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From process-based to technology-driven: a study on functionalities as key elements of collaborative planning methods for construction projects

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ABSTRACT

With the advancement of emerging technologies, significant attempts have been made to develop collaborative planning methods and to involve as many project stakeholders as possible in the construction project planning and control process. However, inadequate consideration has been paid to the characteristics, goals, and principles underlying these methods to meet the needs of collaboration for project planning between project teams. To deal with this, a multi-stage methodology was carried out to achieve the aims of this study. The first step was identifying collaborative planning methods and their functionalities in the construction sector. Further, a quantitative analysis based on Social Network Analysis (SNA) was conducted to determine the most frequently utilized functionalities in collaborative planning methods. The results revealed that process-based collaborative planning methods' functionalities prioritized process and people-related characteristics such as team trust and promise, as well as social interactions, whereas technology-driven methods highlighted visualization along with collaboration and communication as a key element of collaborative planning. Subsequently, this study contributes to the body of construction project planning and control knowledge from both theoretical and practical perspectives by enhancing the understanding and sensemaking of project stakeholders towards the underlying concepts and objectives of collaborative planning methods.

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KEYWORDS
Technology-driven collaborative planning; process-based collaborative planning; functionalities; SNA

Introduction

Over the past decades, the construction industry has been known for its poor productivity performance compared to other sectors (Momade et al. 2023). The lack of effective communication, the fragmented and temporary nature, the uncertain and dynamic environment, and the lack of efficient collaboration between stakeholders are among the important factors contributing to this issue (Durdyev et al. 2019; Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023). Significant efforts, especially with emerging new technologies, have been made to enhance collaboration in the planning process to address any issues posed by poor productivity due to inefficient construction planning and control (Cii 2021).

In construction projects, schedules are crucial for determining payments, completion dates, coordinating various stakeholders, and controlling project progress (Sheikhkhoshkar et al. 2024). Predominantly, the construction industry employs Critical Path Method (CPM) logic as the primary scheduling tool, acknowledged for its efficiency in formulating plans and schedules for projects characterized by high complexity (Olivieri et al. 2019). However, it falls short in fostering collaboration during project planning and scheduling processes (Koolwijk et al. 2018). Due to the complexity of projects and the involvement of many stakeholders, the industry realized the need for better integration in project planning and control. This recognition led to the essential adoption of collaboration as a key process to align participants towards the common goal of delivering projects (He et al. 2022). In this context, the introduction of the Last Planner System (LPS) marked a pivotal transformation in project planning (Ballard 2000; Ballard and Howell 2003), enhancing the productivity of trades (Ballard and Tommelein 2021), reducing waste (Ballard et al. 2020; (Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023), improving collaboration through social conversations (Daniel et al. 2017), increasing the reliability of project planning (Javanmardi et al. 2018; Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023), boosting transparency (Salhab et al. 2021), enhancing the network of commitments (Scala et al. 2022), and improving communication and teamwork among the project team (Daniel, Pasquire, and Dickens 2019). Further advancements have seen the application of agile methodologies, such as Scrum and Kanban, alongside innovative approaches like Advanced Work Packaging (AWP) to bolster planning efficiency and project execution (Guerra and Leite 2020; Rebai et al. 2022; Sakikhales 2021).

Emerging Building Information Modelling (BIM) has further revolutionized collaborative planning, enhancing information

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exchange and project visualization throughout the lifecycle of construction projects (Ayman, Mahfouz, and Alhady 2022). Moreover, the integration of Industry 4.0 technologies with BIM applications has opened new avenues for engaging stakeholders more in project planning and control processes (Dawood, Rahimian, and Sheikhkhoshkar 2022; Sheikhkhoshkar et al. 2019).

Despite these advancements, adopting modern collaborative planning methods faces barriers primarily due to a reluctance to move away from traditional practices and a lack of awareness regarding the underlying concepts and benefits of these innovative approaches (AlNasseri and Aulin 2015; Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023). This gap underscores the need for a deeper understanding of collaborative planning principles and their practical application within the construction industry, leading to the introduction of the 'functionality concept' in this study based on Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh (2023)'s definition for integrated scheduling methods. Functionality refers to the operations and primary goals within collaborative planning methods. In this study, identifying and analysing functionalities can enhance understanding and sensemaking among project stakeholders, such as the engineering team (contractors/engineering cross-disciplinary), project owners, as well as suppliers towards the key features and objectives of technology-driven and process-based collaborative planning approaches. This augmented understanding is pivotal in facilitating the informed selection of the most efficacious collaborative strategy for the planning and control of construction sites, thereby optimizing project outcomes through improved stakeholder alignment and decision-making processes.

This paper aims to address these challenges by providing a comprehensive analysis of collaborative planning methods in construction, focusing on their functionalities and the interconnections between different approaches. To this end, the objectives of this study include:

1. Identify the most significant collaborative planning methods in the construction industry.
2. Identify underlying concepts of collaborative planning methods as their functionalities.
3. Analyse the identified functionalities based on their interconnections and figure out the most frequently utilized functionalities in collaborative planning methods.

It should be noted that this paper focuses on collaborative planning methods for planning and operation phase of the projects and applicable to all types of project delivery including Integrated Project Delivery (IPD)/Alliancing and those employing traditional delivery methods.

