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BWM-Method Prioritizing of Clashes Detected During the Construction Design Phase with Building Information Modeling (BIM)

Iman Bitaraf, Ali Akbar Shirzadi Javid *

School of Civil Engineering, Iran University of Science and Technology, P.O. Box 16765-163, Narmak, Tehran, Iran

ABSTRACT: Today, due to the complexity of construction projects, Building Information Modeling (BIM) is used to increase accuracy and speed and avoid the cost of rework in a building's construction cycle. One of the most important functions of BIM technology in the design and construction phase is the identification of clashes and their reporting. The purpose of this study is to classify and prioritize the serious clashes between the two disciplines of structures and MEP. To do this, each structure type and MEP element must be assigned the required weight, which is done using the best-worst method (BWM). The corresponding questionnaire is distributed to nine BIM experts. With the help of weights and the outputs of the Navisworks software, the process of prioritizing clashes and the methods of eliminating clashes are carried out. Of the structural elements, 32% are accounted for by each beam and column element, 19% by the foundation, 13% by lateral bracing systems , and 4% by the structural floor. Due to the many elements of the MEP, they are divided into six groups. The weighting of MEPs (costs) is 39% for group five, 22% for group two, 15% for group six, 11% for group three, 9% for group four and 4% for group one. Additionally, the MEP weight (time) items are 39% for group five, 20% for group six, 14% for each item from groups two and three, 8% for group four, and 5% for group one.

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1- Introduction

When the design models of different disciplines, including architectural, structural, and MEP (mechanical, electrical, and plumbing), are integrated for coordination purposes, there will be overlap between the various elements of each group and the elements of other groups. These overlaps are referred to as clashes in the coordination discussion. It is normal for clashes to arise between two different disciplines, as each designer in these disciplines models their designs separately and has no knowledge of other designers' models. One of the BIM tools in this area is Autodesk's Navisworks software, which is currently considered the most powerful clash identification and resolution software. On the other hand, it is also worth mentioning that some of the clashes detected by the Navisworks software are considered independent clashes that do not require any action or a clear solution to resolve them. Based on the points discussed, it can be concluded that inaccurate identification and inappropriate prioritization of clashes during the design phase, as well as the persistence of clashes during project execution, have consequences such as deterioration in work quality, non-compliance with the project schedule, rework, increased project costs, and time expenditure due to the Time spent resolving the clashes.

The study by Mangal et al. [1] aimed to study an optimized, automated framework for clash-free steel reinforcement design based on BIM. The aim was to estimate the minimum height of the reinforcing bars and to take into account design regulations and building requirements. In addition, the reinforcement provided must not lead to clashes in the connections between columns and beams. Hua and Castro [2] believed that historical data could also be used to optimize clash detection. In previous studies, they used Bayesian statistics to improve the detection of relevant and irrelevant clashes. Supervised machine learning algorithms automatically detected relevant and irrelevant clashes in another study. In this paper, six automatic clash detection algorithms were used, and the results showed that the Jrip method performed better than other methods [3]. In another article, Mehrbod et al. [4] created a classification of coordination improvement problems and classified clashes based on their causes. This classification improves the design coordination process. Their goal was to understand the causes of design clashes and consider clash factors to resolve them. Another article proposed network analysis to improve clash detection from a comprehensive perspective because a building is an inseparable entity and clashes affect the dependency relationships between its components.

A component-dependent network was created by

*Corresponding author's email: shirzad@iust.ac.ir

adopting three dependent relationships from BIM models that incorporate network thinking in clash management. This article mainly focused on using the network to preprocess clash reports by removing irrelevant clashes, grouping related clashes, identifying central components, and analyzing the environment of focused clashes [5]. A method was developed by Lin and Huang [6] that automatically examines and filters out irrelevant clashes by combining two techniques of rule-based reasoning and supervised machine learning. Although the average prediction accuracy of the combined method is up to 95%, some associated noise is incorrectly identified as irrelevant and filtered out. Hsu et al. [7] developed an effective programming system to automatically resolve clashes in MEP system designs when BIM models are completed by different members of the design team and integrated into a comprehensive and coherent BIM model.

BIM software and Application Programming Interface (API) were used to apply the Simulated Annealing (SA) algorithm to identify design changes and minimize the number of clashes in the design. Another study proposed an artificial intelligence system that uses machine learning techniques and exploratory optimization to coordinate with designers and builders and resolve clashes in the preconstruction phase in a short time. The knowledge-based system proposed in this research consists of two main components: 1) Building a knowledge model from the builder's perspective. 2) Optimize the MEP design with an objective function to "minimize design clashes"[8]. In the latest study in this field, researchers used the AHP fuzzy method to weigh the elements and by finding a suitable relationship and then implementing it in a real project, they developed an add-on for Autodesk Navisworks called Clashes automatically prioritized [9, 10].

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This study proposed a comprehensive and practical approach to improve and optimize the process of identifying and resolving clashes and to address the shortcomings of previous studies as much as possible. Suppose important clashes need to be accurately identified and resolved during the design phase. In this case, the workload increases and jeopardizes the quality, time, and cost of the project. This research aims to improve the accuracy of identifying and resolving clashes in structure and MEP. This research used a formula that was also used in the most recent study, which assigns each clash a quantitative value that can be applied to prioritize existing clashes accordingly. The innovation in this research is to use a method called the Best Worst Method (BWM) to weigh and prioritize clashes and weight and prioritize clash resolution methods instead of the AHP fuzzy method used in previous studies.

2- Research Methodology

As explained in the above section, the innovation of this research is the use of the BWM method, and the advantages of using this method over similar techniques should be identified. The BWM method, like AHP, ANP, and other fuzzy models, is based on a pairwise comparison matrix. However, the difference is that the number of pairwise comparisons in this method is much less than in other similar methods. For example, if the number of criteria is denoted by m, the number of pairwise comparisons in the AHP and BWM methods is as follows:

$$\begin{aligned} &\frac{m(m-1)}{2} = AHP \\ &2m-3 = BWM \end{aligned} \tag{1}$$

The questionnaire method used in the BWM method is easier to implement than other methods based on a paired comparison matrix. In addition, the compatibility of the results is higher in the BWM method. The creator of the BWM method also compared other criteria such as the Minimum Variance (MV), Total Deviation (TD), and Conformity (C) criteria between the BWM and AHP methods in the same problem and the results show the superiority of the BWM method versus AHP method [11, 12].

The first step of this research is to calculate the weights of the elements and clash resolution methods. There are various methods for multiple criteria decision-making (MCDM), and one of these methods is the Best Worst Method (BWM). The steps of the BWM method for determining the criteria weights are as follows:

Step 1: Determine the set of criteria; In this phase, the criteria (C1, C2,..., Cn) that must be used in the decision-making process are taken into account.

Step 2: Determine the best (most desirable and important) and worst (least desirable and least important) criteria: In this section, the decision maker generally determines the best and worst criteria. There is no comparison in this section.

Step 3: Compare the best criterion with other criteria; the performance or importance level of the best criterion compared to other criteria is determined by the decision maker using numbers between 1 and 9.

Step 4: Compare other criteria to the worst criterion: The performance or importance level of other criteria relative to the worst criterion is determined by the decision maker using numbers between 1 and 9.

Step 5: Build and solve a mathematical programming model to get the optimal weights of the criteria (w1*,

Table 1. MEP Elements

"Group number"	"MEP element name"
1	Electrical facilities including cable , rack , …
2	Mechanical equipment
3	Fire Box pipe, Sprinkler pipe, Domestic hot and cold water pipe, Sanitary water pipe, Natural gas pipe
4	Towel drier pipe, Heating and cooling pipe, Cooling system drain pipe
5	Supply air duct, Return air duct, Fresh air duct, Exhaust air duct, Vent
6	Sewer pipe, Rain water pipes

w2*,..., wn*): This process as well as the calculation of the inconsistency rate and some other parameters which will be explained in more detail later, were carried out using Excel software.

2- 1- Identification and classification of structural and facility elements

In order to calculate the weights of the elements and methods for clash resolution, they must first be identified and classified. In the most recent published research, the types of plant elements have been well identified and classified. Additionally, due to the high number of identified MEP elements, the Delphi method was used to classify them into six groups. On this basis, the same classification will be used in this article. Tables 1, 2 [9, 10] show the classification of systems and structural elements.

