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IMPACT OF ORGANIZATIONAL FACTORS ON DELAYS IN BIM-BASED COORDINATION FROM A DECISION-MAKING VIEW: A CASE STUDY

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Abstract. This study analyzed the impact of organizational factors on delays in building information modeling (BIM)-based coordination for mechanical, electrical, and plumbing (MEP) systems from the decision-making perspective. Recently BIM-based coordination has been regarded as a critical phase in project delivery but suffers from delays during the coordination process. This study investigated three complexity factors that often contribute to coordination delays: the number of participants – the total number of participants involved in a decision-making process for resolving a coordination issue; the level of the decision makers – the highest decision-maker involved in a problem-resolution process; and the heterogeneity of participants – the number of trades related to an issue. Using 95 major coordination issues derived from 11,808 clashes in a case study, the correlations between the coordination time and the complexity factors were analyzed. The coordination time linearly increased as each factor increased. The number of participants had the highest correlation with the coordination time, followed by the level of decision makers and the heterogeneity of participants. The findings stress the significance of integration between BIM and lean approaches, such as Obeya (big room) and Shojinka (flexible manpower line), during BIM-based coordination to expedite decision-making processes and eventually to reduce the coordination time.

Keywords: BIM, coordination time, design management, delay, organizational management.

Introduction

Design coordination is challenging because an alternative design to resolve the conflicts in a project must be derived within limited space and time (Lee, Kim 2014). Furthermore, the constructability and economic aspects of each issue increase the complexity. Design errors and clashes that a project team fails to detect before construction can lead to a schedule delay, rework, or legal disputes (Khanzode 2011). To minimize such problems, many projects require that the construction of a certain area cannot begin until the area has been approved as fully coordinated. For example, in Singapore and Middle East Asia, several projects have faced legal disputes due to coordination delays. It is, therefore, critical to shorten the coordination time to expedite the construction process and to avoid potential disputes.

Previous studies have been done in an attempt to improve the decision-making process during the coordination of mechanical, electrical, and plumbing (MEP) designs using innovative tools and an information technology (IT) environment (Fischer *et al.* 2002; Korman, Tatum 2006; Liston *et al.* 2001; Reizgevicius *et al.* 2014; Tabesh, Staub-French 2005). Fischer *et al.* (2002) proposed the iROOM approach, which encourages the use of an integrated 3D and 4D model shared through a large screen during a design coordination meeting based on the Obeya (big rom) concept in lean manufacturing (Fast-Berglund *et al.* 2016). Korman and Tatum (2006) proposed a preliminary knowledge-based decision-making support system for quickly generating resolution plans for coordination issues. Dossick and Neff (2010) identified organizational arrangement as a key driver for improving the building information modeling (BIM)-based coordination process. Khanzode (2011) combined BIM-based coordination with lean management to improve BIM-based coordination.

Another approach was process re-engineering, which has been recognized as an effective means to improve productivity (Koskela 1992; Liker, Meier 2005; Ohno 1988). As Eastman *et al.* (2008) emphasized, BIM is a process

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rather than a static set of information. Many case studies demonstrated that the effectiveness of BIM was maximized when BIM was deployed in an integrated project environment, for example, under the integrated project delivery (IPD) contract (AIA 2011, 2012). The IPD approach is particularly effective in facilitating decision-making on critical issues in an early phase of a project. Another example is a study conducted by Lee and Kim (2014). The study emphasized the importance of a coordination sequence of MEP components to increase coordination productivity. A sequential coordination method distributed the managerial load of decision-making and reduced deficient information to resolve coordination issues by increasing the sharing of information among project participants.

Despite all these efforts, previous studies have rarely looked into what are known to be the common organizational factors that affect the decision-making and coordination time, such as the size of a meeting, the final decision-maker, and the diversity of professionals (Brunsson 2007; Carlopio *et al.* 2012; Kenny, Wilson 1984; Nutt, Wilson 2010; Shapira 2002). As such, this study aims to identify the organizational factors that affect the delay of BIM-based coordination in the decision-making process. The next section reviews the factors that affect BIM-based coordination time in more depth. The third section describes the research method, and the fourth section reports the results. The fifth section discusses the meaning of the results and findings. Finally, the sixth section concludes the study.

1. Background

Many studies have recognized BIM-based coordination as a decision-making process with multiple stakeholders for problems caused by overlapping elements in limited space (Fischer *et al.* 2002; Korman, Tatum 2006; Kuo *et al.* 2011; Liston *et al.* 2001; Tabesh, Staub-French 2005; Wang, Leite 2015). The decision-making process started through the awareness of the problems and subsequently involved creating and evaluating the repeated alternatives (Kenny, Downey 1987); BIM can help project participants detect clashes. Nevertheless, as Korman and Tatum (2006) stated, design coordination is not just about clash detection, but rather, it is a decision-making process involving a defined relocation and economical arrangement. Kuo *et al.* (2011) also defined BIM-based coordination as an attempt to minimize the gap between information and users' understanding to enhance the decision-making process. Many researchers identified that BIM including 3D, 4D, and digital documents could help to make coordination decisions more easily and quickly (Fischer *et al.* 2002; Lin 2014; Tabesh, Staub-French 2005). This section first reviews the factors that previous studies identified as the factors that affect BIM-based coordination time. Then, it reviews the organizational factors that that previous studies identified as the factors that affect the efficiency of decision-making.

