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Quantification of Construction Waste through BIM

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Abstract: Nowadays, green environment is a great concern in the construction industry because of its rapid growth in the construction sector and its direct connection with the detrimental impact on the environment. The construction sector contributes about 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill wastes. Developing country like Bangladesh did not use any proper waste estimation process or tools which can efficiently estimate the volume of materials needed for a construction project which always results in wasting excessive materials. Waste estimation can determine the volume of materials even in the pre-construction stage and thus reducing waste, cost and environmental impact. In the light of the gap of existing tools and methods to estimate the waste amount, Building Information Modelling (BIM) based system plays a vital role to estimate construction waste in the region of the rising amount of construction waste. In this paper, clash detection process has been described to estimate construction waste with the help of Autodesk Navisworks Manage software. Clash detection process contributes to estimate a large amount of waste among total waste generated in a building model. Different manual approaches have also been described that can estimate the total amount of construction waste. This paper also presents an example scenario with a 4-storied residential building model to demonstrate construction waste estimation systems. The case study shows that BIM-based waste estimation using clash detection could prevent 40-45% of construction waste that might have been generated without using BIM.

Keywords: Construction waste, BIM, cash detection, waste estimation

1. Introduction

Waste reduction is an issue in recent times. The amount of construction waste is still growing continuously and is not effectively managed in most countries in the world (Cheng & Ma 2013). Construction waste consists of bricks, concrete, steel, wood and it is generated during new construction and renovation of buildings, roads, bridges, and other infrastructure facilities (Osmani, 2011). Quantification of construction waste is essential for effective waste management and sustainable development (Solís-Guzmánet al. 2009, Saadi et al. 2016, Quiñoneset al. 2021). A massive amount of waste is generated during construction, renovation and demolition (Lu et al. 2017), and hence the quantification of construction waste is essential for effective waste management and sustainable development. According to the American Institute of Architects (AIA) Sustainability Discussion Group, 25% to 40% of total waste comes from building construction, which impacts the environment severely (Ding & materials 2014, Arshadet al. 2017, Khan et al. 2022). These vast amounts of construction waste cause a huge loss to economy and environment. The Construction & Demolition (C&D) waste is not managed effectively in most countries (Yu et al. 2022). Reduction,

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reuse, and recycling of C&D waste is the most used method by different countries to minimise C&D waste. The amount of C&D waste can be estimated and reduced by implementing BIM technology. Hewage & Porwal (2011) developed a system dynamics model and integrated it with BIM models to predict the generation of construction waste (Hewage & Porwal, 2011). Later, they proposed a BIM-based method to analyse reinforced concrete structures to reduce reinforcement waste by selecting proper lengths of rebar and considering available cut-off lengths. The construction waste estimation results could provide fundamental information for practitioners to evaluate the exact size of the waste and hence, make the adequate decision for their minimisation and sustainable management (Jalali, 2007). But there is a lack of construction waste estimation tools, and even available the tools and methods are not convenient enough for contractors to be willing to utilise without spending too much time and effort since information such as material volume needs to be either measured or retrieved from available documents manually. Building information modelling, however, provides the opportunity to fill this gap.

The amount of C&D waste can be estimated and reduced by implementing BIM technology. In the definition of a BIM-based approach for waste estimation, clash detection comes first. Clash detection provides an accurate and effective amount of waste within the total waste generated in the whole project. There are also many manual methods to estimate construction waste like estimation based on constructed area, estimation based on the components in a building, estimation based on indicator value, estimation based on the percentage by weight etc (Kang et al., 2022). By these formulas, total amount of construction waste can be estimated and by BIM-based clash detection, a significant percent of waste can be estimated among the total waste.

This paper is organised as follows. The next section provides a literature review of construction waste, waste estimation formulas and BIM implementation. Section 3 describes the methodology & materials of construction waste estimation according to this research. Section 3 also demonstrates a single unit four-story 4970 ft^2 residential building model. Section 4 presents the result & discussion of the potential use of BIM to estimate construction waste. Section 5 concludes the paper.

2. Literature Review

Building Information Modelling (BIM) based approach helps to estimate construction waste generated by improper design and unexpected changes in building design. Since most of the construction wastes are generated due to design errors, an integrated building design process is required to minimise and manage the waste. Construction waste defines the amount of waste generated in the building during the construction stage. It includes discarded materials such as blocks, bricks, concrete, glass, plastics, wood and soil generated by new building construction. Much building waste is made up of those materials damaged or unused for various reasons during construction. Construction waste causes high costs and therefore, waste reduction is needed to minimise costs. There are different manual formulas for waste estimation. For instance, the estimation based on constructed area, estimation based on the components in a building, estimation of C&D waste in a region through material stocks and flows, and estimation based on quantities obtained from related construction databases (Poonet al. 2001).

Table 1 - Waste Index for the Hong Kong construction industry

Project	Construction waste index (m^3/m^2 GFA)
Public residential	0.175
Private residential	0.250
Commercial office	0.200

Source: Poon et al. (2001)

2.2 Estimation Based on the Components in a Building

The amount of waste depends on the area of a specific component and component index. Jalali (2007) introduced a ‘‘component index’’ approach which helps to estimate waste amount depending on construction components in a building, as shown in Table 2 below.