The following sections address research methodology, then results and analyses, validation, discussion, and future directions, and finally conclusions and limitations.

Literature review

Throughout the review of collaborative planning methods over time, several topics have been discussed, including general discussions regarding collaboration within project planning and scheduling as well as in-depth analyses of specific collaborative planning approaches. Regarding the former, Elsayegh and El-adaway (2021) conducted a comprehensive study into the factors influencing collaborative planning within the construction sector. Elsayegh and El-adaway (2021) proposed a Collaborative Planning Index (CPI) to measure the effectiveness of collaborative planning practices within construction projects. Scala et al. (2022) presented a practical maturity model for Collaborative Scheduling (CS), enabling practitioners to assess the current state of collaboration in their projects across five distinct dimensions or pillars and identify actionable steps for enhancing collaboration. As for the latter category, Pourrahimian, Shehab, and Hamzeh (2023) delved into the effect of collaboration across various phases of the Last Planner System (LPS). According to Daniel et al. (2020), while current construction planning methods, such as CPM and waterfall models, lack adaptability and collaboration support, scrum methods and last planner systems (LPS) are innovative approaches that integrate 'transformation', 'flow' and 'value' view theory, promoting effective collaboration and workflow within projects.

Moreover, the recent technological advancements, particularly in Industry 4.0, have spurred numerous studies on enhancing collaborative planning and control through the integration of BIM applications, notably the fourth dimension (4D), Virtual Reality (VR) (Boton 2018; Rashidi et al. 2022), digital twin that created and continuously updated through integrating of artificial intelligence (AI), internet of things (IoT), machine learning and cognitive computing (Alizadehsalehi and Yitmen 2023; Kim, Ham, and Kim 2021), multi-user VR (Truong et al. 2021; Zhou et al. 2012), touch table and touch wall screens (Boje et al. 2019; Boje et al. 2022), as well as web-based platforms (Kang, Anderson, and Clayton 2007; Lin and Golparvar-Fard 2016) have emerged as key technologies integrated with 4DBIM. These technologies address a range of objectives, including identifying sequencing planning issues, enhancing project and process comprehension, conducting constructability analysis, promoting safety and disaster management, optimizing resource allocation for schedule management, decentralizing work tracking and information sharing on construction sites, facilitating collaborative interactions among team professionals and stakeholders within a unified environment, and embracing a user-centric approach in collaborative planning.

It's worth noting that while collaborative planning literature includes applications in various fields such as urban planning (Lin 2022), digital manufacturing (Wang et al. 2009), process planning and manufacturing in product lifecycle management (Ming et al. 2008), low-carbon innovation strategy development (Wu et al. 2023), and so on, this paper specifically focuses on its relevance within the construction industry.

The analysis of existing literature has consistently highlighted the lack of comprehensive studies on the diverse range of collaborative planning methods employed within the construction industry (Bolshakova et al. 2019; Elsayegh 2021; Scala et al. 2022; Sheikhkhoshkar, El-Haouzi, Aubry, and

Hamzeh 2023). Furthermore, there has been an inadequate exploration of the fundamental principles and concepts that form the foundation of collaborative planning methods. Additionally, there is a notable dearth of knowledge regarding the functionalities that are most commonly utilized in real-world collaborative planning scenarios. These gaps highlight the need for further investigation and a more comprehensive understanding of collaborative planning methods to address the challenges faced in construction planning and control.

Research methodology

A multi-stage methodology is adopted to achieve the goals and objectives of this research. The steps of the approach are shown in Figure 1. Data collection using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), content analysis, and Social Network Analysis (SNA) are the main pillars of the adopted methodology. The following sections elaborate on each of these steps.

Systematic literature review (SLR)

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline and content analysis were followed to collect the required data for this study's objectives. PRISMA offers a standard approach that employs a guideline checklist, which was precisely considered in this paper to ensure the quality assurance and replicability of the review process (Abelha et al. 2020). To do so, a review protocol was established providing a search strategy, the article selection criteria, a screening procedure, and data extraction, as shown in Figure 2.

Search procedure

A systematic search was conducted on two electronic databases, Web of Science and Scopus, addressing collaborative planning methods in the construction industry over the last three decades. The search term was formulated by incorporating the relevant keywords and synonyms to collaborative planning methods using the Boolean operators 'AND' and 'OR' (Table 1) and conducted for the topic (WoS), article title, abstract, and keywords (Scopus). The initial search identified a total of 943 articles.

Eligibility criteria

In order to evaluate the quality of the selected articles, several inclusion and exclusion criteria were employed to ensure that they were relevant to the research objectives as well as methodologically rigorous, as shown in Table 2.

Screening process

The initial identified papers were screened and reviewed using a multi-step process. The filters available in Scopus and WoS, including document type, subject area, and source title, were used in the first stage to reduce the number of articles and eliminate those not meeting the eligibility criteria. Furthermore, the screening process involved removing duplicates, screening the title and abstract and applying inclusion and exclusion criteria in the full-text review stage. Also, to ensure the key publications were included, backward and forward citation searching were applied. In the end, 94 papers were selected for content analysis. The whole procedure of screening is depicted in Figure 2.