Table 1. Major factors affecting coordination efficiency in the literature

Type	Factor	Description and references
Contractual factor	IPD contract	When IPD is used, stakeholders are motivated to create rapid alternatives in BIM-based coordination in the early phase of a project (Collins, Parrish 2014; Eastman *et al.* 2008; Forbes, Ahmed 2010; Ma *et al.* 2014).
Physical factor	MEP density 1 (MEP cost/floor area)	The MEP coordination time has a strong relationship with the MEP cost per floor area (MEP density 1) (Riley *et al.* 2005).
	MEP density 2 (MEP volume/plenum space)	The MEP coordination time has a positive logarithmic relationship with the MEP volume per plenum (MEP density 2) (Lee, Kim 2014).
Environmental factor	Integrated office	An on-site collocated and integrated office physically brings owners, designers, engineers, and builders together and makes them efficiently work together (Dave *et al.* 2013; Eastman *et al.* 2008; Khanzode 2011).
Management factor	Coordination sequence	A sequential coordination method reduces the concentration of information, thereby reducing the overload of a coordinator with decision-making tasks, and facilitates faster BIM-based coordination (Lee, Kim 2014).
	Coordination manual	A manual for BIM-based coordination could assist the efficiency of coordination (Simonian, Korman 2011).
	Last planner system	BIM-based coordination integrated with the last planner system was more efficient than the BIM-only project (Dave *et al.* 2013; Khanzode 2011; Khanzode *et al.* 2006).
	BIM-assisted vs. BIM-led coordination	Compared to BIM-assisted (drawing-led) coordination, BIM-led coordination can reduce the frequency design changes by five times and avoid a project delay by giving a BIM (MEP) coordinator more control over information than the other participants and by increasing the sharing of information (Park, Lee 2017).

1.1. Major factors affecting coordination efficiency in the literature

Various factors that affect the coordination time have been studied to streamline the coordination process and shorten the BIM-based coordination time. They can be grouped into four categories: contractual factors, environmental factors, management factors, and physical factors (Table 1).

A representative example of the contract factors is IPD (Collins, Parrish 2014; Eastman *et al.* 2008; Forbes, Ahmed 2010; Ma *et al.* 2014). IPD has attempted to change the process and organizational management through contracts signed by subcontractors, general contractors, designers, and owners. In the IPD case, additional profit through efficient coordination is shared by the entire IPD team. Therefore, each participant can obtain the same object to enhance coordination. In addition, the design alternative can have a more positive economic effect through the motivation for additional profits (Eastman *et al.* 2008).

Studies to predict the coordination time and find the factors influencing it have been conducted. Riley *et al.* (2005) defined the MEP density as the MEP cost/floor area and found that the MEP coordination time has a strong relationship with MEP density. Lee and Kim (2014) argued that the MEP coordination time has a strong logarithmic correlation with the MEP density because design changes in a highly dense plenum space do not leave the coordination team with many options, and the authors proposed an MEP volume/plenum space as a more direct and accurate definition of MEP density than the MEP cost/floor area.

Another factor is the work environment. Many researchers have found that an on-site collocated and integrated work environment could help owners, designers, engineers, and builders efficiently work together and eventually reduce the coordination time by reducing the travel time and increasing face-to-face conversation (Dave *et al.* 2013; Eastman *et al.* 2008; Khanzode 2011). The concept is called "Obeya (big room)" in the Toyota Production System (TPS) (Fast-Berglund *et al.* 2016). It is also known as the integrated collaborative/concurrent engineering (ICE) room approach (BCA 2013).

The fourth set of factors has to do with management strategies. Khanzode (2011) adopted the lean concept from the TPS for synergy with BIM-based coordination. The lean-concept-based last planner system is a bottom-up planning method that involves decision-making by the subcontractors in the early planning phase. Adjusting the timing of the involvement of different organizations through the last planner system can increase the efficiency of BIM-based coordination. Another approach focuses on the impact of different coordination sequences. Simonian and Korman (2011) suggest that the efficiency of coordination can be improved if the guidelines for applying BIM are made in the preplanning stage.

Lee and Kim (2014) compared a parallel (concurrent) coordination method with a sequential coordination method. Their study showed that communication routing was concentrated on a specific engineer when design elements were coordinated concurrently (the parallel method), whereas various organizations communicated directly with each other when design elements were coordinated sequentially (the sequential method) using the Data Exchange Matrix Analysis (DEMA) developed based on network theory. The coordination speed was three times faster when the sequential method was deployed than when the parallel method was deployed. Al Hattab and Hamzeh (2015) also simulated the efficiency of BIM-based coordination using social network analysis. Park and Lee (2017) analyzed the causes of the differences in coordination efficiency between BIM-assisted (drawing-led) and BIM-led coordination using the DEMA and the degree/closeness/betweenness centrality in social network analysis. The results show that BIM-led coordination can significantly reduce the design changes and coordination time and thus avoid a project delay by empowering a BIM (MEP) coordinator with more control over information and equally sharing information among project participants.

As reviewed above, most of previous studies on BIM coordination, except for Park and Lee (2017), focus on non-organizational factors, although organization factors, such as the meeting size, the position of a decision-maker, and the heterogeneity of participants, have been recognized as critical factors that affect the decision-making time. This study focuses on the impact of organizational factors on the design-coordination time. Before introducing the research method of this study, the next section briefly reviews the organizational factors identified as factors for decision delays by previous studies.

1.2. Organizational factors that affect decision making

Decision making is critical for a successful project because each organization initially starts with only a minimal understanding of the issue and subsequently faces the next step in the decision-making process, which is not fixed in a project but determined according to the characteristics of the issue (Mintzberg *et al.* 1976). Many previous researchers have identified the organizational factors that affect the efficiency of the decision-making process. The organizational factors that were identified in previous studies can be categorized into three groups: the number of participants, the decision-making power and the level of decision makers, and the diversity of team members.

The number of participants. Decision-making routing is not a rational process to follow (Mintzberg *et al.* 1976), and it is continuously diversified during the decision-making process and attracts additional organization (McCall, Kaplan 1985). When the issue is simple, it can be resolved through regular decision-making routing, but standard decision-making routing is seldom implemented in real projects (Astley *et al.* 1982). The decision-making processes conducted by numerous organizations are inefficient because the decision-making repeatedly starts, is delivered, and stops (Mintzberg *et al.* 1976). Thus, the excessive participation of organizations in decision-making routing could lead to delays.