As already mentioned, the weights of the facility and structural elements should be determined using the BWM method to prioritize them in the formula used. A questionnaire on the BWM method was used to interact with experts when determining the weighting.

The corresponding questionnaire is a two-stage process, whereby in the first step each expert selects the most and least important criterion in each question. The output of the first stage of the questionnaire, which represents the most and least important criteria, is used as input for the second stage.

Taking into account the fact that each expert's opinion on the most important and least important option in each question may be different, to determine the most important and least important criteria based on the experts' views, the input data for the second stage of the questionnaire is used using the Criteria are identified that receive more attention from experts. Then, in the second step, the experts were asked to indicate the ratio of the most important criterion to other criteria and the ratio of the other criteria to the least important criterion, using numbers from one to nine for each question.

2- 2- Statistical population

Given that the BIM industry, especially coordination in building information modeling, is a new and emerging topic in Iran, qualified professionals in this field are rare. Therefore, in this study, the snowball sampling method [13] was used to determine the number and individuals of the statistical population. This method is used when the study units are not easily identifiable or when these individuals are very rare and represent a small portion of a large population. With this method, the researcher, after identifying the first individual from the above-mentioned statistical population and filling out the questionnaire with him, asks to identify the second and subsequent individuals from this population, and these actions are until then also carried out for the other individuals introduced carried out the chain is broken.

The same method and procedure were used in this article to identify experts in the field. Ultimately, nine people were identified, research continued, and their experiences were utilized. The general specifications of these individuals are shown in Table 3.

A sample of one of the questions in the questionnaire can be seen in the two tables below, with Table 4 showing the first phase of the questionnaire and Table 5 showing the second phase of the questionnaire.

2- 3- Questionnaire validation

Questionnaires are available in statistical and expert-based form. Statistical questionnaires should be examined for validity and reliability. The most commonly used method for this purpose in these questionnaires is the Cronbach alpha method. With this method, before determining, distributing, and filling out the desired number of questionnaires, a pre-test should be carried out with a statistical population of around 30 people and the Cronbach alpha coefficient should be calculated. Once reliability is confirmed, remaining samples can then be collected until the sample size is complete.

Table 2. Structure Elements

"Structure element name"
Floor structure(Slab)
Shear wall
Foundation
Beam
Column

Table 3. Demographic information of experts

Demographic information of participating experts in the questionnaire		
Experts	**Work experience (years)**	**Level of awareness of this subject**
1	15-20	High
2	15-20	High
3	10-15	High
4	10-15	Average
5	10-15	Average
6	15-20	High
7	5-10	Average
8	5-10	Average
9	0-5	Average

Table 4. First stage of the questionnaire

The weighting of structural elements indices					
Structural groups	Slab	Shear wall	Foundation	Beam	Column
The least important criterion					
The most important criterion					

Table 5. Second stage of the questionnaire

The weighting of structural elements indices					
Structural groups	Slab	Shear wall	Foundation	Beam	Column
The most important criterion			For example: Beam		
Importance ratio (most important criterion/another criterion)				1	

Structural groups	The less important criterion	Importance ratio (most important criterion/another criterion)
Slab	For example: Slab	1
Shear wall		
Foundation		
Beam		
Column		

Our research questionnaire is based on experts and the statistical population is not so large that preliminary tests such as Cronbach's alpha can be applied. In such questionnaires, instead of using methods such as Cronbach's alpha to validate the questionnaire, the inconsistency rate is calculated, and statistical questionnaire validation methods might be more suitable for this type of questionnaire.

The formula used to prioritize clashes is the same formula used in recent research in the literature review section and can be seen in Formula 2 as follows:

$$CI = P * W_S * W_{CM} * W_{TM} \quad (2)$$

P: The degree of interference of elements with each other.
CI: Importance of each clash.
W_s: Weight of structural elements.
W_{TM}: MEP weight over time.
W_{CM}: MEP weight over cost.

The relevant weights such as WS, WCM and WTM are determined using the best-worst method (BWM), which was explained in detail in the section above. In this study, the term "clash" refers to severe clashes, and the study also examines clashes between the MEP elements and the structural elements. Among the MEP and structural elements where clashes have arisen, it is preferred to give priority to the clash resolution process for the MEP elements. Therefore, the weight of such elements has been considered in the above formula in terms of cost and time.

As mentioned in the article, the P-parameter, which indicates the degree of penetration of two elements into each other, is abbreviated as "penetration" and is calculated by the software. When the output is obtained, it will be displayed with the Distance column for each interference as shown in the red box in Figure 1.

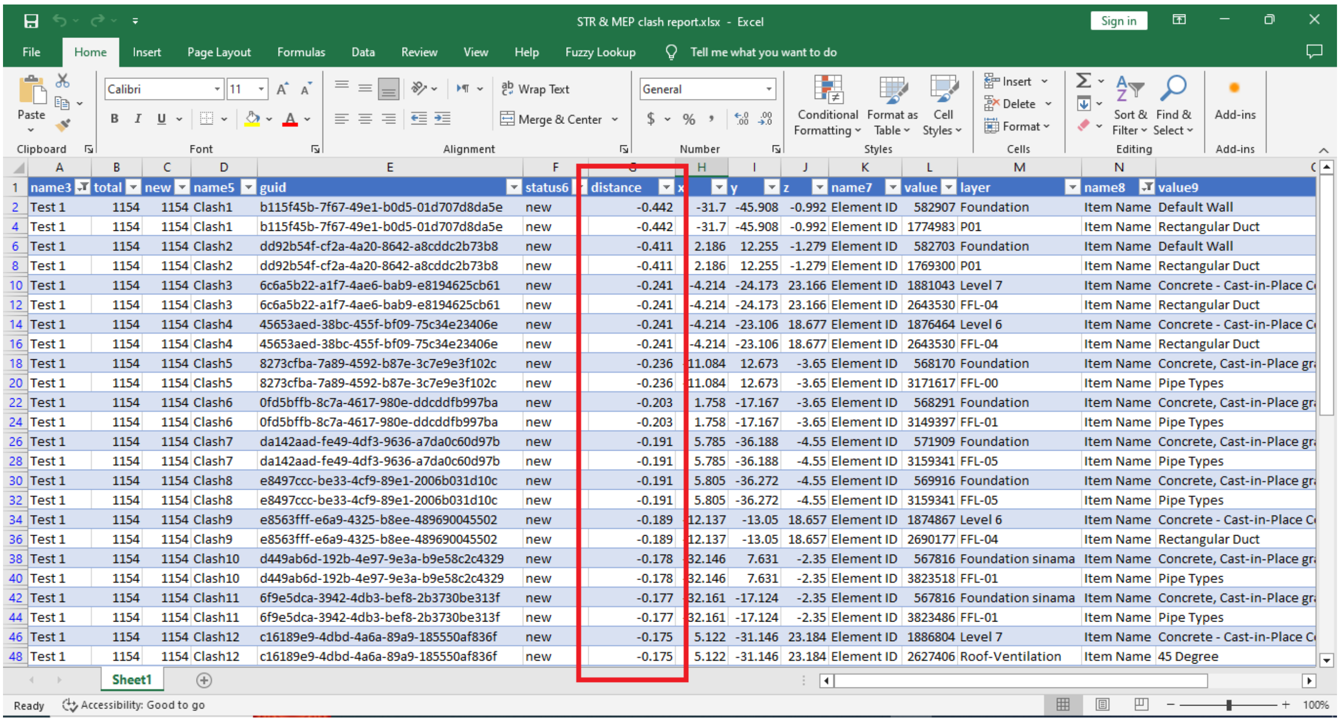
Case Study

To evaluate the performance of the proposed clash prioritization method in civil engineering, the structure and MEP disciplines of a real project in Chabahar were modeled in Revit software. The model was then exported to Navisworks software to identify and prioritize clashes. The software output visually represents the mentioned disciplines and their integration, which helps to identify and prioritize clashes. Figs 2-4 shows Structure Discipline, MEP Discipline and Integration of Structure and MEP Disciplines in Navisworks resepctively.