Table 2 - Component index of a specific component

Component	Component index
Formwork (wood waste	0.39 kg/m2
Armouring (metal waste	1.00 kg/m2
Concrete (concrete rubble	24.92 g/m2

2.3 Estimation Based on Indicator Value

There are three indicator values among which any indicator value can be used to estimate waste relating to constructed area (Villoria Sáez et al. 2012). The indicator values are: 0.12 m^3/m^2- 0.31 m^3/m^2 (Solís-Guzmán et al. 2009)

2.4 Estimation Based on Percentage by Weight

The amount of waste is estimated by the percentage of waste according to the purchased amount. According to Li et al. (2013), the amount of wastage, steel is 21% of the purchased amount, and wastage of brick is 11% of the purchased brick.

2.5 Building Information Modelling (BIM) Tools

In this paper, two BIM tools have been used for construction waste estimation, as follows.

- Autodesk Revit 2016

BIM represents a design as combinations of "objects" or geometric generic models or shapes. BIM design tools allow the extraction of different views from a model for the production of drawing among other things. These different views are automatically consistent, as they come from a single definition of each "object instance". Objects are treated as parameters and are related to other objects with the relational database system. So any changes in one attribute of a member in the project get automatically updated instantly throughout the whole project according to their relationship.

- Autodesk Navisworks Manage 2019

Navisworks is not a 3D modelling program but a program that converts large REVIT 3D model files into smaller 3D models that are far more manageable for a multitude of team members. Navisworks is a powerful desktop application that can filter and separate specific model information. It will not be a program to replace REVIT, but a tool that works in conjunction with REVIT and makes certain processes much more efficient. There are three different versions of Autodesk Navisworks. Those are Autodesk Navisworks Freedom, Autodesk Navisworks Simulate and Autodesk Navisworks Manage. Navisworks Manage has the most powerful tools among those. So we are going to use Navisworks manage.

3. Methodology and Materials

The whole process of this study is described in Fig. 1. This section includes the creation of a residential building model, waste estimation by manual formulas, clash detection, calculation of clash volume, estimation of waste from clash volume, planning of waste and finally, the questionnaire survey mainly to determine the efficiency of clash detection in the waste estimation.

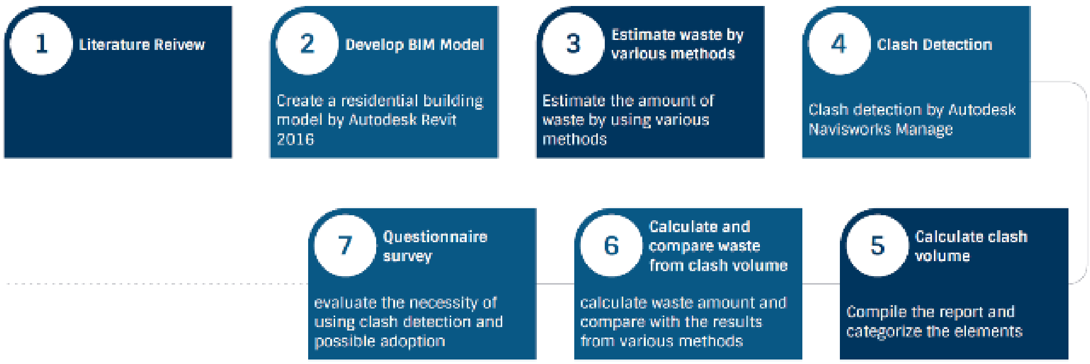


Fig. 1 - Overall process of the study

3.1 Develop BIM Case Model

The residential building model was created in Autodesk Revit 2016. It is a single unit four-story consists of three bedrooms, one guest room, one drawing room, one dining, one kitchen & one storeroom. The total floor area of the four-story is4970 ft^2. The building shape is a '4' shape. The building is made of brick, concrete, mortar and steel. The plan view and 3D model of the case project have been represented in Fig. 2 and 3 respectively.

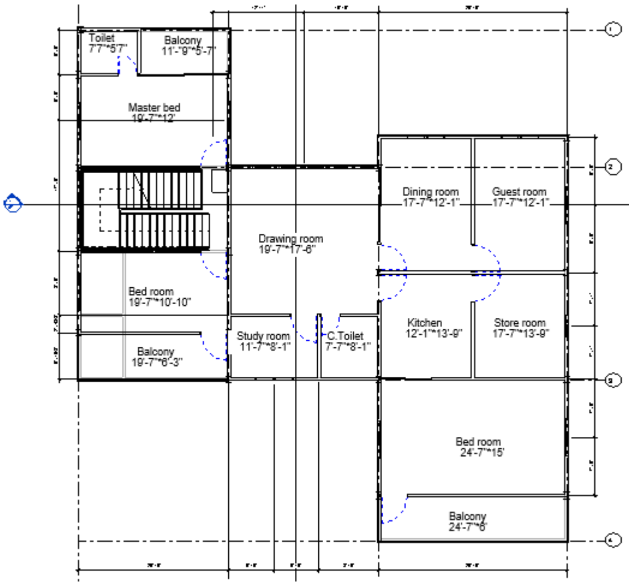


Fig. 2 - Plan view of that residential building

Fig. 3 - D view of that residential building

3.2 Waste Estimation by Manual Formula

3.2.1 Estimation Based on Constructed Area

Total waste in a construction project = GFA * Waste Index
Waste index of private residential area = 0.250 m^3/m^2
Floor area of the case building = 71ft×70 ft≈ 462 m^2
Therefore, the amount of total waste = 462×0.250 = 115 m3
Percentage of waste according to area = 25%