The decision-making power and the level of decision makers. The decision-making organization is divided according to a political structure, with each organization holding different decision-making powers (Zaleznik 1970). In addition, decision-making routing is determined by decision-making power, starting from a low-level decision-maker (Kenny, Downey 1987). A high-level decision-maker is needed when there are critical problems (Kenny, Wilson 1984). Thus, the rearrangement of decision-making power is required for an efficient decision-making process (Kenny, Downey 1987). The organizational structure divided by decision-making power is evident in construction projects. In the communication structure, which is organizationally separated into clients, architects, general contractors, and subcontractors, according to decision-making power, these participants do not directly communicate with each other. The approval process in the vertical communication structure is considered one of the biggest causes of delays in construction projects (Yang, Wei 2010). For example, a subcontractor communicates with an architect and client via a general contractor and, similarly, a client communicates with a subcontractor via a general contractor. This tendency is present also in the case of BIM-based coordination (Dossick, Neff 2010). In a case study by Khanzode (2011), communication routing was determined in accordance with a vertical structure (divided into subcontractor, general contractor, architect, and client) and in BIM-based coordination. When the issue was important and difficult, high-level decision-makers had to be involved.

The diversity (heterogeneity) of team members. Decision-making in construction projects is conducted by numerous organizations. Due to the characteristics of construction projects, decision-making processes are undertaken by networking and communication among the various organizations. Each organization in the decision-making process takes responsibility for the other. Decision-making is undertaken by reciprocating interaction between organizations (Pekericli *et al.* 2003). Thus, even if the number of participating organizations in a meeting remains the same, a decision-making process is likely to become longer if the types of participating organizations becomes larger (Nutt, Wilson 2010; Shapira 2002).

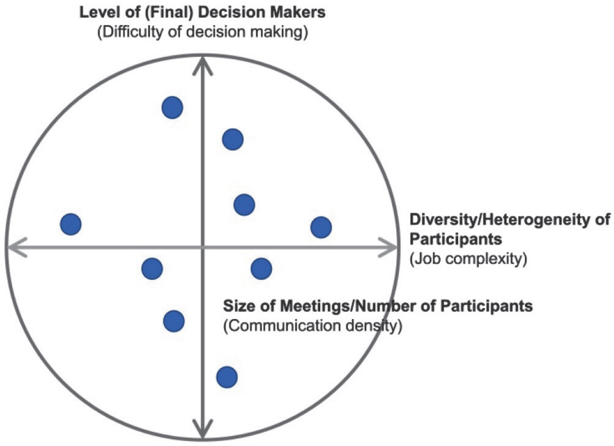

Figure 1. Major organizational factors affecting decision-making efficiency

As discussed in the previous section, the impact of these organizational factors on BIM-based coordination delay have not been studied although they are commonly regarded as factors for efficient decision making. Figure 1 and Table 2 summarize the organizational factors, their implications, and the measurements used in this study to quantify each organizational factor. The method for measuring each factor is described in more detail in the next section.

2. Research method

This section describes the research method. First, it describes the analysis factors. Then, it explains the case-selection criteria, the selected case, and the data collection method.

2.1. Analysis factors

As discussed in the Introduction and Background sections, this study analyzes the impact of the organizational factors that commonly affect decision making on BIM-based coordination delay. As briefly mentioned in Table 2, this study defined the three main organizational factors as follows:

- "Number of participants": the total number of distinctive participants involved in a decision-making process to resolve a coordination issue.

Table 2. Major organizational factors affecting decision-making efficiency

Organizational Factor	Implication	Description and references	Measurement used in this study
Number of participants	Communication complexity	It takes longer to reach a conclusion when a meeting is large (Carlopio *et al.* 2012)	The total number of participants in an issue resolution meeting
Level of decision makers	Criticality of issues	A high-level decision maker is required for critical issues (Shapira 2002)	The level of decision makers
Heterogeneity of participants	Job complexity	It is difficult to find a solution when an issue requires coordination between various types of participants (Nutt, Wilson 2010)	The number of trades involved in an issue

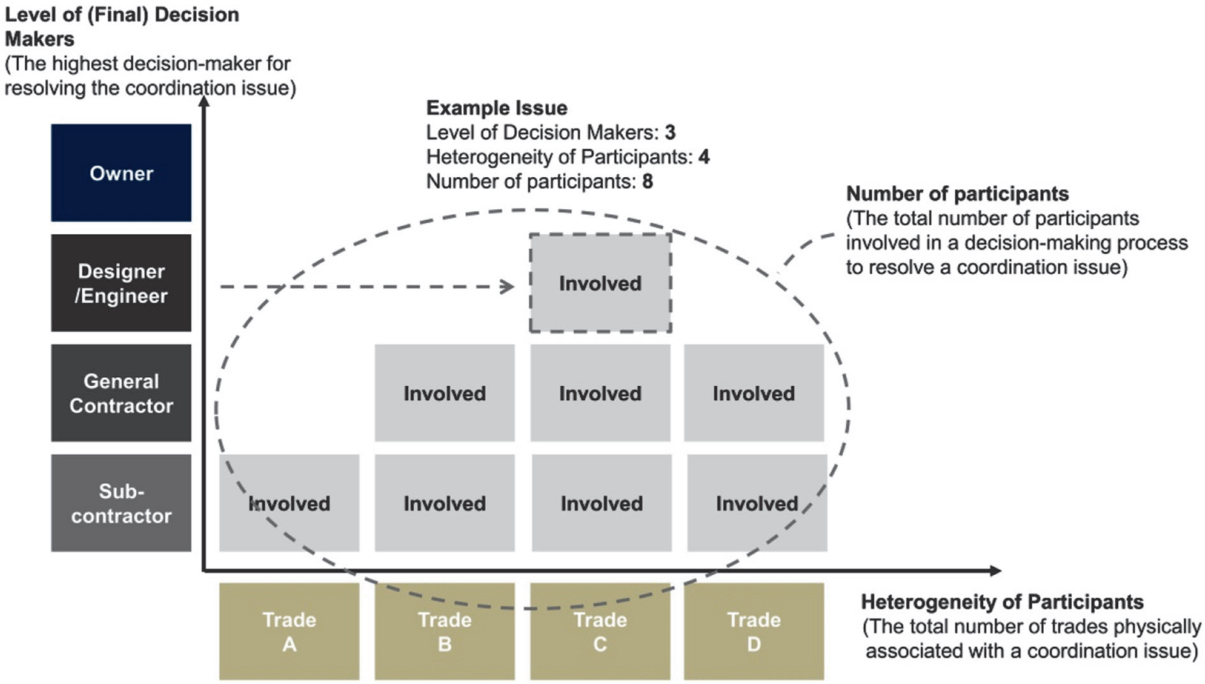

Figure 2. An example of the number of participants, the level of a decision maker, and the heterogeneity of participants in a meeting

