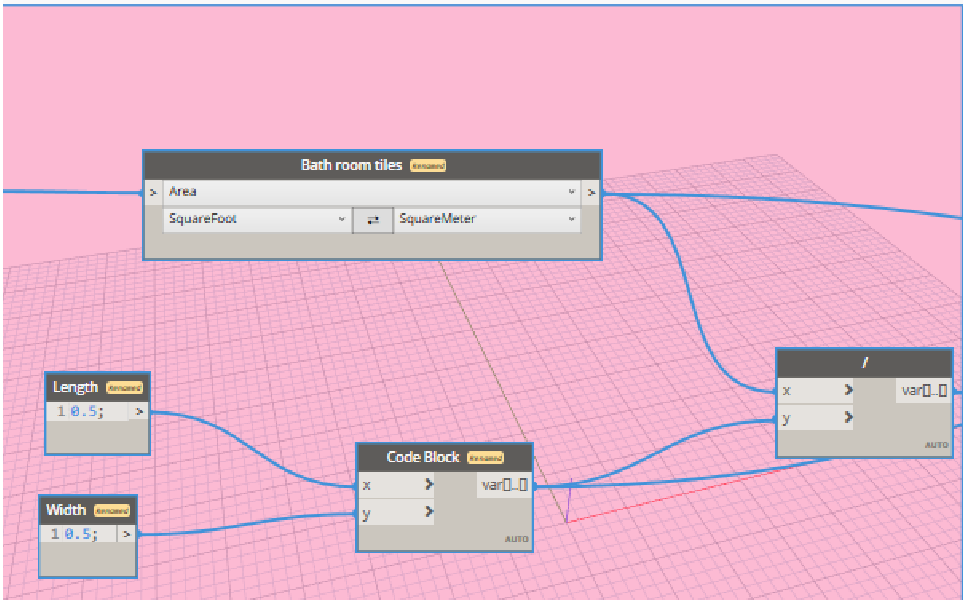

Fig. 10. **Inputting tile dimensions into Dynamo nodes**

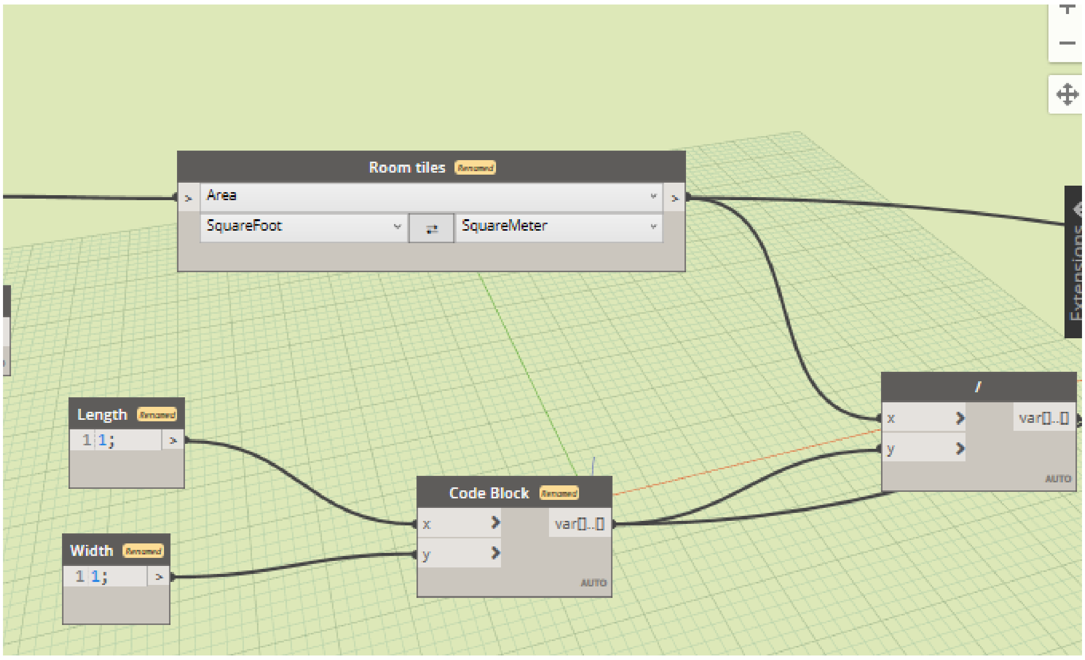

Fig. 11. **Inputting floor tile sizes**

Estimate the amount of waste resulting from using the type specified in the previous step (Fig. 12).

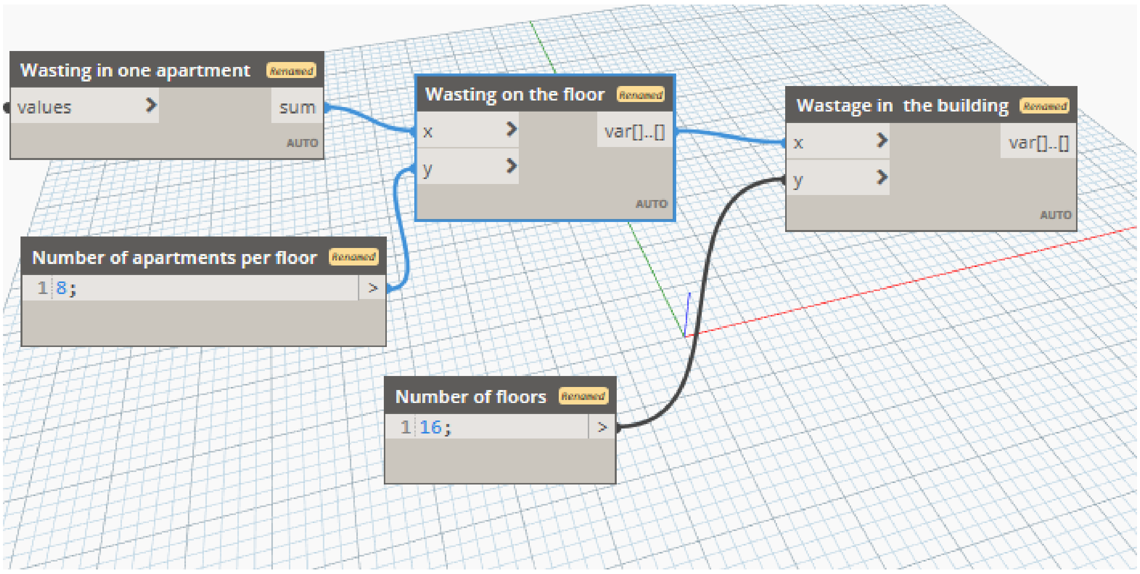

Fig. 12. **Waste measurement for each type of tile sizes**

By applying the previous methodology to all tile sizes by type (rooms, kitchens and bathrooms), the following table shows us the waste results for each size as shown in Table 3.

Table 3

Waste results for each tile size (according to the proposed method)

Room floor tile dim. cm x cm	Bathroom floor tile dim. cm x cm	Apartment waste, m^2	Building waste, m^2	Total project waste, m^2
30*30	15*15	0.09	12.0	240
40*40	15*15	0.11	14.4	288
60*60	15*15	0.27	34.9	697
80*80	15*15	0.23	29.9	598
100*100	15*15	1.05	133.8	2677

Table 3 (continued)

Room floor tile dim. cm x cm	Bathroom floor tile dim. cm x cm	Apartment waste, m^2	Building waste, m^2	Total project waste, m^2
30*30	20*20	0.10	12.3	246
40*40	20*20	0.11	14.7	294
60*60	20*20	0.27	35.2	704
80*80	20*20	0.24	30.2	605
100*100	20*20	1.05	134.2	2683
30*30	30*30	0.11	14.2	283
40*40	30*30	0.13	16.5	331
60*60	30*30	0.29	37.0	740
80*80	30*30	0.25	32.1	641
100*100	30*30	1.06	136	2720
30*30	40*40	0.08	10.3	206
40*40	40*40	0.10	12.7	254
60*60	40*40	0.26	33.2	664
80*80	40*40	0.22	28.2	565
100*100	40*40	1.03	132.2	2643

The waste in the project is shown for each size of floor tiles for each of the rooms and bathrooms.