3.2.2 Estimation Based on the Components in a Building

Amount of waste = Area of specific component*component index
Component index of Formwork (wood waste = 0.39 kg/m^2)
Armoring (metal waste = 1.00 kg/m^2)
Concrete (concrete rubble = 24.92 kg/m^2)
Area of roofing = 21.65×21.34 m^2 = 462 m^2
Formwork waste = 462×0.39 = 180.18 kg
Armouring waste = 462×1.00 = 462 kg
Concrete rubble = 462×24.92 = 11513.04 kg
Total waste =11513.04~11520 kg = 11.5 ton
Percentage of waste according to area = 2.5%

3.2.3 Estimation Based on Indicator Value

Total volume of generated waste =$i_x \times S_t$
Indicator value = 0.27m^3/m^2
Total build surface = 21.65×21.34 m2 = 462 m2
Amount of total waste = 462×0.250 = 115 m3
Percentage of waste according to area= 25%

3.2.4 Estimation of Construction Waste in Thailand

Total waste in a construction project $Q_x = A \times G_{av} \times P_x$
The average waste generation rate G_{av} = 21.38 kg/m^2
Total waste in a construction project = 462 × 21.38 = 9877.56 kg = 9.9 ton

3.2.5 Estimation Based on Percentage by Weight

Wastage of steel = Amount of purchased steel × 21/100
Wastage of cement = Amount of purchased cement × 25/100
Wastage of sand = Amount of purchased sand × 28/100
Wastage of mortar = Amount of mortar × 50/100
Wastage of brick = Amount of purchased brick × 11/100

3.3 BIM-Based Waste Estimation

3.3.1 Clashed Detection

Clash detection is a BIM-based approach for waste estimation. Autodesk Navisworks Manage 2019 has been used for clash detection and the overall process has been represented in Fig. 4. Due to the clash detection in this research firstly the software Navisworks manage has been opened and clash detective option is chosen. For clash detection two models are needed, architectural Revit model (.rvt extension) and structural Revit model. So these two models are added in add test stage under clash detective. At the final stage, two models are selected for the test run and finally run the test. After run test the clash report is ready and saved in html file.

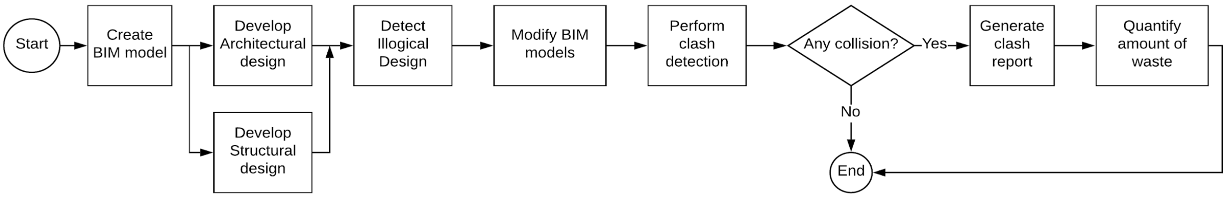


Fig. 4 - Clash detection process through BIM based design

3.3.2 Calculation of Clash Volume

To calculate the clash volume, first, different types of clashes are selected. Like column-roof clash, column-wall clash, wall-column clash, wall-slab clash, wall-beam clash, roof-column clash, tread/riser-beam clash, tread/riser-column clash, beam-wall clash, cable tray-beam clash, railing-slab clash, railing-column clash, railing-beam clash, railing-beam 2 clash, stringer-column clash, stringer-beam clash.

Column-roof clash volume = column length*column width*roof thickness
Column-wall clash volume = column length*column width*wall thickness
Wall-column clash volume = wall height*wall thickness*column width
Wall-slab clash volume = wall length*wall thickness*slab thickness
Wall-beam clash volume = beam height*beam width*wall thickness

3.3.3 Waste Estimation from Clash Volume

Amount of waste according to each element is estimated. Like amount of waste done by column, beam, wall, roof, railing etc. Percentage of waste done by each element is also determined. And finally amount of waste estimated by clash detection among total waste is determined.

Amount of waste due to wall = ∑Clash volume done by wall *100/Total clash volume
Amount of waste due to beam= ∑Clash volume done by beam *100/Total clash volume

3.4 Questionnaire Survey

A questionnaire survey was conducted to evaluate the necessity of performing clash detection in Bangladesh, the reasons of adopting BIM and the limitations of BIM-based approaches. A sample survey form was prepared emphasising on the reducible amount of waste by clash detection. 8 questions were involved in the form and there were options to marking on a scale of 1 to 5 numbers.

3.5 Model Validation

As software-based simulations are very complex and hard to calculate manually, model validation is needed for that simulation. Model validation ensures the results and steps of an approach by using the same method on different models and comparing the outcome. In this study, results are validated by comparing with a reference model. A reference model was taken from (Wonet et al., 2016) where there were two test cases. Case 1 was chosen for its functionality and design. Case 1 involved two residential buildings, which are reinforced concrete structures with a total floor area of about 120,000 m^2 the authors of the paper deployed BIM-based design validation in the preconstruction and construction phases because BIM models in the cases were created after design processes were completed. Since the case was complicated, the contractor decided to adopt BIM to effectively manage the project.