– "Level of decision makers": the highest decision-maker for resolving the coordination issue. The involvement of a high-positioned decision-maker can slow down the resolution process for the BIM-based coordination issue. In this study, the level of decision makers is defined in the following order from the highest to the lowest according to the general approval line in Korea: owner (4 points), designer/engineer (3 points), general contractor (2 points), and subcontractor (1 point). We refer to the issues related to the level of decision makers as the "vertical coordination" issue because it has to do with vertically aligned decision-making power (an approval line) (see Figure 2 for an illustrated example).
– "Heterogeneity of participants": the total number of trades physically associated with a coordination issue. It could represent the geometric challenges and difficulties in design coordination. We refer to the issues related to the heterogeneity of participants as the "horizontal coordination" issue because it involves coordination between participants (i.e., different trades) in a horizontal relationship (see Figure 2 for an illustrated example).

Figure 2 shows an example of an issue resolution meeting. The meeting involved a total of eight participants: four subcontractors, three general contractors, and one designer. The highest decision maker is the designer. The participants were from four different types of trades. Thus, the number of participants is 8. The level of the decision maker is 3, and the heterogeneity of participants is 4.

2.2. Requirements for case selection and the case

To analyze the causes and processes of BIM-based coordination delays in detail, selection criteria for a case study were specified. The selection criteria were as follows:

1. The project must be sufficiently complex to entail complex coordination issues:
   – The project must deal with complex issues that require coordination between several trades during BIM-based coordination.
   – The floor area of the project must exceed 10,000 m^2 to reveal complex issues.
   – The project should not be a building type with a repetitive pattern, such as an apartment complex.
2. The project must deploy a BIM-based coordination method known to be efficient and practical to minimize the impact of factors generally known as bad practice:
   – BIM projects must have a collocated project team (also referred to as the "big room (Obeya)" method). A collocated project team is known to be more productive than are those with a geographically dispersed project team (Dave, Koskela 2009).
   – For efficient coordination, the "sequential coordination" method, rather than "parallel (simultaneous) coordination," must be applied (Lee, Kim 2014).

The Hyundai "Motorstudio" project – an exhibition complex – satisfied all the requirements and was selected as a case study project. Located in Gyeong-gi Province in the Republic of Korea, the complex is nine stories high and

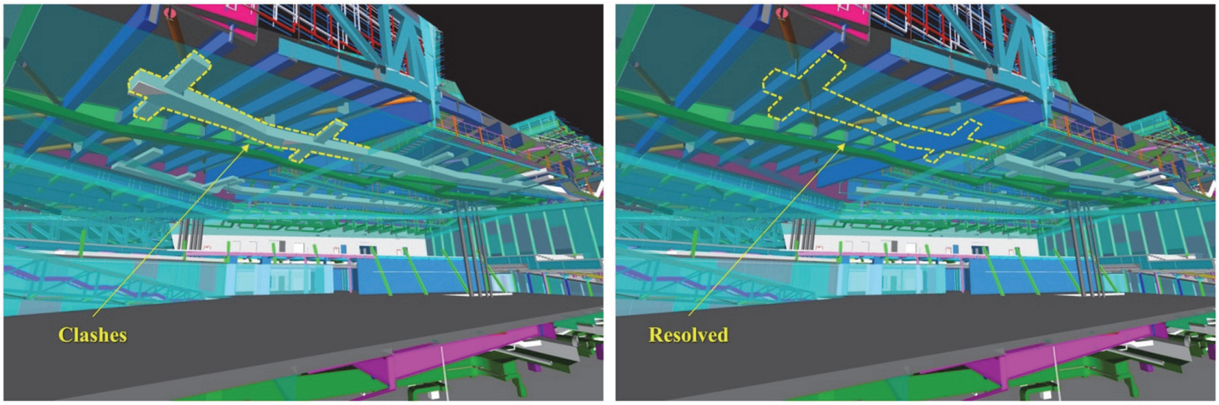

Figure 3. An example of coordination issue (Before and after coordination)

has four underground floors. It is a multi-purpose building, consisting of office, exhibition, and automobile repair areas. The total floor area is 62,755 m^2, and the total project duration is 37 months. The underground structure has a steel-reinforced concrete frame, and the ground structure has a steel frame. During the construction documentation phase, a BIM-based coordination process was conducted involving a client, designer, general contractor, and subcontractors. The trades involved in BIM-based coordination were reinforced concrete (RC); steelwork; exterior; interior; fire protection; sanitary plumbing; heating, ventilation, and air conditioning (HVAC); and electrical. These trades were classified by Korea's standard work classification structure (Korea Estimation Standard 2015). The project delivery was a design-bid-build (DBB) project – the most common project delivery method today. The general contractor was responsible for the design validation for constructability. Major subcontractors, such as a steel fabricator and MEP subcontractors, participated in the design coordination meetings. All project participants had experience in more than one BIM-based coordination project.