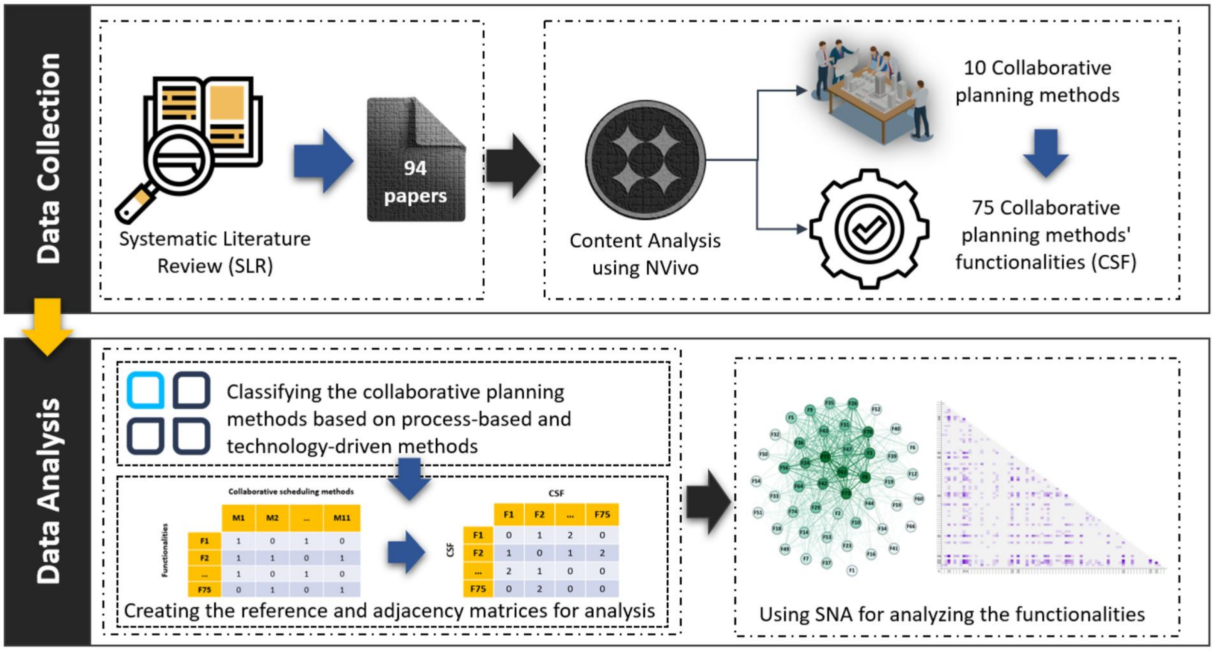

Figure 1. The process of applied methodology.

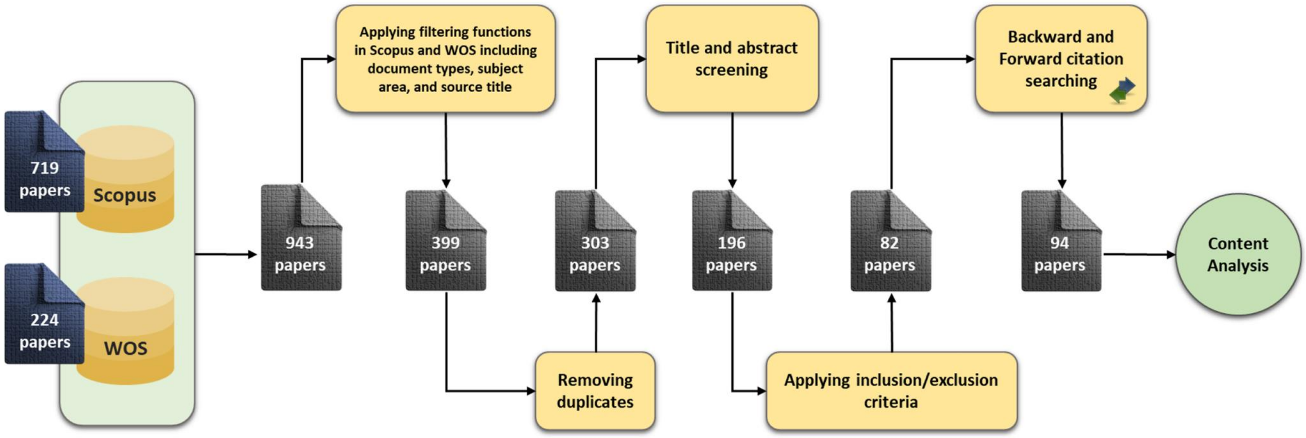

Figure 2. Applied review process.

Table 1. Search query.

Search databases	Search term
Web of Science & Scopus	("collaborative scheduling" OR "collaborative planning" OR "4D" OR "4DBIM" OR "last planner system" OR "LPS" OR "VR" OR "virtual reality" OR "Metaverse" OR "Digital Twins" OR "Agile") AND ("project planning" OR "project scheduling" OR " project control" OR "construction planning" OR "construction scheduling")

Table 2. Employed eligibility criteria.