The reference model had 136 design errors which was later categorised and calculated. There was no methodological difference from our process. Each design error were identified during the process, was recorded using a BIM issue report template with screenshots and short descriptions of the problem. The result of construction waste reduction was 15.2% which varies ~4% from our result. The reason for the variation might be the exclusion of MEP design file in our paper.

4. Results & Discussion

Clash detection results are compared with manual formulas. There are four manual formula for estimation. Estimation based on constructed area refers to estimate with the help of index value. The index value differ from public residential building to private residential building and Industrial office. Estimation based on the components in a building helps to estimate according to separate component. Like roof, formwork, armoring, and concrete waste. Estimation based on indicator value, there are three different indicator value. One of these values is used to estimate the amount of waste. According to estimation of construction waste in Kofoworola & Gheewala (2009), total waste depends on the average waste generation rate and area of the building.

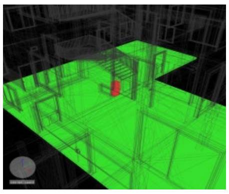
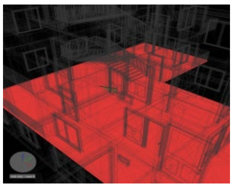
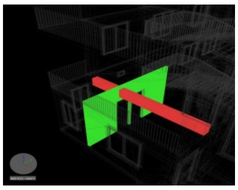
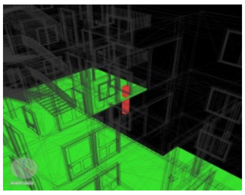
4.1 Amount of Waste Based on Manual Formula

- Estimated waste based on constructed area: 25%
- Estimated waste based on the components in a building: 2.5%
- Estimation based on indicator value : 25%
- Estimation of construction waste in Thailand: 9.9 ton

4.2 Clash Report

Clash detection has been run on the case model and the result has been shown in table 3.

Table 3 - Report of Clash Detection

Clash Name	Component 1	Component 2 (Clashing with component 1)	Image
Clash 1-Clash 6	Structural Columns: Concrete-Rectangular-Column: 12 x 18	Roofs: Basic Roof: S6	
Clash 7-Clash20	Structural Foundations: Foundation Slab: 6" Foundation Slab	Railing	
Clash21	Structural Framing: Concrete-Rectangular Beam: 12 x 24	Walls: Basic Wall: 5 in wall	
Clash22	Structural Columns: Concrete-Rectangular-Column: 12 x 18	Roofs: Basic Roof: S6	

4.3 Estimate Waste Amount from Clash Volume

Table 4 - Clash volume categorised by elements

Element	Clash Name	Volume (ft^3)
Column (roof)	Clash 1-6 Clash 22-30 Clash 34-102 Clash 112-116 Clash 682-684 Clash 1038	576*95=54720=32 ft3 =1.7%
column (wall) TOTAL=5.12%	Clash 167-194 Clash 204-211 Clash 232-234 Clash 405-411 Clash 418-423) Clash 431-432 Clash 520 Clash 528-535 Clash 541 Clash 543-548 Clash 677-681 Clash 704 Clash 713-714 Clash 717-727 Clash 740-741 Clash 877-878	1080*97=104760=61 ft3 =3.42%
WALL (column)	Clash 117-130 Clash 144-163 Clash 216-217 Clash 230-231 Clash 236-237 Clash 240-247 Clash 265-278 Clash 280 Clash 282-289 Clash 291-314 Clash 326-371 Clash 416-417 Clash 468-478 Clash 487-490 Clash 494-501 Clash 552-562 Clash 574-577 Clash 583-585 Clash 587-5970 Clash 598 Clash 606-642 Clash 646 Clash 652-666 Clash 692-699 Clash 709-712 Clash 810 Clash 811-820 Clash 827-837 Clash 869-870	5040*319=1607760=930 ft3 =52.07%

	Clash 967-969 Clash 980-982 Clash 986-988 Clash 1004-1015	
WALL (slab)	Clash 195-203 Clash 253-264 Clash 316-325 Clash 436-466 Clash 579-581	2160*65=140400=81.25 ft3 =4.55%
WALL (beam) TOTAL=58.5%	Clash 582 Clash 913-932 Clash 939-941 Clash 951-960 Clash 1024-1029	1440*40=57600=33.33 ft3 =1.88%
ROOF (column) TOTAL=4.5%	Clash 372-404 Clash 413-414 Clash 425-430 Clash 467 Clash 473 Clash 474 Clash 479-486 Clash 491-493 Clash 503-507 Clash 509-517 Clash 521-527 Clash 535-539 Clash 549-551 Clash 566-570 Clash 573 Clash 578 Clash 601-605 Clash 651 Clash 685-691 Clash 1039	1296*105=136080=78.8 ft3 =4.5%
TREAD/RISER (beam)	Clash 138-143 Clash 647-648	34560*8=276480=160 ft3 =8.96%
TREAD/RISER (column) TOTAL=9.96%	Clash 758-761 Clash 766-767 Clash 776-777 Clash 786-791 Clash 800-805 Clash 742-745	1296*24=31104=18 ft3 =1%
BEAM (wall) TOTAL=3.03%	Clash 228-229 Clash 250-252 Clash 279 Clash 281 Clash 290 Clash 301 Clash 312 Clash 315 Clash 331 Clash 348 Clash 364 Clash 412	1440*65=93600=54.17 ft3 =3.03%