2.3. Data collection method

One of the authors attended and recorded coordination meetings from July 15, 2014 to November 20, 2014 (5 months, 17 weeks). After every coordination meeting, the status of coordination issues, project participants involved in each issue and coordination meetings, and the total coordination time were recorded and analyzed by a BIM manager every week. The coordination time was defined as the time required to resolve an issue from the moment of finding the issue. The issues that could not be resolved during the first coordination meeting related to the issues were regarded as delayed issues. In general, coordination meetings were held every week, and the issues that could not be resolved within a week were regarded as delayed issues.

This study tracked 95 major coordination issues and analysis-resolving processes. These major issues were derived from the results of clash detection. Initially, a total of 11,808 clashes were detected. Minor issues that could be resolved simply without a coordination meeting were removed. In addition, associated clashes or the other issues representing the closely connected problems were grouped and counted as one issue. Detailed analyses of the issues are reported in the next section.

3. Analysis results

This section shows the results of the case study and analysis of the relationships between the coordination time, the heterogeneity of participants, the number of participants, and the level of decision makers. It first provides an overview of the coordination process and describes the coordination time and the relationships between the coordination time, heterogeneity of participants, the number of participants, and the level of decision makers in detail.

3.1. Coordination process

This process involved not only correcting the error or clash, but also seeking an economical alternative, as Korman *et al.* (2008) described. For example, Figure 3 shows the clashes between an HVAC duct and an interior ceiling. Several steps of engineering and decision-making were needed to resolve the issue. It was dealt with in BIM-based coordination meetings, and the engineer in charge of the initial engineering was selected to reroute the HVAC duct. The engineer found that it was impossible to reroute the duct without lowering the ceiling. The subcontractor engineer forwarded the opinion to the general contractor, who was in the upper level of decision-making. The general contractor's manager in charge of the HVAC requested of the general contractor's manager in charge of the interior that the ceiling be lowered. This manager attempted to change the details of the ceiling by resolving the issue through communication with the subcontractor, but this was impossible. This issue was taken to the client via a review of the designer. The client then gave an opinion and guidelines to the designer for resolving the issue by keeping the current ceiling level. The designer reduced the length of the HVAC duct in that space of the interface by adopting a ceiling-return system for air control. The changed design concept was reviewed by the general

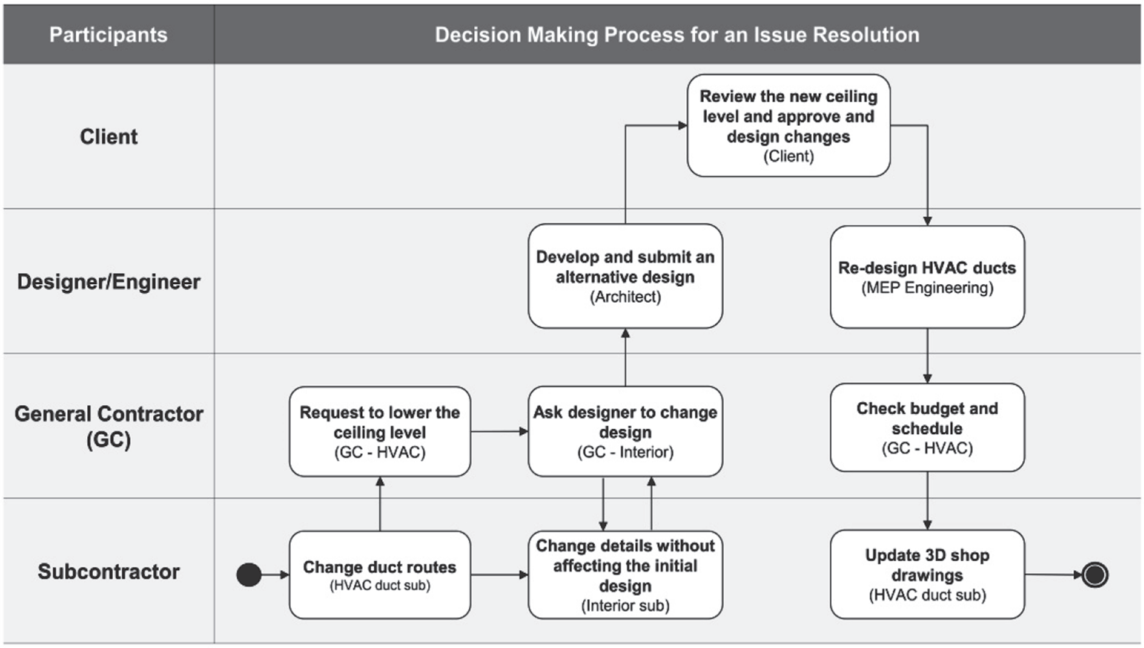

Figure 4. An example of issue-resolution process

contractor for constructability and cost. Then, the subcontractor revised the BIM model and finalized the issue. The process of resolving the issue is illustrated in Figure 4.

3.2. Coordination time

As described in the previous section, a total of 95 major issues were tracked (Figure 5). Among the 95 major issues, 28.4% were resolved by just one coordination meeting, but most issues (72.6%) needed an additional decision-making process, which consumed considerable time after the coordination meeting. In particular, 14.7% required more than six weeks to resolve. The average coordination time of each issue was 3.19 weeks, and the most time-consuming issue required 14 weeks (Figure 6). When the issues were analyzed by trade, those related to steel structural frames were most frequent and took the longest time to resolve. The number of HVAC-related issues was not high, but these issues took longer to resolve than other issues, such as those related to reinforced concrete or interior work.