3- Results and Discussion

3- 1- Methods for resolving clashes between MEP elements

MEP element clash resolution methods are used because changes to MEP elements are much easier and less expensive than changes to structural elements when there is a clash



	name3	total	new	name5	guid	status6	distance	x	y	z	name7	value	layer	name8	value9
2	Test 1	1154	1154	Clash1	b115f45b-7f67-49e1-b0d5-01d707d8da5e	new	-0.442	-31.7	-45.908	-0.992	Element ID	582907	Foundation	Item Name	Default Wall
4	Test 1	1154	1154	Clash1	b115f45b-7f67-49e1-b0d5-01d707d8da5e	new	-0.442	-31.7	-45.908	-0.992	Element ID	1774983	P01	Item Name	Rectangular Duct
6	Test 1	1154	1154	Clash2	dd92b54f-cf2a-4a20-8642-a8cddc2b73b8	new	-0.411	2.186	12.255	-1.279	Element ID	582703	Foundation	Item Name	Default Wall
8	Test 1	1154	1154	Clash2	dd92b54f-cf2a-4a20-8642-a8cddc2b73b8	new	-0.411	2.186	12.255	-1.279	Element ID	1769300	P01	Item Name	Rectangular Duct
10	Test 1	1154	1154	Clash3	6c6a5b22-a1f7-4ae6-bab9-e8194625cb61	new	-0.241	-4.214	-24.173	23.166	Element ID	1881043	Level 7	Item Name	Concrete - Cast-in-Place C
12	Test 1	1154	1154	Clash3	6c6a5b22-a1f7-4ae6-bab9-e8194625cb61	new	-0.241	-4.214	-24.173	23.166	Element ID	2643530	FFL-04	Item Name	Rectangular Duct
14	Test 1	1154	1154	Clash4	45653aed-38bc-455f-bf09-75c34e23406e	new	-0.241	-4.214	-23.106	18.677	Element ID	1876464	Level 6	Item Name	Concrete - Cast-in-Place C
16	Test 1	1154	1154	Clash4	45653aed-38bc-455f-bf09-75c34e23406e	new	-0.241	-4.214	-23.106	18.677	Element ID	2643530	FFL-04	Item Name	Rectangular Duct
18	Test 1	1154	1154	Clash5	8273cfba-7a89-4592-b87e-3c7e9e3f102c	new	-0.236	11.084	12.673	-3.65	Element ID	568170	Foundation	Item Name	Concrete, Cast-in-Place gr
20	Test 1	1154	1154	Clash5	8273cfba-7a89-4592-b87e-3c7e9e3f102c	new	-0.236	11.084	12.673	-3.65	Element ID	3171617	FFL-00	Item Name	Pipe Types
22	Test 1	1154	1154	Clash6	0fd5bffb-8c7a-4617-980e-ddcddfb997ba	new	-0.203	1.758	-17.167	-3.65	Element ID	568291	Foundation	Item Name	Concrete, Cast-in-Place gr
24	Test 1	1154	1154	Clash6	0fd5bffb-8c7a-4617-980e-ddcddfb997ba	new	-0.203	1.758	-17.167	-3.65	Element ID	3149397	FFL-01	Item Name	Pipe Types
26	Test 1	1154	1154	Clash7	da142aad-fe49-4df3-9636-a7da0c60d97b	new	-0.191	5.785	-36.188	-4.55	Element ID	571909	Foundation	Item Name	Concrete, Cast-in-Place gr
28	Test 1	1154	1154	Clash7	da142aad-fe49-4df3-9636-a7da0c60d97b	new	-0.191	5.785	-36.188	-4.55	Element ID	3159341	FFL-05	Item Name	Pipe Types
30	Test 1	1154	1154	Clash8	e8497ccc-be33-4cf9-89e1-2006b031d10c	new	-0.191	5.805	-36.272	-4.55	Element ID	569916	Foundation	Item Name	Concrete, Cast-in-Place gr
32	Test 1	1154	1154	Clash8	e8497ccc-be33-4cf9-89e1-2006b031d10c	new	-0.191	5.805	-36.272	-4.55	Element ID	3159341	FFL-05	Item Name	Pipe Types
34	Test 1	1154	1154	Clash9	e8563fff-e6a9-4325-b8ee-489690045502	new	-0.189	12.137	-13.05	18.657	Element ID	1874867	Level 6	Item Name	Concrete - Cast-in-Place C
36	Test 1	1154	1154	Clash9	e8563fff-e6a9-4325-b8ee-489690045502	new	-0.189	12.137	-13.05	18.657	Element ID	2690177	FFL-04	Item Name	Rectangular Duct
38	Test 1	1154	1154	Clash10	d449ab6d-192b-4e97-9e3a-b9e58c2c4329	new	-0.178	32.146	7.631	-2.35	Element ID	567816	Foundation sinama	Item Name	Concrete, Cast-in-Place gr
40	Test 1	1154	1154	Clash10	d449ab6d-192b-4e97-9e3a-b9e58c2c4329	new	-0.178	32.146	7.631	-2.35	Element ID	3823518	FFL-01	Item Name	Pipe Types
42	Test 1	1154	1154	Clash11	6f9e5dca-3942-4db3-bef8-2b3730be313f	new	-0.177	32.161	-17.124	-2.35	Element ID	567816	Foundation sinama	Item Name	Concrete, Cast-in-Place gr
44	Test 1	1154	1154	Clash11	6f9e5dca-3942-4db3-bef8-2b3730be313f	new	-0.177	32.161	-17.124	-2.35	Element ID	3823486	FFL-01	Item Name	Pipe Types
46	Test 1	1154	1154	Clash12	c16189e9-4dbd-4a6a-89a9-185550af836f	new	-0.175	5.122	-31.146	23.184	Element ID	1886804	Level 7	Item Name	Concrete - Cast-in-Place C
48	Test 1	1154	1154	Clash12	c16189e9-4dbd-4a6a-89a9-185550af836f	new	-0.175	5.122	-31.146	23.184	Element ID	2627406	Roof-Ventilation	Item Name	45 Degree

Fig. 1. Structure Discipline.

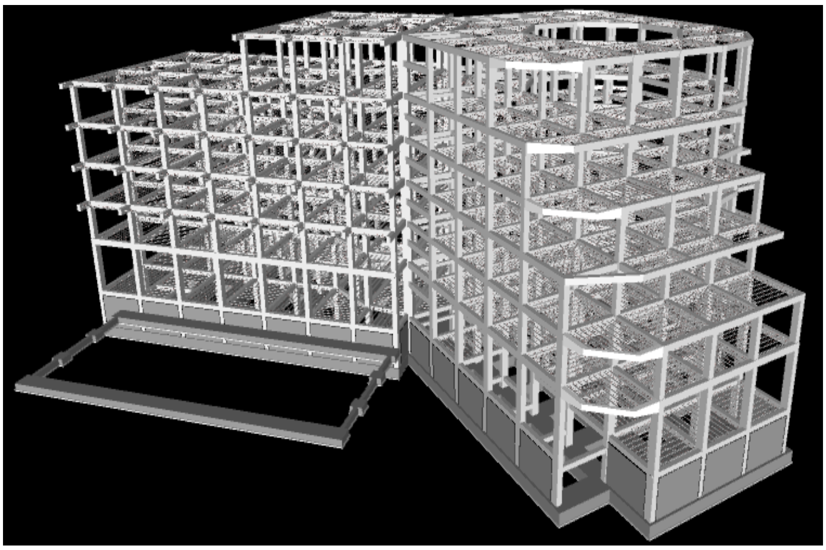


Fig. 2. Structure Discipline.