	Clash 434-435 Clash 449 Clash 455 Clash 488 Clash 502 Clash 518-519 Clash 540 Clash 542 Clash 546 Clash 586 Clash 598 Clash 600 Clash 844-868 Clash 871-876 Clash 879-882 Clash 1062	
CABLE TRAY (beam) TOTAL=0.26%	Clash 131 Clash 164-166	2016*4=8064=4.67 ft3 =0.26%
RAILING (slab)	Clash 7-20 Clash 700-703 Clash 730-739	216*28=6048=3.5 ft3 =0.2%
RAILING (beam)	Clash 667-676 Clash 705-708	34560*14=483840=280 ft3 =15.68%
RAILING (column) TOTAL=17.48%	Clash 746-757 Clash 762-765 Clash 768-785 Clash 792-799 Clash 806-809 Clash 942-0946 Clash 970-1003 Clash 1040-1061	432*96=41472=24 ft3 =1.34%
RAILING (beam)	Clash 883-892 Clash 909-912	576*14=8064=4.67 ft3 =0.26%
STRINGER (beam)	Clash 715-716 Clash 838-843	576*8=4608=2.67 ft3 =0.15%
STRINGER (column) TOTAL=1.15%	Clash 212-215 Clash 223-226 Clash 238-239) Clash 248-249 Clash 643-644 Clash 649-650 Clash 728-729 Clash 821-826 Clash 893-908 Clash 933-938 Clash 947-950 Clash 961-966 Clash 1016-1023 Clash 1030-1037	432*72=31104=18 ft3 =1%
	Total =	3085704=1786 ft3

4.3.1 Clash Volume Categorised by Elements

Fig. 6 represents percentage of clash volume covered by each element separately. The X axis represents percentage of clash volume and Y axis represents element name. This diagram shows that maximum clash volume is covered by wall, chronologically railing, tread, column, roof, beam, stringer and the minimum volume is covered by cable tray. Wall covers 58.50% waste among total waste estimated by clash detection.

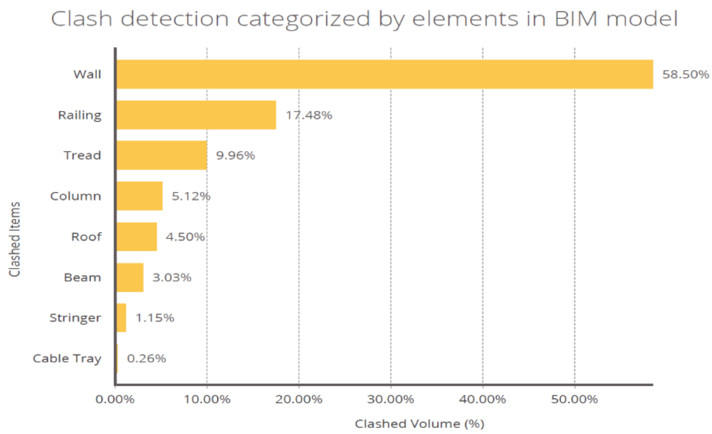


Fig. 6 - Clash detection categorised by element in BIM model

4.3.2 Clash Volume Categorised by Wall

Fig. 7 represents the clash volume covered by wall. Wall clashes with different element like beam, slab and column. Each type of clash covered different amount. This Fig. shows that clash volume covered by wall with column is maximum; it includes 89% of clash done by wall. Wall also clash with slab and beam and it includes 7.8% and 3.2% of total volume covered by wall.

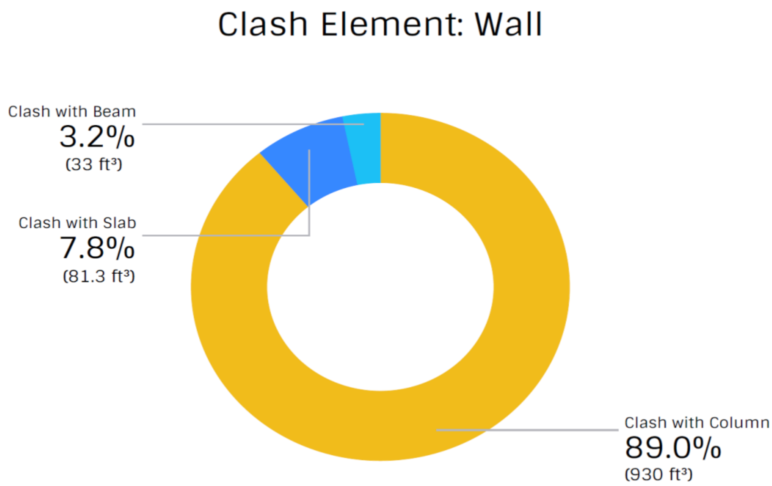


Fig. 7 - Clash detection categorised by the wall in BIM model

4.3.3 Clash Volume Categorised by Column

Fig. 8 represents the clash volume covered by column. Column clashes with different elements like roof and wall. Each type of clash covered a different amount. It shows that clash volume covered by column with the wall is maximum; it includes 66.8% of clash done by column. Column also clashes with the roof and it includes 33.2% of the total volume covered by the column.