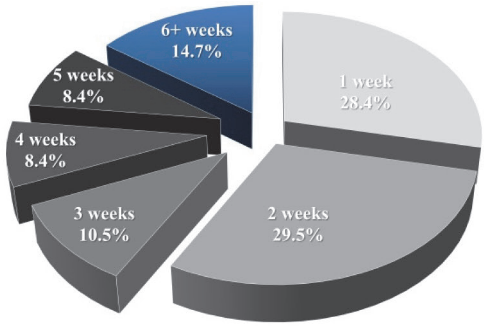

Figure 5. Distribution of issues according to coordination time

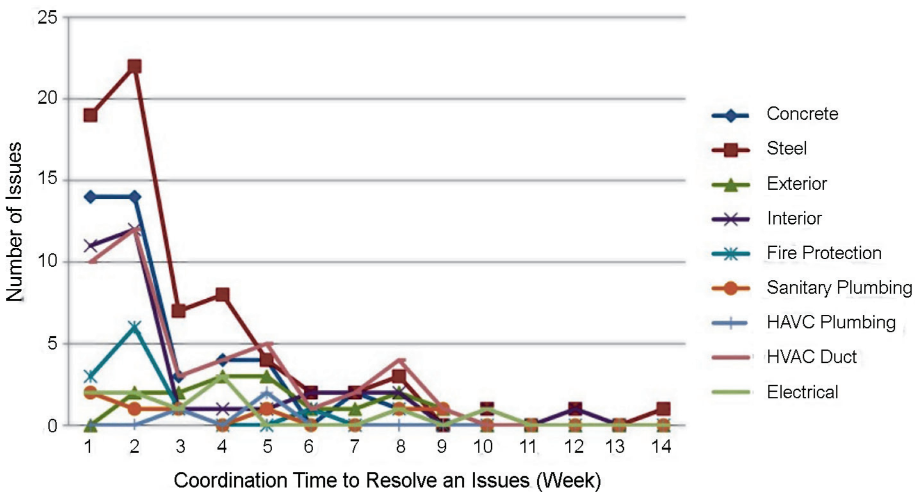

Figure 6. Coordination time to resolve issues by trade

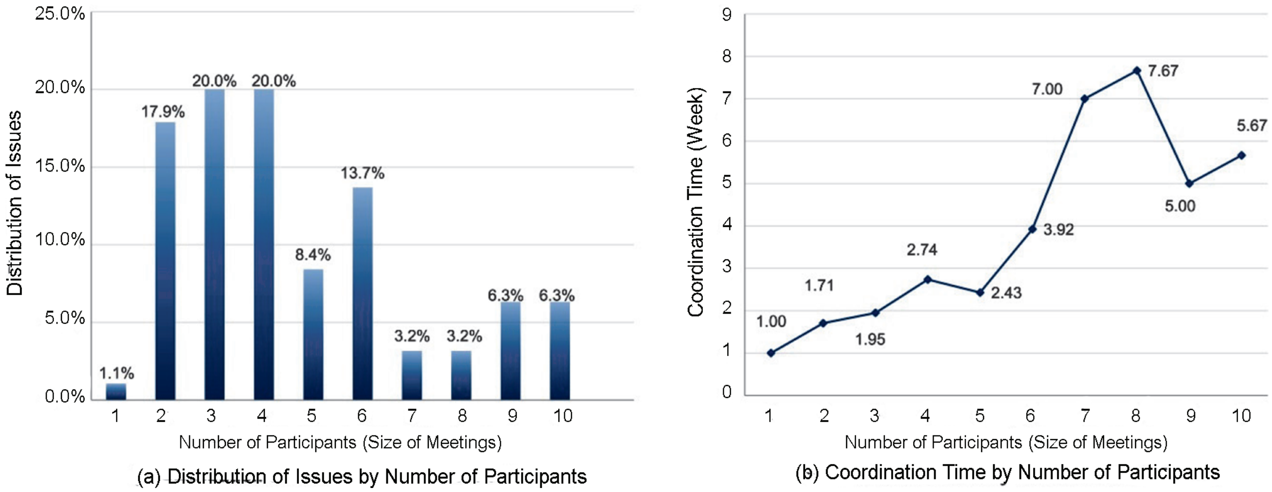

Figure 7. Distribution of issues and coordination time by the number of participants

3.3. Number of participants and coordination time

The distribution and coordination time of the issues were analyzed by the number of participants (Figure 7). On average, 4.66 participants were needed to solve one coordination issue. Approximately, 80% of issues were resolved by two to six participant meetings (Figure 7(a)). Some issue required a maximum of 10 participants; specifically, 12.6% required 9–10 participants. As a rule of thumb, 4–7 is known to be an adequate number of participants for decision-making meetings. The rule is called the "rule of seven" (EAB 2017). The results conform to this general rule of thumb.

Figure 7(b) illustrates the coordination time by the number of participants. Although not completely linear, the coordination time linearly increases as the number of participants increases in general. Nevertheless, the coordination time may exponentially increase beyond 10 or more due to the increased complexity in communication among meeting participants.

3.4. Level of decision makers and coordination time

Critical problems are known to require a high-level final decision maker (Kenny, Wilson 1984). Figure 8(a) illustrates the distribution of issues by the level of final decision makers. Only 23.2% of the issues were resolved by a subcontractor. The issues that were resolved solely by a subcontractor concerned the constructability and relocation of an object without many changes to the cost and construction sequence. In addition, 25.3% of the issues required final decision-making by the general contractor. These issues caused changes in the cost and construction sequence, owing to changes in the location and routing of trades. Therefore, mediation and decision-making steps by the general contractor between trades were needed. Meanwhile, 44.2% of the issues were found to undergo an approval process for engineering or decision-making by the designer or engineer. These issues accompanied the re-engineering of the MEP system and structural re-design by the designer and engineer. Some of