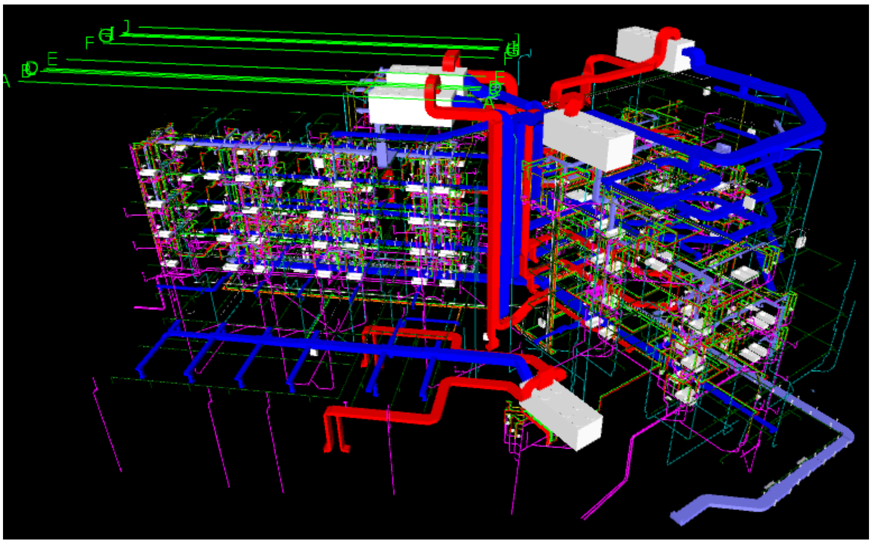


Fig. 3. MEP Discipline.

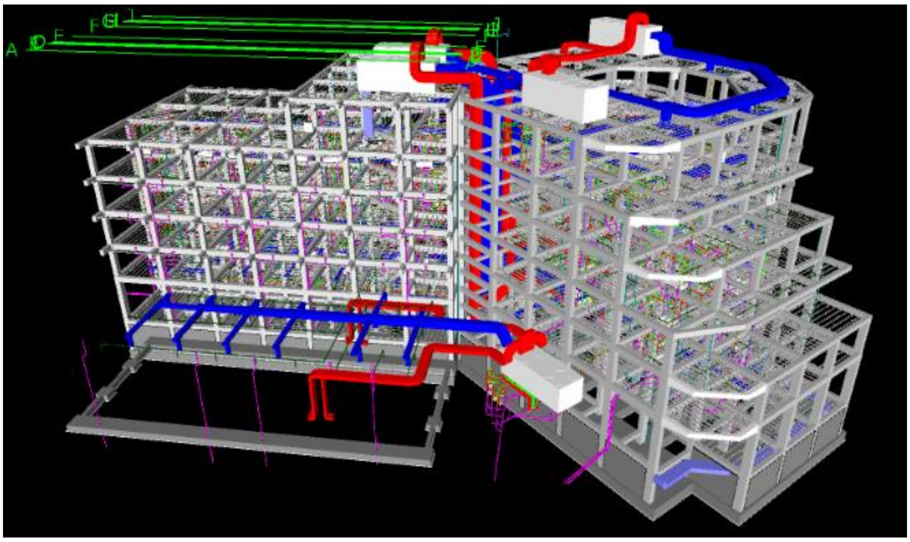


Fig. 4. Integration of Structure and MEP Disciplines in Navisworks.

Table 6. Methods of solving clash according to each group

Method	changing direction	changing slope	Resizing	moving an element
	creating a deviation in the path	creating an angle in the element	Changing size and dimensions	moving the entire element
Group1	+	+	+	+
Group2	-	-	-	+
Group3	+	+	+	+
Group4	+	+	+	+
Group5	+	+	+	+
Group6	+	+	-	+

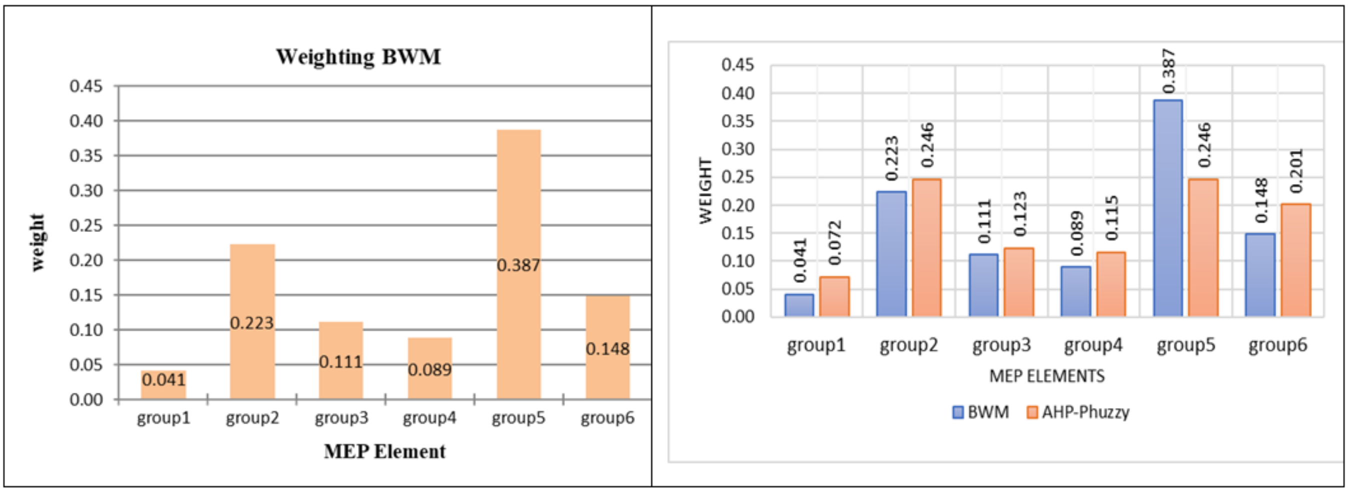


Fig. 5. Weighting the elements of MEP based on cost and comparison with previous research

between structural elements and MEP.

After consulting with experts in the field, the following clash resolution methods were suggested (Table 6): In the second group of building services which refers to mechanical devices, only the movement of the element can be used to resolve clashes. Also, for the elements in Group 6, which include rainwater and sewer pipes, element resizing is not recognized as a valid clash resolution method because water moves through these pipes by gravity.

3- 2- Ranking the MEP and Structural Elements

Analysis of MEP Elements Based on Cost Ranking

Figure 5 shows the weighting results for each of the relevant elements. The ranking of MEP elements based on the cost parameter using the BWM method is as follows: Group 5, Group 2, Group 6, Group 3, Group 4 and Group 1. It seems that they are in this range with the latest version agreeing research in all cases, except that in the AHP fuzzy method, groups 2 and 5 have equal weight, but in the BWM method, group 5 is more significant than group 2.

Three notable components are ε^*, the input-based consistency ratio, and the associated threshold, respectively. If the input-based consistency ratio is smaller than the associated threshold, the level of pairwise compatibility is acceptable; otherwise, it is unacceptable [14]. In this question, the pairwise comparison of these values is 0.058, 0.143, and 0.315, respectively. By comparing the second and third values, it can be concluded that the pairwise compatibility level is acceptable.

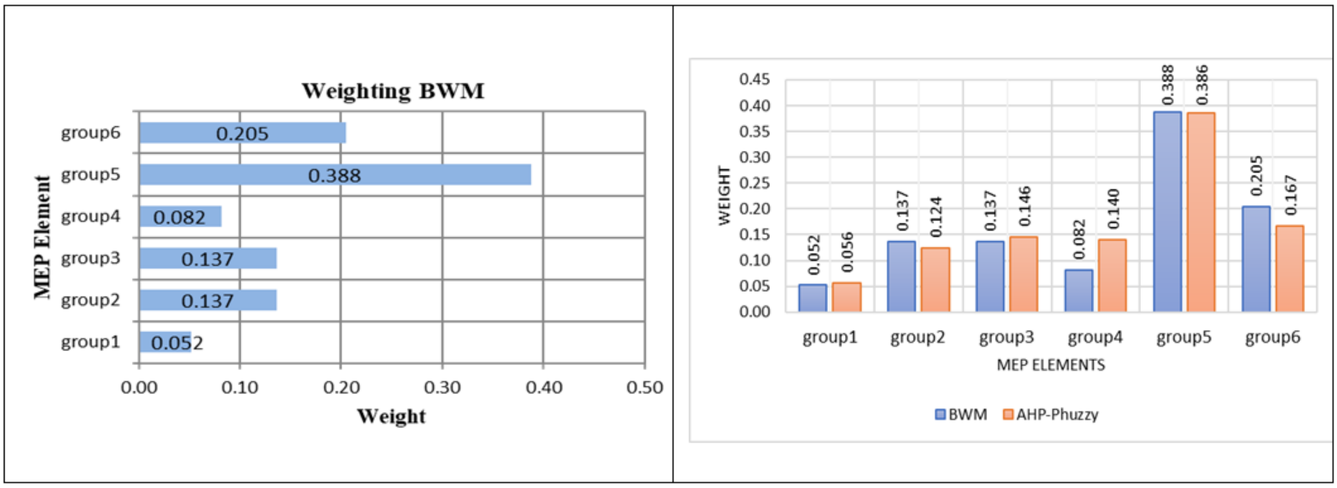


Fig. 6. Weighting the elements of MEP based on time and comparison with previous research