The order according to the colors is shown below in Fig. 13 and the order of appearance from left to right, as well as the order of the colors at the bottom of Fig. 13.

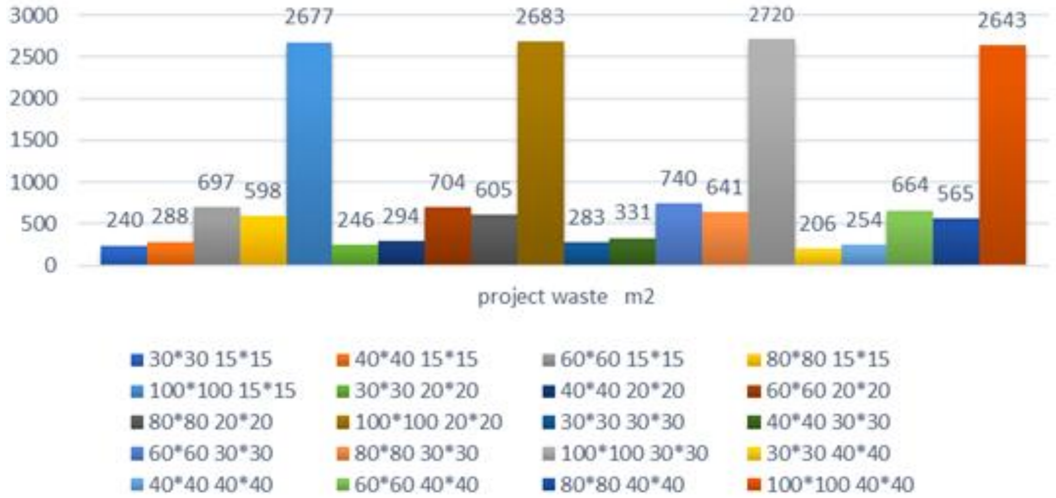

Fig. 13. **Wastage amount in tile sizes tested according to the new/proposed technique**

Construction waste amount for each size of bathroom and kitchen tiles in the apartment, building, and the whole project are shown in Table 4.

Table 4

CW amount for bathroom and kitchen tile sizes

Bathroom and kitchen tile sizes, cm*cm	One apartment waste, m^2	One building waste, m^2	Project total CW, m^2 (b&k)
40*40	0.15	19.2	384
30*30	0.07	9	179
20*20	0.01	1.3	26
15*15	0.01	1.2	23

Construction waste amounts mentioned in Table 4 are expressed according to the following Fig. 14.

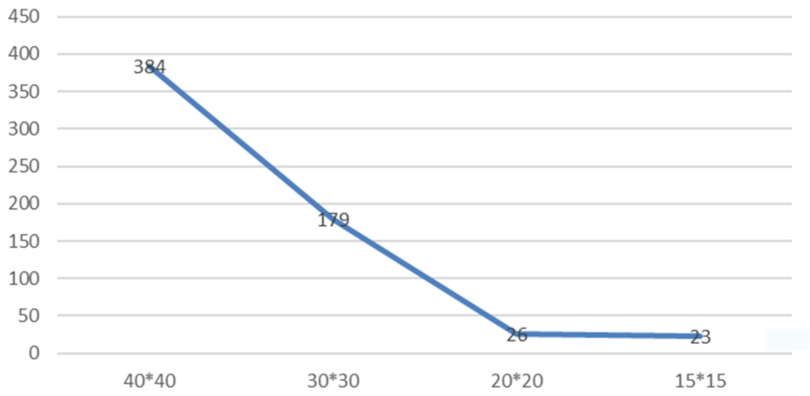

Fig. 14. **General curve of CW amount for tile sizes (bathrooms and kitchens), that were tested according to the new methodology**