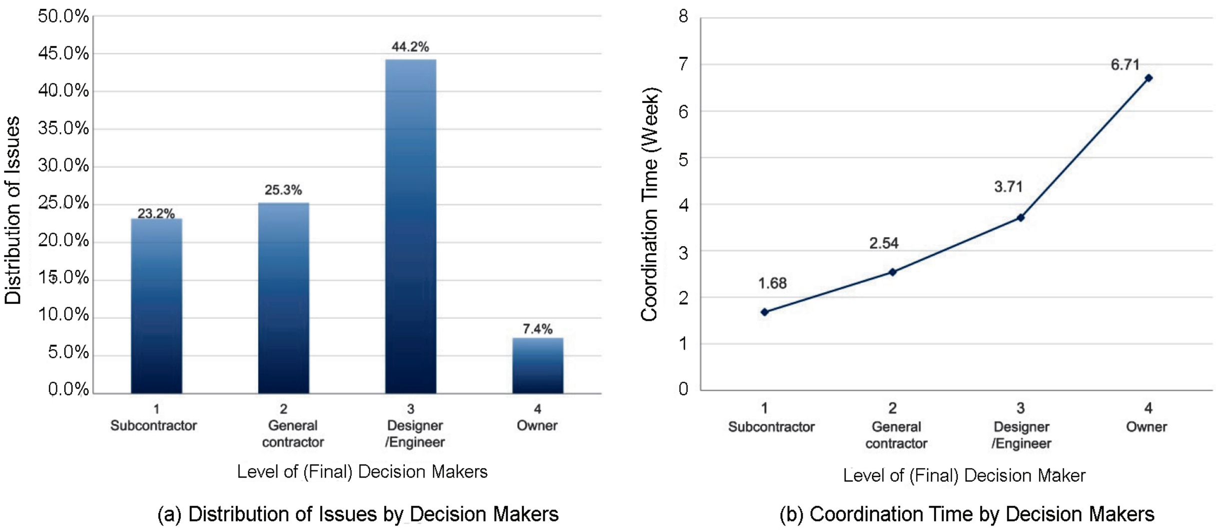

Figure 8. Distribution and coordination time of issues by the level of final decision makers

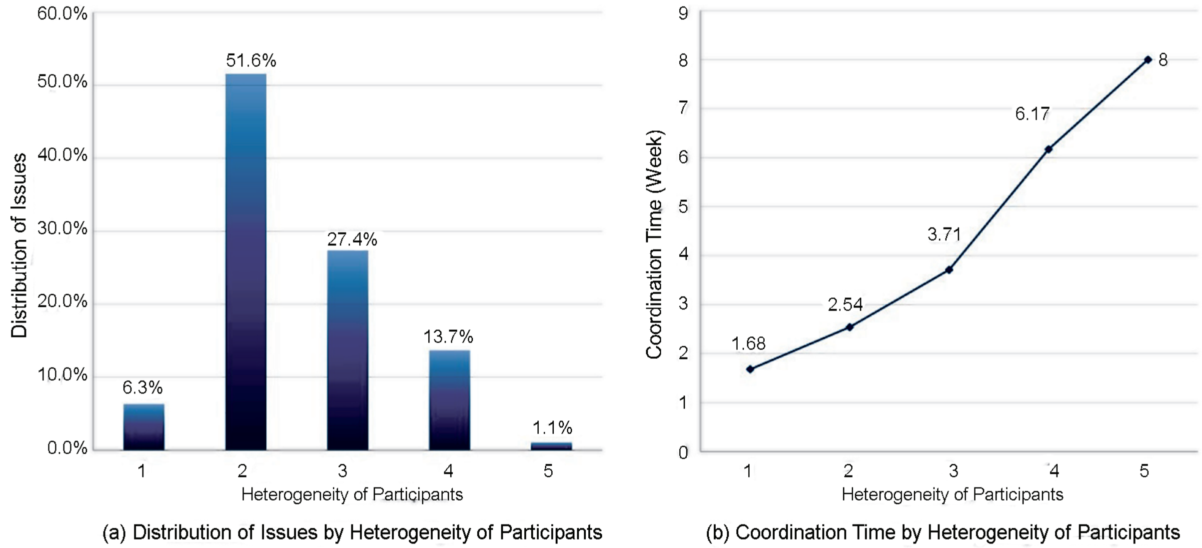

Figure 9. Distribution and coordination time according to the heterogeneity of participants

these issues simply needed approval by the designer/engineer because the general contractor had already made them, considering the cost and construction schedule. Only 7.4% required decision-making by the owner. These kinds of issues accompanied design changes that would affect the user and did not involve engineering. However, approval steps were required for design alternatives. The coordination time rapidly increased after the fourth decision-making level.

Figure 8(b) shows the trend of the coordination time according to the level of decision makers. As the level of decision makers increases, the coordination time increases. In quite a few cases, it was unknown who would be the final decision maker during the initial coordination phase. For example, in some cases, the final decision maker can be determined only after the trials and errors of re-engineering of a problematic design. However, if the final decision maker can be identified as soon as an issue is detected, the expected coordination time can be more accurately predicted and managed in the early coordination stage.

3.5. Heterogeneity of participants and coordination time

In general, coordination issues are physically associated with the conflicts between two or more trades in the same space. With the increase in the heterogeneity of participants, restrictions in coordination issues can increase, and the process of engineering and decision-making can be complicated. Therefore, an increase in the heterogeneity of participants can lead to coordination delays.

Figure 9(a) illustrates the distribution of issues according to the heterogeneity of participants. More than half of the issues (51.6%) were physically related to two trades and took an average of 2.54 weeks to be resolved. Next, 27.4% of the issues were related to three trades and took an average of 3.71 weeks to be resolved. Meanwhile, 14.8% of the issues were physically related to more than four trades, and 6.3% of the issues were a single-trade issue.

Figure 9(b) shows the trend of coordination time owing to the increase in the heterogeneity of participants. When coordination issues had a high level of heterogeneity of participants (job types), the issues generally needed more time for resolution than the others. The heterogeneity of participants was the factor that could be simply calculated in the initial phase. Thus, the coordination manager could approximately predict the coordination time for each issue and arrange a design management schedule and construction sequence according to the expected delay.

3.6. Correlation analysis between three organizational factors and coordination time

The correlations between the three organizational factors and the coordination time were statistically analyzed. First, the correlations among the three factors and the coordination time were investigated. A Pearson product-moment correlation coefficient was computed to assess the relationship between the coordination time and three organizational factors.