Inclusion criteria	Exclusion criteria
Written in English	Papers in languages other than English
Peer-reviewed publications from reputable construction and manufacturing journals and conferences	Not peer-reviewed scientific reports and documents
Relevant to the aims of this study (collaborative planning methods)	Outside the scope of this research
Within the scope of the construction industry	Not applicable to the construction industry

Content analysis

The content analysis was performed on 94 finalized papers that passed the screening process to extract the collaborative planning methods and their functionalities for further analysis. To do this, NVivo 12 was used to codify the required contents. Considering Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh (2023)'s study, the authors established three distinct codes to extract the functionality of collaborative planning methods. These codes include (1) the goals and objectives of collaborative planning methods, (2) the research questions of each paper, and (3) the advantages of each collaborative planning method. The analysis and coding of 94 finalized papers identified 157 objectives and underlying concepts related to collaborative planning methods in the initial stage. In order to streamline the functionalities, duplicate functionalities were eliminated, and those with similar concepts were merged. The first author carried out the aggregation of functionalities and assessed and approved by the other authors of the paper. Finally, ten collaborative planning methods and 75 functionalities were identified for further analysis.

Quantitative data analysis

After performing a content analysis, the authors formulated two reference matrices, $\boldsymbol{C}$ and $\boldsymbol{T}$, to analyse the identified functionalities. To do so, the finalized papers were classified according to their collaborative planning methods. This study divided collaborative planning methods into two groups. The first category consisted of process-based collaborative planning methods, such as the Last Planner System (LPS), agile (Scrum and Kanban), Advanced Work Packaging (AWP), and some papers that discussed this topic in a general sense and were considered to be general collaborative planning. The second category comprised technology-driven collaborative planning methods, such as web-based 4DBIM, conventional 4D (refers to stand-alone dedicated 4DBIM tools), 4D-VR, multi-user VR, multi-touch screen-based 4D, and 4D-digital twins. The articles discussing process-based collaborative planning methods were included in the reference matrix $\boldsymbol{C}$. In addition, the articles that covered the technology-driven collaborative planning methods were included in the reference matrix $\boldsymbol{T}$. In a reference matrix, the columns indicate the analysed articles and the rows correspond to the identified functionalities. A value of 1 is entered into the cell that corresponds to a functionality if it is specified in the article; otherwise, a value of 0 is provided. The Social Network Analysis (SNA) approach was employed to analyse the developed reference matrices quantitatively, and the simplified analysis approach was used to verify the results. Further details regarding these approaches are provided as follows.

Social Network Analysis

Social Network Analysis (SNA) is a mathematical approach based on graph theory that considers the interconnections of a network's variables to study its behaviour (Elsayegh and El-adaway 2021). In SNA, nodes and edges are used to illustrate relationships and various metrics and statistics can be utilized for analysing these networks. As measuring a node's centrality in a network is the easiest and most reliable method of discovering its significance (Hosseini, Maghrebi, et al. 2018), in this study degree centrality (DC) is utilized to analyse and quantify each node's importance. The preference for the SNA method stems from its ability to evaluate interactions among various aspects of collaborative planning methods discussed in various papers. It also provides visual representations of findings and patterns, as well as uncovering connections and patterns among functionalities that would otherwise remain hidden in a simplified analysis (Elsayegh and El-adaway 2021; Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023).

Weighted adjacency matrices and metrics

In order to calculate the DC metric for reference matrices ***C*** and ***T***, it is necessary to construct the weighted adjacency matrices. The weighted adjacency matrix is a square matrix of dimensions $f \times f$, where f indicates the number of functionalities, and the values v_{ij} are the weights of the edges depicting the interconnectivity or co-occurrences between each pair of functionalities. This matrix is calculated using Eq. (1).

$$W_{f\times f} = \begin{cases} M_{f\times p} \times M^T_{f\times p} & \text{for } i \neq j \\ 0 & \text{for } i = j \end{cases} \tag{1}$$

where $W_{f\times f}$ = weighted adjacency matrix; $M_{f\times p}$ = reference matrix; $M^T_{f\times p}$ = transpose of the reference matrix; f = number of identified functionalities (i.e. 75); and p = number analysed papers (i.e. 64 in matrix ***T***). The procedure of developing the weighted adjacency matrix is performed for both matrices, ***C*** and ***T***.

Following the development of the weighted adjacency matrices, the DC for each functionality of collaborative planning methods is calculated based on Eq. (2).

$$DC_i = \sum_{j=1}^{n} v_{ij} \tag{2}$$

where DC_i = degree centrality of functionality i; v_{ij} = value of ith row and jth column of the weighted adjacency matrix; and n = number of functionalities. Given the varying number of articles employed in each matrix, to ensure score consistency and facilitate functionalities comparison, a normalized DC_i was computed within a range of 0 to 1. The calculation of normalized DC values is shown in Eq. (3), whereby the DC value of each functionality is divided by the maximum DC value in the corresponding network.

$$\overline{DC_i} = \frac{DC_i}{\max\{DC_f\}} \tag{3}$$

Validation method

To evaluate whether the SNA is working as expected, several studies utilized the simplified analysis technique (Elsayegh and El-adaway 2021; Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023). The same approach was applied to validate the SNA results in this paper. This method calculates a score for each functionality by summing all related cells in the row using Eq. (4).

$$S_i = \sum_{j=1}^{n} a_{ij} \tag{4}$$

where S_i = normalized simplified score of a functionality i; and a_{ij} = value of ith row and jth column of the reference matrix. Considering the normalization reason and procedure for DCs, the normalized score for the simplified analysis is calculated using Eq. (5).

$$\overline{S_i} = \frac{S_i}{\max\{S_p\}} \tag{5}$$

Results and analysis

In this section, the research results are presented and discussed, from data collection to analysis.