Table 5

Waste amount for room tile sizes

Room tile sizes cm*cm	One apartment waste (rooms), m^2	One building waste (rooms), m^2	Project total CW, m^2 (rooms)
30*30	0.08	10.8	217
40*40	0.10	13.2	265
60*60	0.26	33.7	674
80*80	0.22	28.8	575
100*100	1.04	132.7	2654

Construction waste amounts mentioned in Table 5 are expressed according to the following Fig. 15.

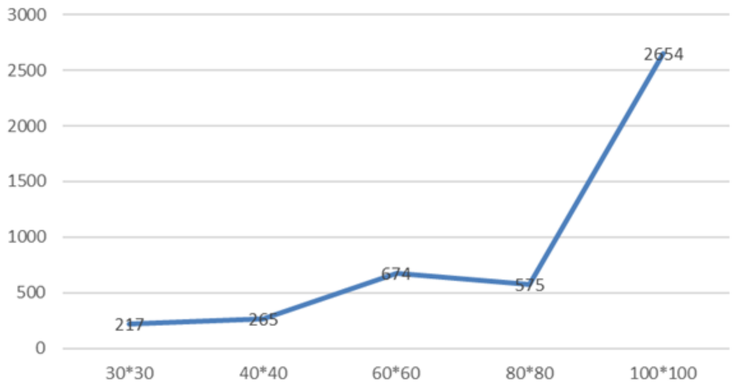

Fig. 15. **General curve of CW amount in rooms for tile sizes that were tested according to the new methodology**

The new methodology was applied by selecting floor tile sizes according to what is available in the local market for bathrooms and other rooms (bedrooms and sitting rooms) according to Table 1. Accordingly, by comparing the expected waste of sizes, it became clear that there are large differences between one size and another, as it appears to us that the difference in the percentage of waste in the sizes that achieve the least waste and those that achieve the highest amount of waste is only 92.4%.

Thus, the new methodology has shown the large differences in waste occurring for each size during the design phase, as shown in Table 6.

Table 6

Comparison between minimum and maximum waste amount according to the new methodology-NM

Floor tile sizes (max CW NM), cm	Floor tile sizes (min CW NM), cm	Min waste, m^2	Max waste, m^2	Waste reduction% 100*(max-min)/max
100*100 – Rooms 30*30 – Bath room	30*30 – Rooms 40*40 – Bath room	206	2720	92.4%

Results and discussion

From the above results, we can interpret them as follows. The explanation for our obtaining this large percentage of savings is due to the new technology reliance on visual programming provided by the Dynamo application within the BIM system, where waste is arranged between rooms in descending order, so that the waste (for the size used) is calculated in each room, and then by calculating the remaining size of one piece of tile and considering the possibility of using it in another room, for example, if we have the size for which the waste calculated is 40*40 cm and there are 30 cm wide tiles remaining in the room (X), while we need pieces with a width 20 cm in the room (Y) to finish the floor tile process in it. Thus, the proposed technique will calculate the waste through the residual or waste generated or produced in the smaller room only, because the pieces resulting from room (X) can be used to fill the space (20 cm) remaining from using the whole pieces (40*40 cm) in room (Y), and therefore according to this methodology we can say that the waste will be minimal, and it will allow us to direct work crews to carry out the work according to the order that will be determined by the proposed methodology for waste occurring in the rooms.