In general, social science determines a very strong correlation if the number is more than 0.5 (Cohen 2013). The results show that there was a very strong correlation between the coordination time and number of participants, $r = 0.540$, $p = 0.000$, $n = 95$. There was a positive correlation between the coordination time and the level of decision makers, $r = 0.467$, $p = 0.000$, $n = 95$. In addition, there was a positive correlation between the coordination time and the heterogeneity of participants, $r = 0.375$, $p = 0.000$, $n = 95$ (Table 3).

A correlation analysis between the three organizational factors shows that the number of participants had a very strong positive correlation with both the level of decision makers ($r = 0.761$, $p = 0.000$, $n = 95$) and the heterogeneity of participants ($r = 0.768$, $p = 0.000$, $n = 95$) although the level of decision makers and the heterogeneity of participants had a weak positive correlation ($r = 0.292$, $p = 0.000$, $n = 95$) (Figure 10).

Table 3. Correlation analysis between issues resolving the coordination time, heterogeneity of participants, number of participants, and level of decision makers

		Number of participants	Level of decision makers	Heterogeneity of participants
Coordination Time per Issue	Pearson Correlation	0.540**	0.467**	0.375**
	Sig. (2-tailed)	0.000	0.000	0.000
	N	95	95	95

Note: ** Correlation is significant at the 0.01 level (2-tailed).

According to the results, the number of participants has the strongest correlation with the coordination time followed by the level of decision makers, and then by the heterogeneity of participants. In addition, lowering the level of final decision makers is also expected to have a significant effect in reducing the coordination time. Although the heterogeneity of participants had a relatively weak correlation with the coordination time, it is also important to manage the diversity of participants. The strong correlations between the number of participants and the level of decision makers and between the number of participants and the heterogeneity of participants imply that the number of participants may substitute the other two factors although a further investigation is required to draw a more concrete conclusion.

Discussion and conclusion

Although BIM-based design coordination as a decision-making process has significant potential to have a strong correlation with organizational factors such as the number of participants, the level of decision makers, and the heterogeneity of participants, little study has been conducted in this area. This study analyzed the impact of such organizational factors on the coordination delay through a case study. The main findings and contributions of this study are as follows:

1) Previous studies identified contractual, management, environment, and physical factors such as IPD contract, lean approaches, a collocated work environment, and the MEP density as the main factors that affect design coordination. This study identified that common organizational factors – the number of participants, the level of decision makers, and the heterogeneity of participants – had a strong positive correlation with the coordination time/efficiency.
2) Regarding the number of participants, 80% of meetings required two to six participants and two to four weeks to reach a resolution. The coordination time may be reduced by deploying the "Obeya (big room, an integrated and collocated work environment)" approach (Fast-Berglund *et al.* 2016; Liker, Meier 2005) to bring all the major decision makers into a room and to facilitate the communication between them.
3) Regarding the level of final decision maker (the "vertical coordination" issue), 44.2% issues were associated with design and engineering issues. If the design and engineering issues could be detected and resolved during the design phase, the coordination time could be greatly reduced. This study analyzed the DBB project – the most common project delivery method thus far – as a case study. Nevertheless, this result confirms that the efficiency of design coordination can be greatly improved if an IPD approach (AIA 2011, 2012) is taken.
4) Regarding the heterogeneity of participants (the "horizontal coordination" issue), the coordination time rapidly increased as the types of trades associated with an issue increased. An integrated team or "Shojinka (flexible manpower line, multi-functional manpower)" in the lean concept (Monden 2012; Wang *et al.* 2017) can reduce the heterogeneity of participants, and thus the coordination time.

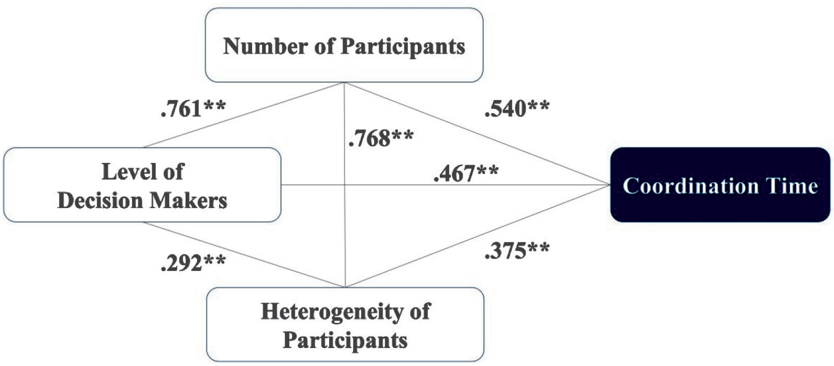

Figure 10. Correlation analysis between issues resolving the coordination time, heterogeneity of participants, number of participants, and level of decision makers (*Note*: **<0.01)

5) This study analyzed 95 coordination issues extracted from a total of an initial 11,808 clashes. The number of issues was limited in deriving statistically reliable equations for predicting the impact of the organizational factors on coordination time. Nevertheless, this study introduces the possibility of developing such equations in the future. When more data are acquired, a statistical equation for predicting and thus effectively managing the coordination time can be derived.
6) As described above, the coordination factors identified by previous studies are not independent of the organizational factors identified by this study in future studies. They can be used to monitor and analyze each other. For example, the impact of Obeya, IPD, and Shojinka on the coordination efficiency can be analyzed by analyzing the changes in the meeting size, the level of final decision-makers, and the heterogeneity of participants.

The main contribution is that this study identified the organizational factors that affect the coordination time and their relationships, which was overlooked by previous studies. Thus, this study contributes to understanding the impact of the organizational factors on the coordination time and to providing the opportunity to establish various change management and design coordination strategies associated with an organizational structure and a decision-making process as well as others. Nevertheless, many things still require further investigation. For example, in this study, the number of participants was the same as the number of organizations because it was very rare to have more than one participants from each organization, but the number of organizations and the number of participants may have a different impact on the coordination time. This and the impact of other organizational factors remain to be studied.

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