Data collection efforts

Through a systematic literature analysis, 94 papers were deemed to meet the necessary quality requirements for further analysis. Table 3 indicates the details of the selected papers in three decades. As can be seen in Table 3 and the right side of Figure 3, most of the approved papers were published after 2019. This highlights that collaborative planning methods are a research domain that has attracted increasing interest in recent years. In addition to the published articles, this claim is supported by the attention of the Construction Industry Institute (CII) in 2021 to investigate the challenges and opportunities associated with implementing collaborative scheduling in construction projects (Cii 2021). The distribution of publications throughout the research period is depicted in Figure 3. As shown on the left side of Figure 3, despite variations in the number of papers published between 2016 and 2023, there is a considerable rise in the number of publications compared to 1999 to 2016. This increase in focus on this domain is a reaction to the challenges construction project managers are still facing in deploying methods to promote collaboration in construction project planning, despite the availability of various tools, technologies and methods to enhance collaborative planning and scheduling (He et al. 2022).

Identified collaborative planning methods

After reviewing the full text of the selected articles, ten collaborative planning methods were discovered. In order to investigate the different perspectives of their functionalities, these methods were divided into two groups: process-based collaborative planning methods and technology-driven methods. Table 4 presents the methods assigned to each group; the details are explained below.

In the context of this research, technology-driven collaborative planning methods are those that have used technologies such as Building Information Modelling (BIM), Virtual Reality (VR), touch table or touch wall screen, digital twins, and web-

Table 3. Reviewed articles list.

Years	Finalized papers	No. of papers
1999–2008	(Jongeling et al. 2008; Kang, Anderson, and Clayton 2007; Li et al. 2006; Retik and Shapira 1999; Shelbourn et al. 2007; Sriprasert and Dawood 2003; Strelzoff and Sulbaran 2008; Verheij and Augenbroe 2006; Yerrapathruni et al. 2003)	9
2009–2018	(Altun and Akcamete 2018; Bataglin et al. 2017; Bolshakova et al. 2017; Boton 2018; Boton, Kubicki, and Halin 2013; Daniel et al. 2017; Dawood and Sikka 2009; De Vargas, Bataglin, and Formoso 2018; El-Sabek and McCabe 2018; Ganah and John 2017; Guerriero et al. 2017; Hamledari et al. 2017; Lin and Golparvar-Fard 2016; 2017; Mirzaei et al. 2018; Olivieri, Seppänen, and Peltokorpi 2017; Peñaloza et al. 2016; Pratama 2015; Priven and Sacks 2016; Ratajczak et al. 2018; Ribeiro and Costa 2018; Romigh, Kim, and Sattineni 2017; Sacks et al. 2013; Schimanski et al. 2018; Su and Cai 2016; 2018; Von Heyl and Teizer 2017; Zegarra and Alarcón 2015; Zhao and An 2016; Zhou et al. 2012; 2014)	31
2019–2023	(Afzal and Shafiq 2021; Alizadehsalehi and Yitmen 2023; Alzarrad et al. 2021; Ayman, Mahfouz, and Alhady 2022; Ballard et al. 2020; Ballard and Tommelein 2021; Boje et al. 2019; 2022; Bolshakova, Guerriero, and Halin 2020; Bolshakova et al. 2019; Bortolini, Formoso, and Viana 2019; Boton et al. 2022; Bourlon and Boton 2019; Cii 2021; Daniel, Pasquire, and Dickens 2019; Daniel et al. 2020; Doukari et al. 2022; 2022; Elghaish and Abrishami 2020; Elmughrabi et al. 2020; Elsayegh and El-adaway 2021; 2021; Fazeli et al. 2022; Guerra and Leite 2020; He, Du, and Perlin 2020; He et al. 2022; Huang et al. 2021; 2022; Jimenez Anders 2022; Kandregula and Le 2020; Khan et al. 2021; Khataei, Akcamete, and Sonmez 2020; Kim, Ham, and Kim 2021; Korb and Sacks 2021; Ma, Zhang, and Chang 2020; Pérez and Bastos Costa 2021; Poudel, Garcia de Soto, and Martinez 2020; Rashidi et al. 2022; Rebai et al. 2022; Roupé et al. 2020; Sakikhales 2021; Salhab et al. 2021; Scala et al. 2022; Schiavi et al. 2022; Sheikhkhoshkar et al. 2019; Tallgren, Johansson, and Roupé 2022; Tallgren, Roupé, and Johansson 2021; Tomar and Bansal 2022; Torres-Calderon et al. 2019; Truong et al. 2021; Viklund Tallgren et al. 2020; Wu et al. 2021; Yang et al. 2021)	54