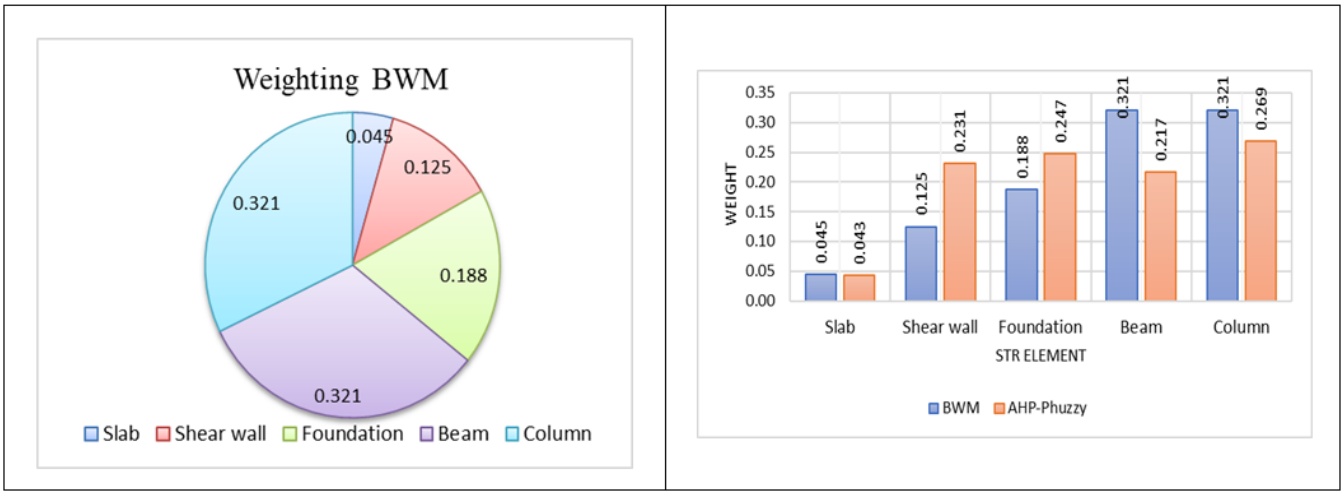


Fig. 7. Weighting the structural elements and comparison with previous research

Analysis of MEP Elements based on Time Ranking

The weighting results for each relevant MEP element are visible in Figure 6. The ranking of building services elements based on the time parameter using the BWM method is as follows: Group 5, Group 6, Group 2, Group 3, Group 4 and Group 1. However, there seems to be a slight difference with the latest research results which in the AHP fuzzy method, similar to the BWM method, the first and second priorities are group 5 and group 6. However, the AHP fuzzy method still prioritizes groups 3, 4, 2, and 1, unlike the BWM method.

Furthermore, the three components ε*, the input-based consistency ratio, and the associated threshold value in this question have pairwise comparison values of 0.022, 0.071, and 0.303, respectively. Comparing the second and third values, one can conclude that the level of pairwise compatibility is acceptable.

Analysis of the Structural Elements Ranking

Figure 7 shows the weight of each structural element using the BWM technique. Due to the weighting of the structural elements according to the BWM method, taking into account the weightings mentioned above, the ranking of the structural elements is as follows: beam, column, foundation, wall shear or moment-bearing frame, and floor structure (slab).). It seems that the results obtained by this method are almost the same as the results of the AHP fuzzy method, and the only difference is the meaning of the bar element. The results of the AHP fuzzy method showed that the importance of the beam element is after the column, the foundation, and the shear wall, but the results of this method rank the importance of the element equal to that of the column.

Therefore, in this question, the three components ε*, the input-based consistency ratio, and the associated threshold

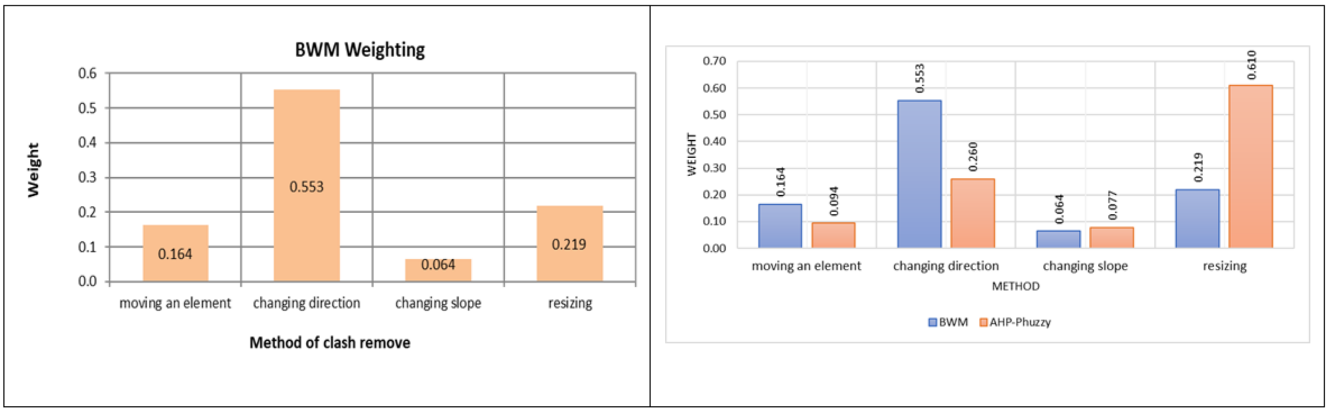


Fig. 8. The weighting of clash resolution methods for Group 1 MEP based on cost and comparison with the previous study

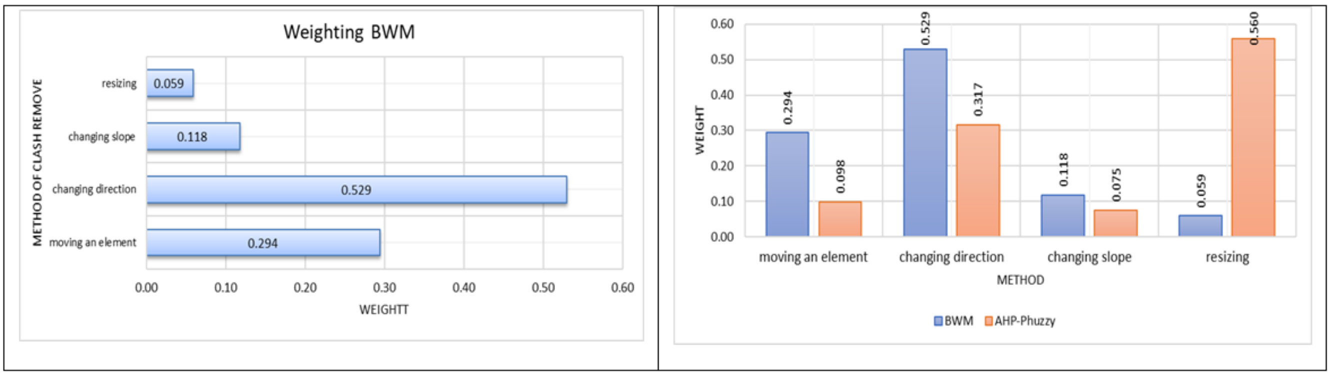


Fig. 9. The weighting of clash resolution methods for Group 3 MEP based on cost and comparison with the previous study

have pairwise comparison values of 0.054, 0.2, and 0.264, respectively. Comparing the second and third values, one can conclude that the level of pairwise compatibility is acceptable.