We have made a comparison of the expected waste in floor tiles for the current design sizes of the project, which will be implemented in traditional ways (without specifying any order in implementing the tile work in the rooms or spaces of the residential apartment) with the same sizes, but using the proposed method. Therefore, we interviewed some engineers and technicians specialized in implementing floor tiling works, who have experience in this field. We found out that the average rate of waste is approximately 5.5% of the floor tile area according to traditional working conditions (knowing that the average construction waste rate in engineering studies in Syria is 5%).

Table 8 shows a comparison between several options for choosing the appropriate floor tile size that gives the least amount of waste. The ratio of the minimum waste values mentioned in Table 7 to each of the waste occurring in the design size can be calculated according to the traditional and the new method.

Table 7

Comparison of CW between the used and ideal design option using the traditional and the proposed method

$W_{min.n}$, m^2	$W_{d.n}$, m^2	$W_{d.t}$, m^2	$W_{min.n}/W_{d.t}$	$W_{min.n}/W_{d.n}$	$W_{d.n}/W_{d.t}$
206	740	5775	3.6%	27.8%	12.8%

We coded some results with abbreviations such as $W_{min.n}$, $W_{d.n}$, $W_{d.t}$ according to the following:

- $W_{min.n}$ – minimum waste amount of tile sizes according to the new method.
- $W_{d.n}$ – waste amount of the design size according to the new method.
- $W_{d.t}$ – waste amount of the design size according to the traditional method.

Table 7 can be expressed according to the following two forms (Fig. 16 and Table 8).

From what was previously presented in Table 7, it is possible to infer the percentage of reduction that can be obtained in wasting floor tiles by comparing the previous options, which shows the possibility of significantly reducing waste according to the proposed method, as shown in Table 8.

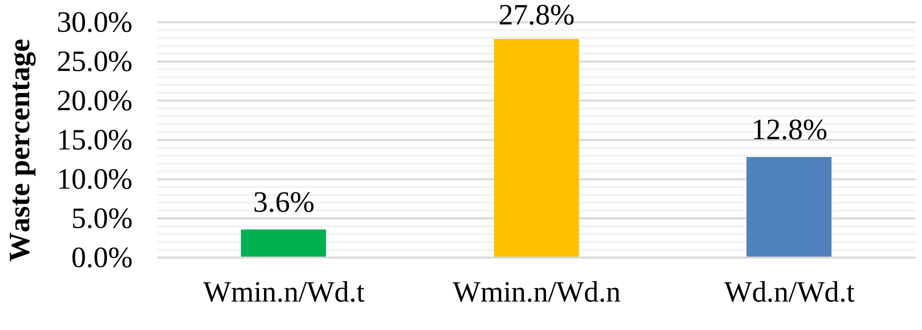

Fig. 16. **Comparing CW between the used design option and the ideal in the traditional and the proposed method**

Table 8

Comparison between the percentage of CW in the traditional and the new method

$W_{min.n}$	$W_{d.n}$	$W_{d.t}$	Ratio of CW reduction% for trad. method	Percentage of CW reduction between the wasteful size and the design size according to the new method	Percentage of CW reduction between the new and traditional method in the case of sizes approved in the project
m^2	m^2	m^2	$100 - (W_{min.n}/W_{d.t})$	$100 - (W_{min.n}/W_{d.n})$	$100 - (W_{d.n}/W_{d.t})$
206	740	5775	96.4%	72.2%	87.2%

Table 8 can be expressed according to the following form:

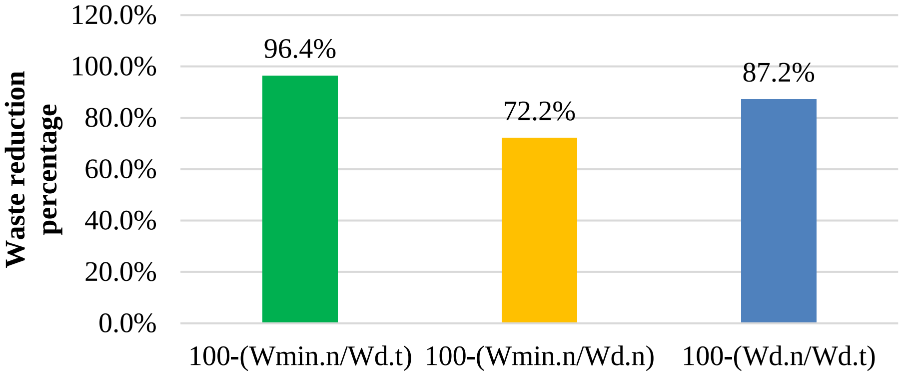

Fig. 17. **Comparison of CW reduction between the new and the traditional method**

The previous comparison of CW reduction achieved by the proposed method and with the traditional method contributes to supporting the shift to the use of the BIM technique in managing and reducing CW, which will contribute to creating more sustainable projects.

Most of the previous studies focused on reducing waste in floor tiles by theoretical modeling of some rooms. It is clear that this method does not lead to actual results, and does not lead us to solve the problem of construction waste formation in the project, that is, in our example, the problem of floor tile waste formation, as it does not focus on managing floor tile waste in the project in an integrated manner. Therefore, our research aimed to study a real project according to the design dimensions that will be implemented and we developed a technique that adopts the visual programming provided by BIM, as a result, we found that construction waste can be reduced to 96.42% by integrating implementation skills within BIM in a way that ensures the order of execution between rooms. That is, this sequential implementation that we obtained as a result of applying the visual programming method using Dynamo within the Revit or BIM in the design phase of the floor tile work in the residential/apartment project gives the least amount of waste possible. Here, the remaining sizes in the rooms can be measured and recommended directly, in advance, from the factory according to the actual dimensions and placed in special boxes numbered according to their sizes or place of installation. In this way, construction waste can be reduced to zero. In addition, implementation time can be reduced by up to 40% because floor tile technicians do not break or split them during their work. That is, the prefabrication process leads to a reduction in the project duration in general.

Conclusions

Based on the previous results, it seems to us that the new methodology for reducing waste in the design stage, relying on the BIM technique, especially relying on the visual programming provided by Dynamo, can actually achieve a reduction in construction waste in floor tiles by up to 96.4%. This percentage is considered very promising for reducing the cost of the project if it is applied and generalized to all project works or items, especially with the increase in the prices of building materials and the lack of financing and resources. Hence, sustainability standards can be achieved by preserving resources and reducing their waste. The new methodology also allows us to develop plans to implement the studied activities in a pre-directed manner, to achieve the desired goal of reducing waste, and to accurately identify resources at each stage to prevent waste.

This research highlighted the importance of adopting practices during the design phase that would achieve sustainability standards in the construction industry, as the clear success in reducing construction waste in our research demonstrates the possibility of using this methodology or method on a large scale, and not only for the benefit of companies seeking to reduce costs, but to contribute to a greener and more sustainable future.

Recommendations

The results of this research showed us the importance of using BIM techniques in the design stage as a key factor in reducing construction waste. These results indicate that reducing waste in the design stage leads to reducing costs, and also contributes to the possibility of reducing construction time by studying advance planning of the stages and steps of work in giving less time for activities or pre-cutting of tiles (or similar project work items) before tiling work begins, thus reducing the time required to carry out tiling operations.

The current model can also be developed to deal with large projects and other items in the project, and additional outputs related to cost and savings can be added, allowing the savings achieved to be measured directly, but this matter requires additional research in this field to achieve sustainability standards in the implementation of construction projects. Researchers also strongly recommend using this methodology in design and implementation, especially in large projects - Mega Project.

Author contributions

Conceptualization, MS and HA; methodology, MS and HA; software, HA; validation, HA; results discussion, HA and MS; writing – original draft preparation, HA; writing – review and editing, MS, HA; supervision, MS. All authors have read and agreed to the published version of the manuscript.

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