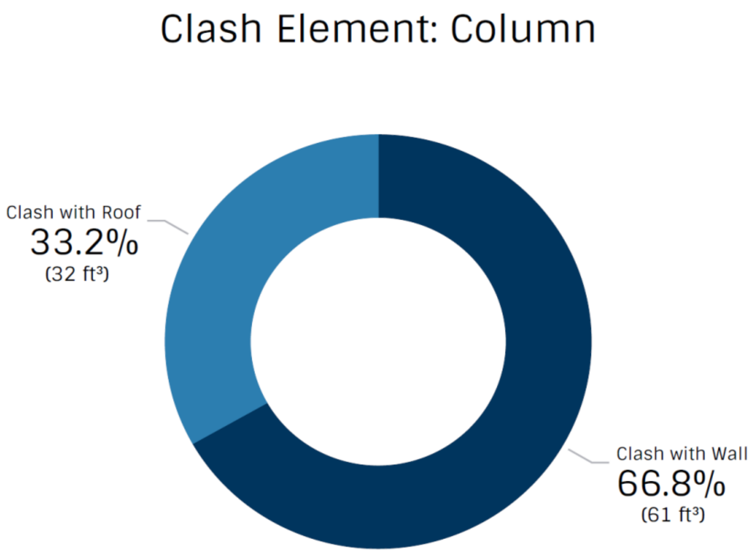


Fig. 8 - Clash detection categorised by column in BIM model

4.3.4 Clash Volume Categorised by Railing

Fig. 9 represents the clash volume covered by the railing. Railing clashes with different elements like slab, column and beam. Each type of clash covered a different amount. It shows that clash volume covered by railing with the beam is maximum; it includes 91.18% of the clash done by the railing. The railing also clashes with slab and column, it includes 1.15% and 7.67% of the total volume covered by the railing.

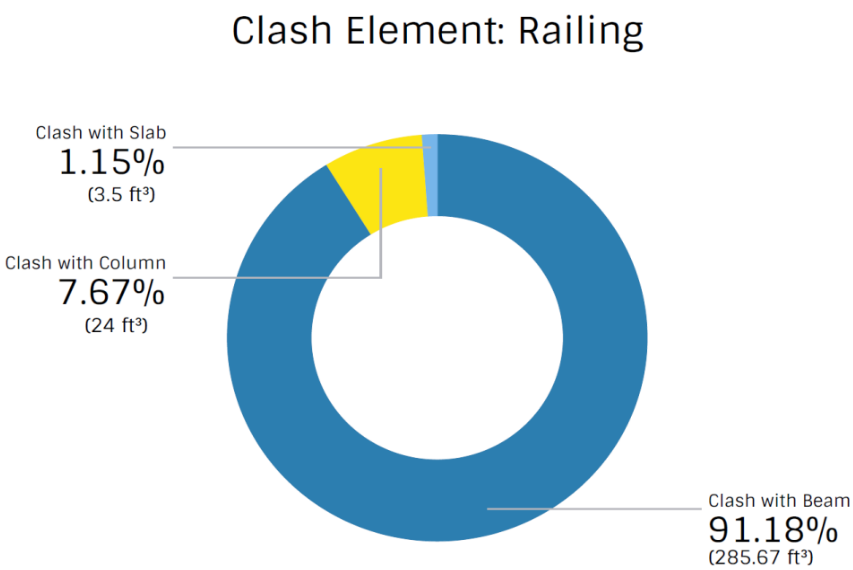


Fig. 9 - Clash detection categorised by the railing in BIM model

4.3.5 Clash Volume Categorised by Tread

Fig. 10 represents the clash volume covered by tread. Tread clashes with different elements like beam and column. Each type of clash covered a different amount. This Fig. shows that clash volume covered by tread with the beam is maximum; it includes 90% of clash done by tread. Tread also clash with a column, it includes the rest 10% of the total volume covered by tread.

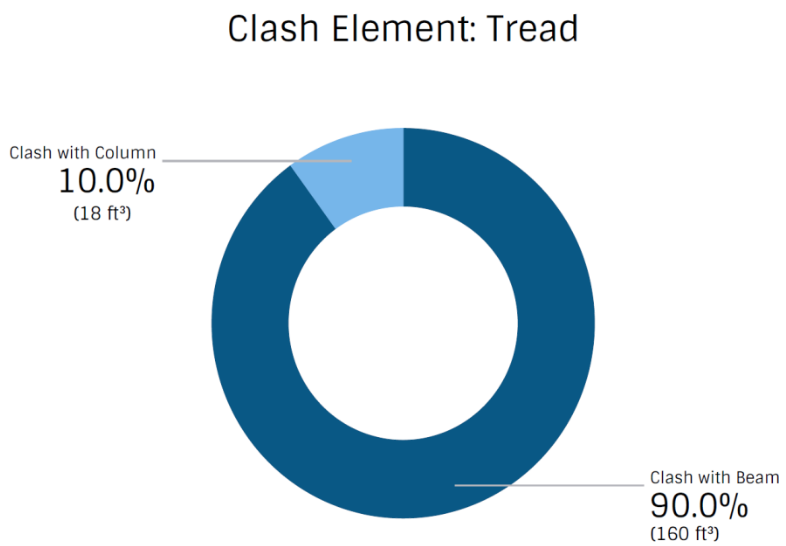


Fig. 10 - Clash detection categorised by tread in the BIM model

4.4 Total Waste

Total waste estimated by clash detection = $1786/3.28^3$ = $50.61m^3/462 * 100$ = 10.96% = ~11%. The volumes of construction waste avoided by using BIM-based design validation (Clash detection) were 11% compared with the total volume of the project which is shown in Fig. 11.