3- 3- Ranking the cost-effectiveness of MEPs' clash resolution methods

Analysis of ranking clash resolution methods for Group 1 MEP in terms of cost

The ranking and weighting in Figure 8 shows that the best methods for resolving clashes in Group 1 MEP systems based on the BWM method are as follows: changing direction, changing size, moving an element, and changing the slope. Comparing the results of the two methods shows that the results of this approach are somewhat consistent with the results of the previous study because the previous method also proposed the following order of methods: changing size, changing direction, moving an element, and changing slope. Finally, in this question, the three components ε*, input-based consistency ratio, and associated threshold have values of 0.103, 0.19, and 0.246, respectively. By comparing the second and third values, we can conclude that the level of compatibility in pairwise comparisons is acceptable.

Analysis of ranking clash resolution methods for Group 3 MEP in terms of cost

The weights of each clash resolution method for Group 3 MEP systems are shown in Figure 9. Based on these weights, the best clash resolution methods in Group 3 MEP systems are as follows: change of direction, movement of an element, change of inclination, etc. change of size. When comparing the results of this method with the previous approach, the results are relatively consistent, with the only difference being that the least important method in the BWM method corresponds to the most important method in the AHP fuzzy method. Furthermore, the values of the three components ε*, input-based consistency ratio and associated threshold in this question along with pairwise comparisons are 0.059, 0.125, and 0.252, respectively. By comparing the second and third values, it can be concluded that the level of compatibility in pairwise comparisons is acceptable.

Analysis of ranking clash resolution methods for Group 4 MEP in terms of cost

Based on the given weight in Figure 10 for clash resolution methods in MEP of group 4, the best methods for resolving clashes in this MEP group according to the BWM method are as follows: change direction, move an element, change slope, and change size. These methods are compatible with the results of the previous study on cost-based clash resolution methods for Group 3. The three components ε*, input-based consistency ratio, and associated threshold in this question, along with pairwise comparisons, have values of 0.092, 0.214, and 0.252, respectively. By comparing the second and third values, it can be concluded that the level of compatibility in pairwise comparisons is acceptable.

Analysis of ranking clash resolution methods for Group 5 MEP in terms of cost

The results of weighting each clash resolution method for each element are shown in Figure 11. Based on the cost parameter, the ranking of clash resolution methods for Group 5 MEP is as follows: change direction, change size, move an element, and change slope. It is perfectly consistent with the results of the previous study. The components ε*, the input-based consistency ratio, and the associated threshold in this question, along with pairwise comparisons, have values of 0.044, 0.1, and 0.199, respectively. By comparing the second and third values, it can be concluded that the level of compatibility in pairwise comparisons is acceptable.

Analysis of ranking clash resolution methods for Group 6 MEP in terms of cost

The weights of each clash resolution method for Group 6 MEP are shown in Figure 12. Based on these weights, the best clash resolution methods in Group 6 MEP are as follows: changing direction, moving an element, and changing the slope. The results are consistent and consistent by comparing the results obtained using this method with previous research. The components ε*, the input-based consistency ratio, and the associated threshold in this question, along with pairwise comparisons, have values of 0.062, 0.071, and 0.131, respectively. By comparing the second and third values, it can be concluded that the level of compatibility in pairwise comparisons is acceptable.

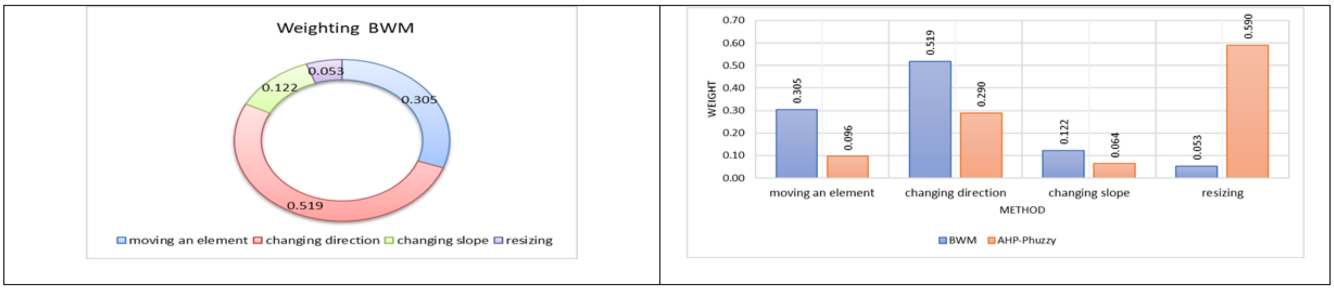


Fig. 10. The weighting of clash resolution methods for Group 4 MEP based on cost and comparison with the previous study

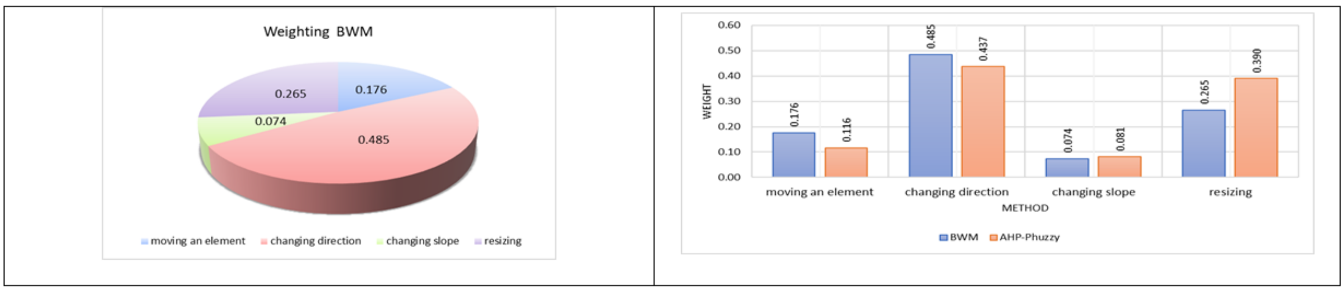


Fig. 11. The weighting of clash resolution methods for Group 5 MEP based on cost and comparison with the previous study

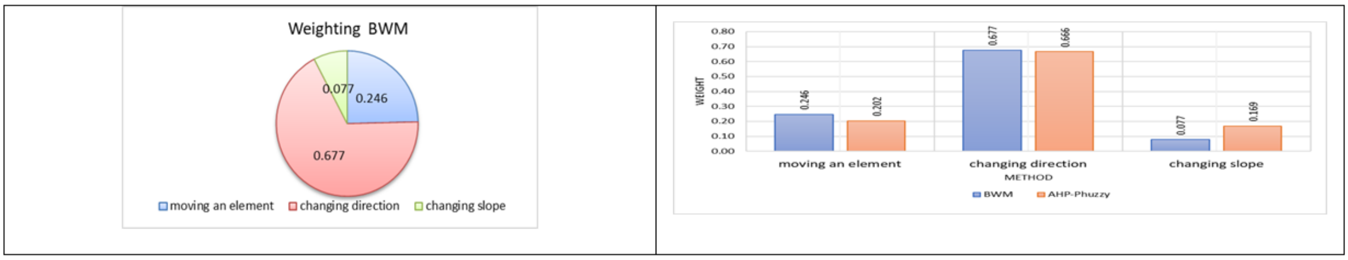


Fig. 12. The weighting of clash resolution methods for Group 6 MEP based on cost and comparison with the previous study

3- 4- Ranking the time-effectiveness of MEPs' clash resolution methods

Analysis of ranking clash resolution methods for Group 1 MEP in terms of time

Based on the time parameter, the best methods for resolving clashes in Group 1 MEP systems are as follows: change direction, change size, move an element, and change slope. These methods are also shown in Figure 13, which shows some consistency with the results of the previous study. In the previous study, the AHP fuzzy method also proposed the same order of methods: resize, change direction, move elements, and change tilt. The three components ε*, input-based consistency ratio, and associated threshold in this question, along with pairwise comparisons, have values of 0.044, 0.1, and 0.199, respectively. Comparing the second and third values shows that the level of compatibility in pairwise comparisons is acceptable.