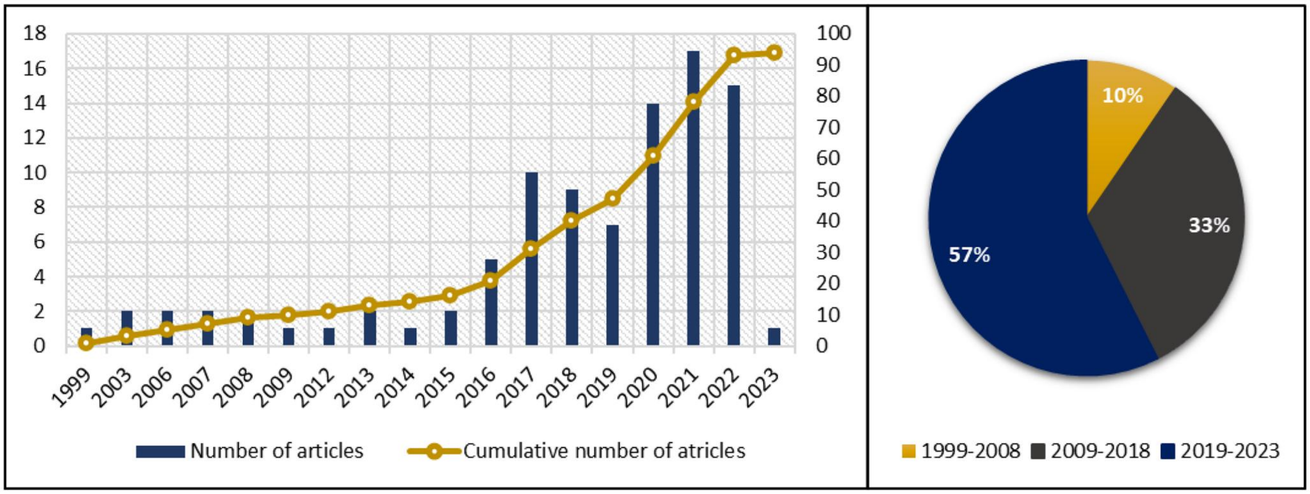

Figure 3. The distribution of articles over time.

based platforms to facilitate collaboration between project stakeholders in project planning and control. Web-based 4D Building Information Modelling (BIM) emerges as a pivotal facilitator of remote collaboration. Leveraging accessible platforms, this technology enables real-time collaboration among stakeholders situated in disparate locations. Concurrently, Conventional 4D BIM assumes significance in its role as a visual representation tool for project timelines. Its utility lies in aiding project teams in comprehending temporal aspects and identifying potential conflicts during the planning phase. Multi-user Virtual Reality (VR) presents a critical role by creating an immersive shared environment, providing stakeholders with a virtual construction site experience that enhances comprehension and decision-making through realistic simulations. Furthermore, Multi-touch Screen-based 4D offers an interactive platform, fostering collaborative planning sessions where multiple team members can contribute concurrently. The integration of time into Virtual Reality, as exemplified by 4D-VR, provides a unique immersive perspective of the project's temporal evolution. Lastly, 4D-Digital Twins (4D-DT) integrates real-time monitoring and predictive analysis, collectively enhancing decision-making efficacy. The combination of these technologies contributes synergistically to a paradigm shift in collaborative planning, fostering real-time collaboration, augmenting visualization, and incorporating temporal dimensions into the decision-making process. This synthesis underscores the profound impact of these technologies within the academic discourse on construction project planning.

It should be mentioned that conventional 4D BIM in this group refers to the 4D model created by integrating the 3D model and Critical Path Method (CPM)-based scheduling in stand-alone software such as Navisworks, Synchro, or similar ones.

In addition, process-based collaborative planning methods are those that attempt to involve stakeholders by changing and simplifying the process and improving communication, such as the Last Planner System (LPS) and Advanced Work Packaging (AWP). It is worth noting that some articles have discussed collaborative planning methods in general, and without focusing on a specific method or technique, these articles were

Table 4. Identified collaborative methods.

ID	Collaborative planning methods		References
1	Technology-driven	Web-based 4D BIM	(Kang, Anderson, and Clayton 2007; Lin and Golparvar-Fard 2016; Olivieri, Seppänen, and Peltokorpi 2017)
2		Conventional 4D BIM	(Bortolini, Formoso, and Viana 2019; Doukari et al. 2022; Fazeli et al. 2022; Huang et al. 2022; Ma, Zhang, and Chang 2020; Torres-Calderon et al. 2019)
3		Multi-user virtual reality (VR)	(Truong et al. 2021; Zhou et al. 2012; 2014)
4		Multi-touch screen-based 4D	(Boje et al. 2022; Bolshakova, Guerriero, and Halin 2020; Bolshakova et al. 2019)
5		4D – virtual reality (4D-VR)	(Bourlon and Boton 2019; Rashidi et al. 2022; Roupé et al. 2020; Schiavi et al. 2022; Tallgren, Johansson, and Roupé 2022)
6		4D – digital twins (4D-DT)	(Alizadehsalehi and Yitmen 2023; Huang et al. 2021; Kim, Ham, and Kim 2021; Von Heyl and Teizer 2017)
7	Process-based	General collaborative planning	(Daniel et al. 2020; Elsayegh and El-adaway 2021; He et al. 2022; Scala et al. 2022; Verheij and Augenbroe 2006)
8		Last planner system (LPS)	(Ballard et al. 2020; Ballard and Tommelein 2021; Daniel et al. 2017; Priven and Sacks 2016; Salhab et al. 2021; Viklund Tallgren et al. 2020)
9		Advanced work packaging (AWP)	(Guerra and Leite 2020; Rebai et al. 2022; Wu et al. 2021)
10		Agile (scrum, kanban)	(Daniel et al. 2020; Jimenez Anders 2022; Poudel, Garcia de Soto, and Martinez 2020; Sakikhales 2021)