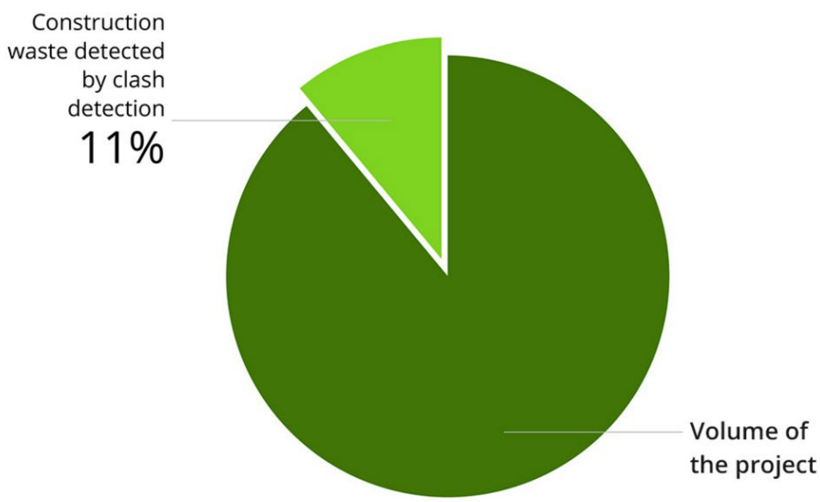


Fig. 11 - Clash volume vs. Total volume of the project

Then, the amount of construction waste estimated from clash detection (11%) was compared with the amount of construction waste estimated by various methods (25%). The reducible waste quantified by clash detection among total construction waste was (11 * 100/25) % = 44%) that has been represented in fig. 12.

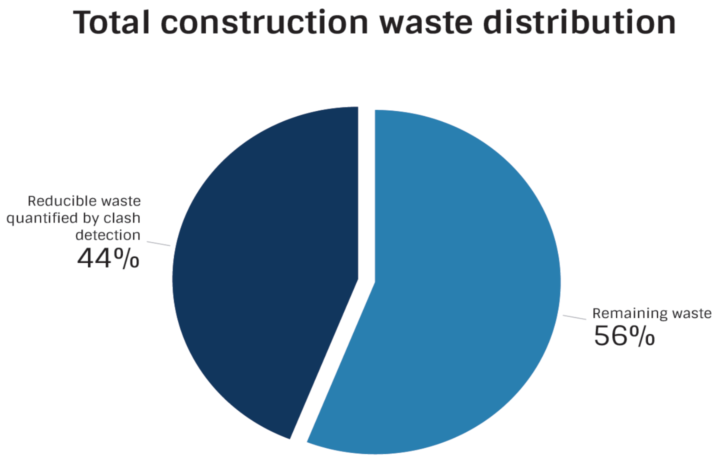


Fig. 12 - Total construction waste distribution

4.5 Questionnaire Survey

The survey was based on two major questions. One of these is that BIM-based approach reduces 44% of construction waste so will firms of Bangladesh adopt BIM in the construction industry. 85% of BIM experts said yes it is and the rest 15% said no & gave their opinion on not adopting BIM. Fig. 13 represents the possibility of adopting BIM in Bangladesh according to experts' opinions.

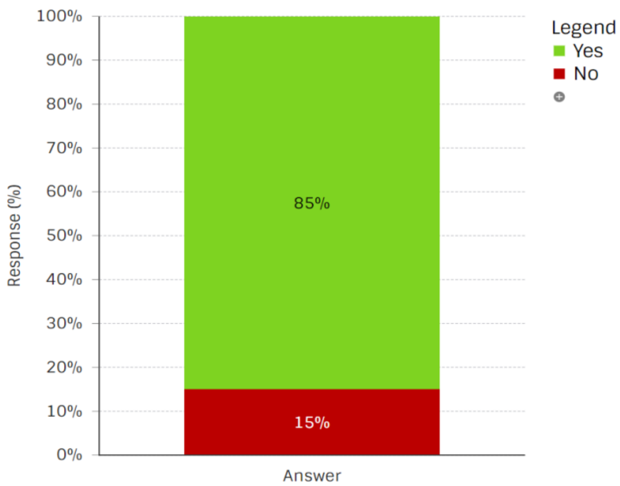


Fig. 13 - Possibility of adopting BIM in Bangladesh

The second major question was as clash detection was the major tool of BIM used in our research to estimate and reduce waste, how likely will it be used considering its efficiency? It was ranked in 1 to 5. 1 means least likely and 5 means very likely thus likeliness increases to increase the number. Fig. 14 shows that maximum experts choose number 3 which means the medium level of likeliness. 65% experts choose number 3, 10% choose 2, 25% choose 4 and rest 10% choose number 5.