Analysis of ranking clash resolution methods for Group 3 MEP in terms of time

The time weights of the individual clash resolution methods for Group 3 MEPs are shown in Figure 14. Based on these weights, the best clash resolution methods in Group 3 MEP are as follows: change of direction, movement of an element, change of tilt, and change of size. When comparing the results of this method with the results of previous methods, there is a significant degree of consistency between them, except that the least important method in the BWM method corresponds to the most important method in the AHP fuzzy method. Apart from this difference, the order of importance for the remaining clash resolution methods is the same for both methods. Furthermore, the values of the three components ε*, input-based consistency ratio and associated threshold in this question along with pairwise comparisons are 0.072, 0.119 , and 0.246, respectively. Comparing the second and third values shows that the level of compatibility in pairwise comparisons is acceptable.

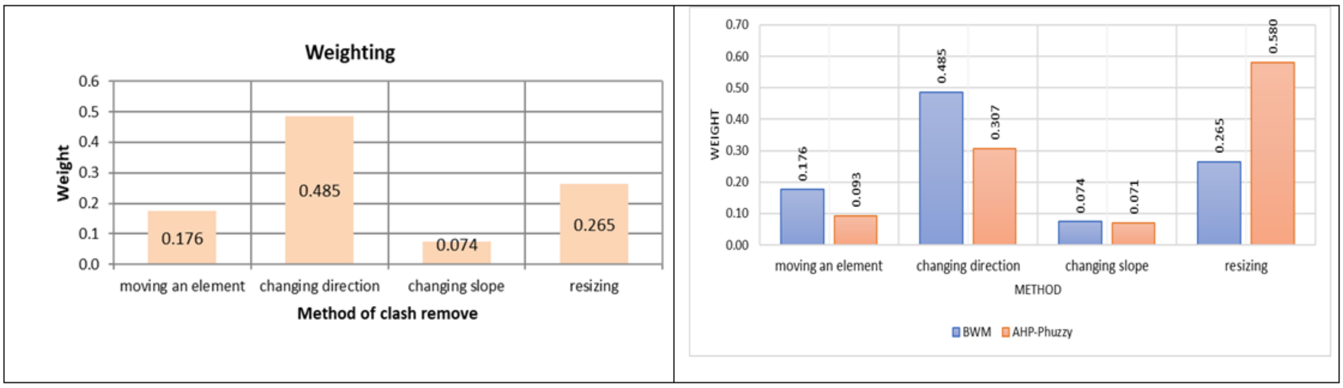


Fig. 13. Weighting of clash resolution methods for Group 1 MEP based on time and comparison with the previous study

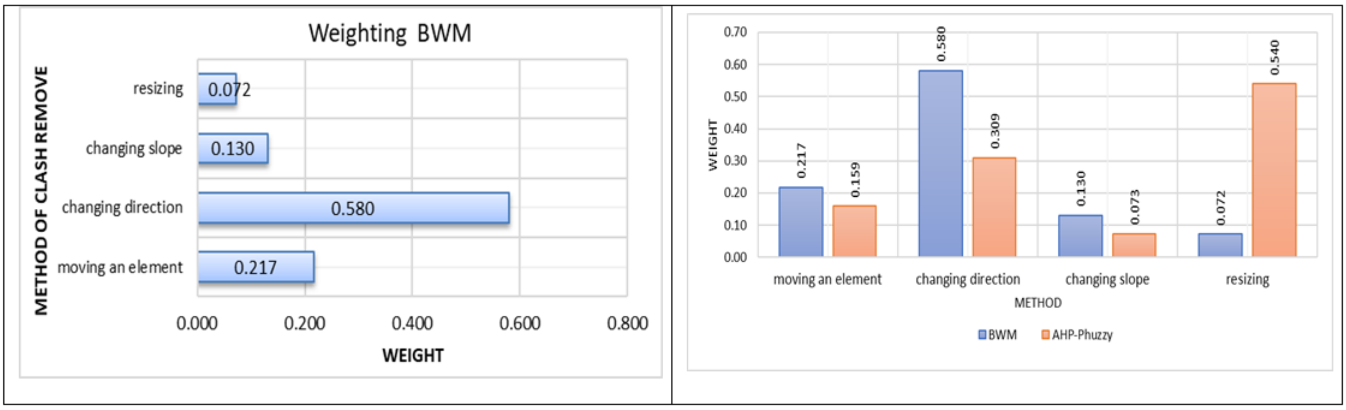


Fig. 14. Weighting of clash resolution methods for Group 3 MEP based on time and comparison with the previous study

Analysis of ranking clash resolution methods for Group 4 MEP in terms of time

Based on the reported weighting in Figure 15 for clash resolution methods in Group 4 MEPs, the best methods for resolving clashes in this group of MEPs are as follows: change direction, move an element, change slope, and change size. These methods are compatible with the results of the previous study on time-based clash resolution methods for Group 3 MEPs. The three components ε*, input-based consistency ratio, and associated threshold in this question, along with pairwise comparisons, have values of 0.051, 0.1, and 0.199, respectively. Comparing the second and third values shows that the level of compatibility in pairwise comparisons is acceptable.

Analysis of ranking clash resolution methods for Group 5 MEP in terms of time

The results of weighting each clash resolution method for each element are shown in Figure 16. As a result, the ranking of clash resolution methods for Group 5 MEP based on the time parameter is as follows: changing direction, changing size, moving element, and changing slope. These results are perfectly consistent with the results of the previous study. The components ε*, the input-based consistency ratio, and the associated threshold in this question, along with pairwise comparisons, have values of 0.06, 0.119, and 0.246, respectively. By comparing the second and third values, it can be concluded that the level of compatibility in pairwise comparisons is acceptable.

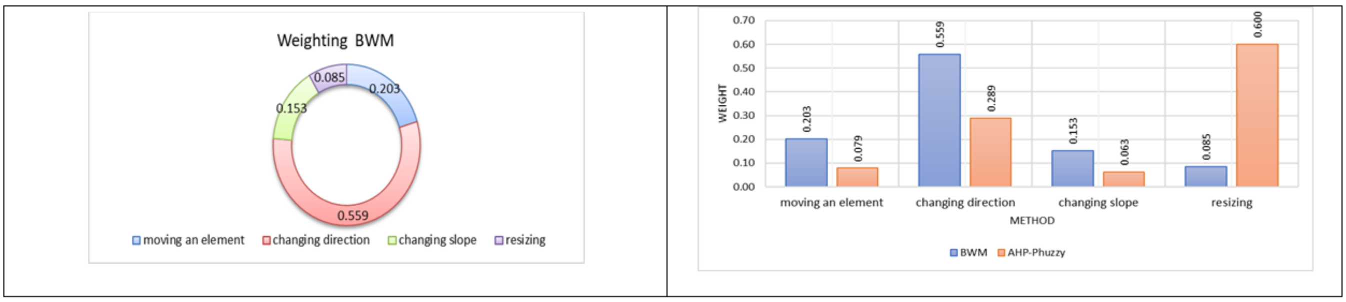


Fig. 15. Weighting of clash resolution methods for Group 4 MEP based on time and comparison with the previous study

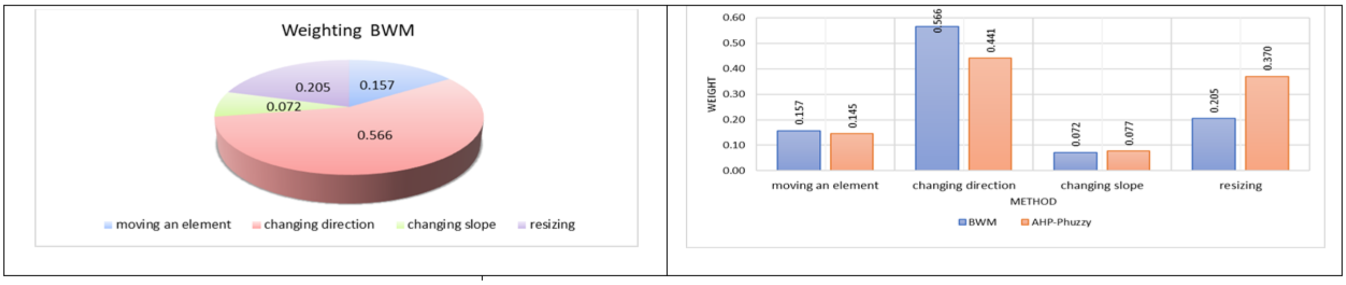


Fig. 16. Weighting of clash resolution methods for Group 5 MEP based on time and comparison with the previous study