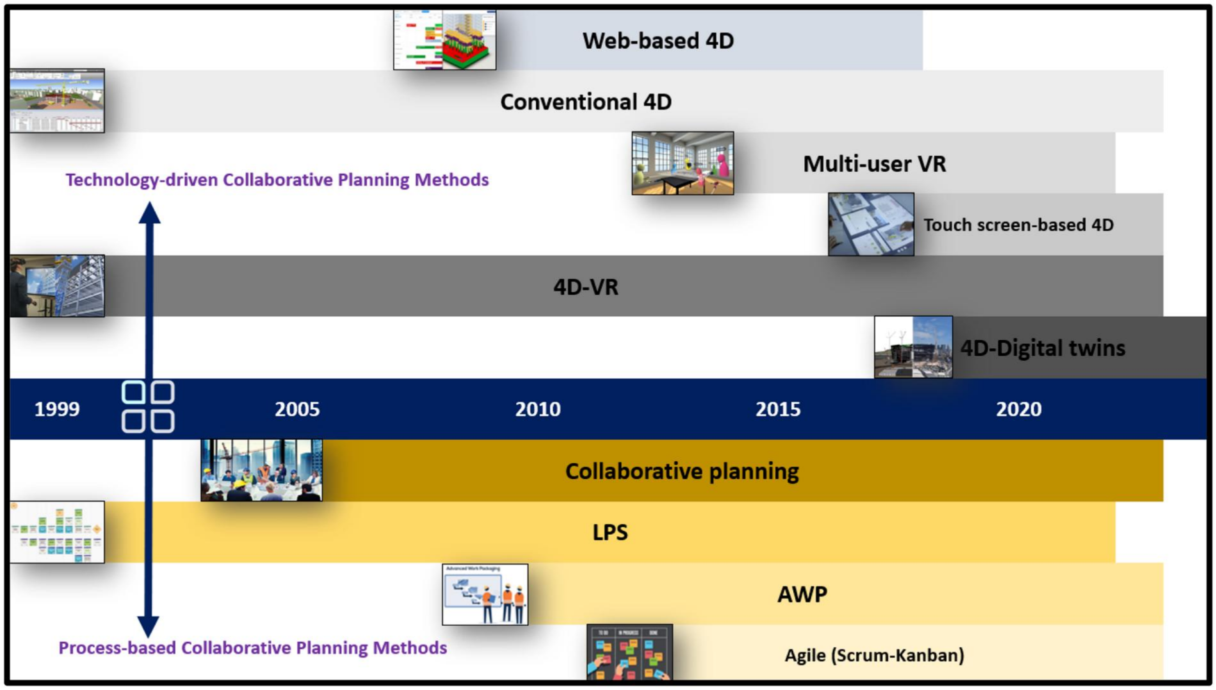

Figure 4. Evolution of collaborative planning methods over time.

categorized in the form of general collaborative planning methods and put in the process-based methods group.

Figure 4 depicts the evolution of collaborative planning methods over twenty-four years. The diagram is divided into two sections, the upper part for technology-driven methods and the lower part for process-based methods, each representing a specific period for their corresponding methods. The left section of the diagram represents the starting point 24 years ago, illustrating the emphasis placed on the last planner system to incorporate the project team into the project planning process (Ballard 2000). Although the emergence of technology-driven methods such as conventional 4D and 4D-VR in the early years (Retik and Shapira 1999), the technological, organizational, hardware, and software maturity required to use them for collaborative planning in the construction industry was not available. Moving to the right and with technological advancement, the diagram depicts technology integration into collaborative planning methods. In recent years, with the development of technology in the era of the fourth industrial revolution, the focus has shifted towards the use of technologies such as virtual reality, web-based platforms, multi-user touch screens, digital twins and metaverse for collaborative planning (Boje et al. 2022; Huang et al. 2021; Rashidi et al. 2022; Truong et al. 2021), although the focus on process-based collaborative methods has also been an integral part of collaborative planning.

Quantitative analysis of collaborative planning methods' functionalities

By reviewing the papers provided in Table 3, in addition to identifying collaborative planning methods, the authors discovered 75 of their functionalities in the construction industry, illustrated in Table 5. As detailed in the methodology part, two reference matrices, ***T*** and ***C***, were created to analyse these functionalities. The matrix ***T*** contains 64 papers and 64 functionalities, resulting in a matrix of dimensions 64 by 64. Similarly, matrix ***C*** consists of 30 papers and 46 functionalities, creating a matrix of dimensions 46 by 30. After constructing the reference matrices, SNA was utilized as a quantitative technique to analyse the functionalities of collaborative planning methods. The following explains the results of the functionalities analysis.