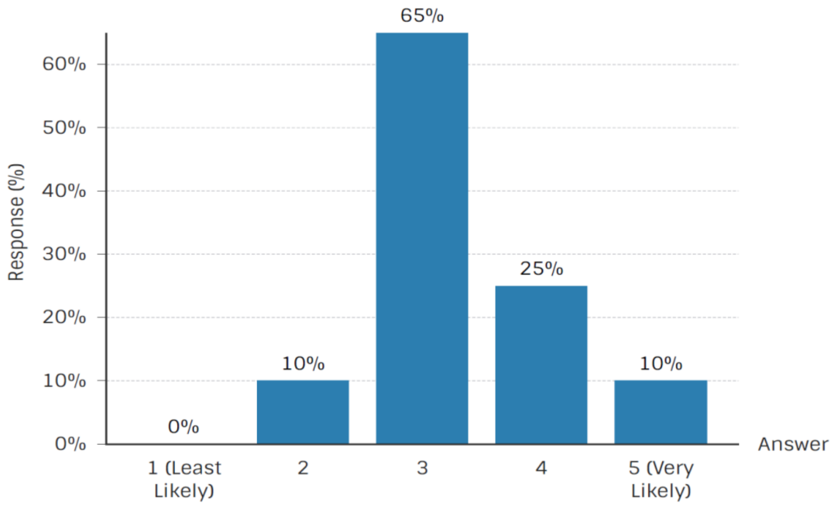


Fig. 14 - Likeliness of using clash detection

5. Conclusion

The amount of total construction waste generated within the building is 25% of constructed area. The quantifiable amount of waste by clash detection is 11%, whereas the clash detection estimates around 44% of total waste. This 44% of waste is generated because of design errors and unforeseen clashes. Therefore, a proper designing should be prioritised and BIM-based tools stated in this research should be used to verify the design and reduce construction waste. It will save materials, cost and time which is important to economise the project and prevent cost overrun. It will help to make the project environment-friendly. The waste estimation includes two concepts manual formula and clash detection. Between these two, clashes detection is the most accurate and efficient approach. BIM-based approach clash detection helps to estimate a large amount of waste in the pre-construction stage. By estimating waste in the pre-construction stage we can easily reduce construction waste. Clash includes a large part of construction waste. Clash detection is one of the most accurate and efficient approaches for quantification and reduction of construction waste. Wall causes the maximum amount of waste and it is 25.74% within 44% waste, railing causes 7.69% waste, tread causes 4.4% waste, column causes 2.25% waste, roof causes 1.98% waste, beam causes 1.33% waste, cable tray causes 0.51% waste.

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References

Arshad, H., Qasim, M., Thaheem, M. J., & Gabriel, H. F. (2017). Quantification of material wastage in construction industry of Pakistan: An analytical relationship between building types and waste generation. Journal of Construction in Developing Countries, 22(2), 19-34.

Cheng, J. C., & Ma, L. Y. (2013). A BIM-based system for demolition and renovation waste estimation and planning. Waste management, 33(6), 1539-1551.

Ding, G. K. (2014). Life cycle assessment (LCA) of sustainable building materials: an overview. Eco-efficient construction and building materials, 38-62.

Hewage, K., & Porwal, A. (2011, July). Sustainable construction: an information modelling approach for waste reduction. In International Conference on Building Resilience, Kandalama, Sri Lanka.

Jalali, S. (2007). "Quantification of construction waste amount."Kang, K., Besklubova, S., Dai, Y., & Zhong, R. Y. (2022). Building demolition waste management through smart BIM: A case study in Hong Kong. Waste Management, 143, 69-83.

Khan, A., Yu, R., Liu, T., Guan, H., & Oh, E. (2022). Drivers towards Adopting Modular Integrated Construction for Affordable Sustainable Housing: A Total Interpretive Structural Modelling (TISM) Method. Buildings, 12(5), 637.

Kofoworola, O. F., & Gheewala, S. H. (2009). Estimation of construction waste generation and management in Thailand. Waste management, 29(2), 731-738.

Li, J., Ding, Z., Mi, X., & Wang, J. (2013). A model for estimating construction waste generation index for building project in China. Resources, Conservation and Recycling, 74, 20-26.

Lu, W., Webster, C., Peng, Y., Chen, X., & Zhang, X. (2017). Estimating and calibrating the amount of building-related construction and demolition waste in urban China. International Journal of Construction Management, 17(1), 13-24.

Osmani, M. (2011). Construction waste. Waste, Elsevier.

Porwal, A., & Hewage, K. N. (2012). Building information modeling–based analysis to minimize waste rate of structural reinforcement. Journal of construction engineering and management, 138(8), 943-954.

Porwal, A., & Hewage, K. N. (2012). Building information modeling–based analysis to minimize waste rate of structural reinforcement. Journal of construction engineering and management, 138(8), 943-954.

Quiñones, R., et al. (2021). "A Multiplatform BIM-Integrated Construction Waste Quantification Model during Design Phase. The Case of the Structural System in a Spanish Building, 6(3): 62.

Saadi, N., Ismail, Z., & Alias, Z. (2016). A review of construction waste management and initiatives in Malaysia. Journal of Sustainability Science and Management, 11(2), 101-114.

Solís-Guzmán, J., Marrero, M., Montes-Delgado, M. V., & Ramírez-de-Arellano, A. (2009). A Spanish model for quantification and management of construction waste. Waste Management, 29(9), 2542-2548.

Villoria Sáez, P., del Río Merino, M., & Porras-Amores, C. (2012). Estimation of construction and demolition waste volume generation in new residential buildings in Spain. Waste management & research, 30(2), 137-146.

Won, J., Cheng, J. C., & Lee, G. (2016). Quantification of construction waste prevented by BIM-based design validation: Case studies in South Korea. Waste Management, 49, 170-180.

Yu, S., Awasthi, A. K., Ma, W., Wen, M., Di Sarno, L., Wen, C., & Hao, J. L. (2022). In support of circular economy to evaluate the effects of policies of construction and demolition waste management in three key cities in Yangtze River Delta. Sustainable Chemistry and Pharmacy, 26, 100625.