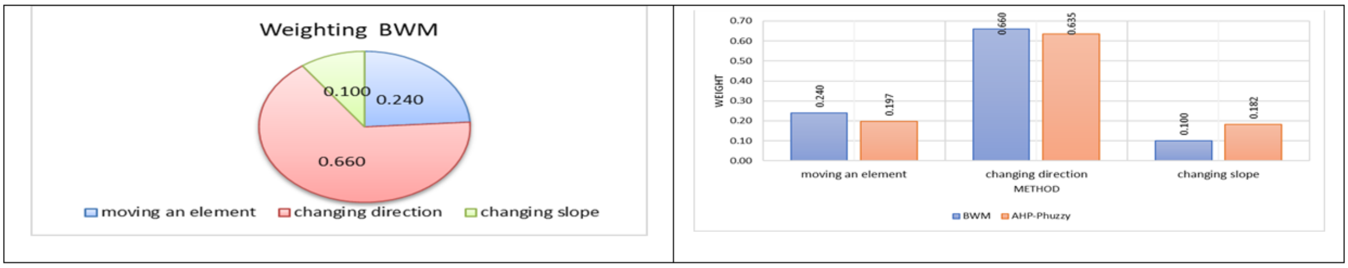


Fig. 17. Weighting of clash resolution methods for Group 6 MEP based on time and comparison with the previous study

Analysis of ranking clash resolution methods for Group 6 MEP in terms of time

The temporal weights of each clash resolution method for Group 6 MEPs are shown in Figure 17. Based on these weights, the best clash resolution methods in Group 6 MEP are as follows: change of direction, movement of an element, and change of inclination. When comparing the results obtained using this method with the results of previous research, there appears to be a significant degree of consistency and agreement between them. Therefore, the components ε*, the input-based consistency ratio, and the associated threshold in this question, along with pairwise comparisons, have values of 0.06, 0.1, and 0.133, respectively. Comparing the second and third values shows that the level of compatibility in pairwise comparisons is acceptable.

In the case study, the images of which can be seen in Figures 2, 3, and 4, 1154 clashes between structural elements and MEP were identified. To examine Formula 2, 100 clashes were randomly selected from the Excel file due to the high number of clashes. In the Excel output file, the names of the two clash elements are mentioned and appropriate weights have been assigned to each of these two elements taking into account the associated MEP and structures. On the other hand, the level of penetration for each clash was indicated in the output Excel file. Using Formula 2, this project examined the results and prioritization of these hundred clashes.

3- 5- Cost and Time Analysis for Clash Resolution Methods

Table 7 compares two methods for prioritizing and resolving clashes between structural and MEP (Mechanical, Electrical, and Plumbing) elements within a building project. The first method, BWM (Best-Worst Method), is a structured decision-making technique that considers both the severity of the clash and the potential impact on the project. The second method, the Traditional (experience-based) Method, relies on standard industry practice to rank clashes based on historical experience.

In terms of cost, BWM (Method 1) incurs a total of $25,200 for resolving the five identified clashes. The clashes involve critical structural elements like concrete beams, columns, and ceilings interacting with major MEP ducts. These types of clashes are more complex and costlier to resolve, especially when ducts interact with beams or columns, as the consequences of these clashes can lead to significant disruptions if not addressed early. For instance, the fifth priority clash in Method 1, involving a ceiling-to-duct interference with a high level of 0.241, incurs a cost of $7,500 due to the need for significant adjustments.

On the other hand, the Traditional Method (Method 2) results in a lower total cost of $12,250. This method identifies clashes primarily between beams and pipes, which are generally easier and less expensive to resolve compared to duct-related clashes. While this method results in faster clash

Table 7. Comparing two methods (BWM (Method 1) and Traditional (Method 2)) for prioritizing and resolving clashes

Method	Priority	Clash Type	Interference Level	Estimated Cost (USD)	Time to Resolve (Weeks)
BWM (Method 1)	1	Concrete Beam vs. Duct	0.097	4,500	2
	2	Concrete Beam vs. Duct	0.089	4,200	2
	3	Concrete Beam vs. Duct	0.080	4,000	1.5
	4	Concrete Column vs. Duct	0.050	5,000	2.5
	5	Concrete Ceiling vs. Duct	0.241	7,500	3.5
Total BWM				**25,200**	**11.5**
Traditional (Method 2)	1	Concrete Beam vs. Pipe	0.147	2,500	1
	2	Concrete Beam vs. Pipe	0.145	2,450	1
	3	Concrete Beam vs. Pipe	0.092	2,000	0.8
	4	Concrete Beam vs. Pipe	0.074	1,800	0.7
	5	Concrete Beam vs. Duct	0.097	3,500	2
Total Traditional				**12,250**	**5.5**

resolution at a lower cost, it focuses on clashes that are less critical in the grand scheme of the construction project. The highest-priority clash in Method 2 has an interference level of 0.147, leading to a cost of $2,500, far lower than the costs associated with the BWM method.

Despite the higher cost of Method 1, its ability to identify and prioritize clashes with more severe consequences for the project demonstrates its effectiveness. If these critical clashes were left unresolved during the design phase, they could lead to costly redesigns or delays during the construction phase, when modifications would be significantly more expensive and time-consuming. Thus, the higher initial investment in clash resolution via the BWM method is justified by the potential savings in terms of avoided disruptions and schedule delays.

In addition to cost, time is a crucial factor when resolving clashes in construction projects. BWM (Method 1) requires a total of 11.5 weeks to address all clashes. The longer time requirement is attributed to the complex nature of the clashes, particularly those involving critical structural elements and ducts, which are more challenging to access and adjust. For example, the fifth clash, with an interference level of 0.241, takes approximately 3.5 weeks to resolve due to its complexity and impact on the surrounding structure.

By contrast, the Traditional Method (Method 2) requires significantly less time, approximately 5.5 weeks, to resolve all clashes. The clashes identified by this method involve beams and pipes, which are generally quicker and easier to address. However, the faster resolution times reflect the fact that Method 2 has identified less critical clashes that, while important, do not carry the same potential for disruption as those identified by the BWM method.

In conclusion, although Method 1 requires more time to resolve clashes, this longer time investment is an indication of its thoroughness and ability to detect high-priority, critical clashes that could lead to substantial delays during the construction phase if left unresolved. Addressing these issues early in the design phase helps ensure a smoother construction process, preventing delays and complications that could arise if these clashes were discovered later. Therefore, the longer resolution time in Method 1 reflects its overall effectiveness in improving project outcomes.

4- Conclusions

A summary of all the findings and successes of current research is as follows:

By weighting the elements and methods and using the formula provided, clashes and clash resolution methods were prioritized.

The results of this study were compared with the results of the previous study and the associated weighting method. Despite the differences in the statistical populations of the two studies, a comparison was made due to the similarity of research methods.

Based on the weights applied in this study, structural elements such as beams and columns are equally important and more important than other elements. In terms of importance, they are followed by foundations, shear walls or braces, and structural floors, respectively.

Based on the cost weights applied in this study, the importance ranking of the MEP elements is as follows: Group 5, Group 2, Group 6, Group 3, Group 4, and Group 1, in descending order of importance.

Based on the time weights used in this study, Group 5 and Group 6 are ranked higher in importance, followed by Group 2 and Group 3 with similar weight and priority. Finally, Group 4 and Group 1 are placed next in importance.

For each clash that occurred, an appropriate clash resolution method was adopted based on the specific situation and conditions under which the clash occurred. This decision was made taking into account the prioritization of clash resolution methods established by the experts in this study.

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