Social Network Analysis

As a result of the constructed reference matrices, the weighted adjacency matrices, $\boldsymbol{C}_{46\times46}$ and $\boldsymbol{T}_{64\times64}$, were developed to calculate the degree of centrality (DC) for identified functionalities. The results of the scores for each functionality are provided in the Appendix, Table A. Using this metric within this study's context can emphasize the understudied and extensively studied functionalities in both technology-driven and process-based collaborative planning methods. In this regard, Figure 5(a) and Figure 6(a) show the networks of functionalities for process-based and technology-driven collaborative planning methods, respectively. The process-based collaborative planning methods' functionalities network (Network C) includes 864 edges and 46 nodes, indicating that process-based collaborative planning methods covered 46 functionalities out of 75. Also, the functionalities network for technology-driven collaborative planning methods (Network T) consists of 1558 edges and 64 nodes, demonstrating that technology-driven collaborative planning methods can support 64 out of 75 functionalities. The network nodes reflect the functionalities, whereas the edges indicate the interdependence or co-occurrence of each pair of functionalities. The node's colour corresponds to the computed DC of the associated functionality, higher DC values equate to darker colours. Furthermore, the thickness of the edges reveals the degree of interconnection between functionalities, with greater thickness indicating a higher degree of co-occurrence. As networks have a significant number of connections, colour-coded matrices are provided to illustrate the co-occurrence of functionalities more clearly, Figure 5(b) and Figure 6(b). The matrices are colour-coded according to the strength of the link between the two functionalities. The blank cells correspond to a pair of functionalities that never co-occurred in any of the collaborative planning methods, while darker cells indicate high weights and, so, a high co-occurrence between functionalities in the collaborative planning methods. The collaborative planning methods' functionalities in each network can be discussed from two perspectives: (1) the functionalities that were extensively studied or considered in collaborative planning methods, and (2) the functionalities that were neglected or understudied.

Addressing the first point of view, Figure 5(a) reveals that the most often utilized functionalities in process-based collaborative planning methods are F72 (supporting the trust and reliable promises among the team), F61 (reducing uncertainty and risk), F8 (continuous improvement process), F73 (systematic identification and removal of constraints), F70 (supporting collaboration through social conversations), and F3 (assisting in reducing waste). In addition, as shown in Figure 6(a), F36 (improving communication and teamwork between the project team), F41 (improving safety management on site), and F74 (visualizing alternative construction sequences based on various what-if scenarios) are the most frequently employed functionalities in technology-driven collaborative planning methods.

Concerning the second perspective, based on Figure 5(a) and Figure 6(a), F66 (solving disputes more efficiently), F1 (allowing just-in-time (JIT) purchasing and delivery of material), F41 (improving safety management on site), and F59 (reducing the change orders during construction) have received the least attention in process-based collaborative planning methods. Also, the results indicate that F1 (allowing just-in-time (JIT) purchasing and delivery of material), F73 (improving decision-making among geographically dispersed industry practitioners), F60 (reducing the impacts of potential causes of delay), and F20 (enabling real-time collaborative 4D planning to gain a robust construction plan) are functionalities with little consideration in technology-driven collaborative planning methods.

The interesting point is that F41 (improving safety management on site) is one of the most used functionalities in technology-driven collaborative planning methods, while it has been one of the least used functionalities in process-based methods. This indicates that technology-driven methods pay more attention to various project planning aspects, including safety. Moreover, another finding indicates a weakness in supply chain management within current collaborative planning methods, as evidenced by the low DC value for F1 (allowing just-in-time (JIT) purchasing and delivery of material) in both process-based and technology-driven approaches. Further study and investigation will be required to address this issue.

The co-occurrence analysis of functionalities, based on the colour-coded matrix of Figure 5(b) and Figure 6(b), shows that the pairs of F70 (supporting collaboration through social conversations) and F3 (assisting in reducing waste), F72 (supporting the trust and reliable promises among the team) and F61 (reshaping an individual's cognitive determinants to influence collaboration throughout project delivery), F72 (supporting the trust and reliable promises among the team) and F73 (systematic identification and removal of constraints), and F72 (supporting the trust and reliable promises among the team) and F70 (supporting collaboration through social conversations) are considered most in process-based collaborative planning methods. Also, F36 (improving communication and teamwork between the project team) and F74 (visualizing alternative construction sequences based on various what-if scenarios), F36 (improving communication and teamwork between the project team) and F7 (constructability evaluation), F65 (site layout and environment management) and F41 (improving safety management on site), and F13 (dynamic collision detection and spatial-temporal conflict analysis) and F17 (empowering automated project progress

Table 5. Collaborative planning methods' functionalities.

ID	Collaborative planning methods' functionalities
F1	Allowing just-in-time (JIT) purchasing and delivery of material
F2	Allowing the interactions of multiple team professionals and stakeholders in a common environment.
F3	Assisting in reducing waste
F4	Automated planning of concrete joint layouts
F5	Automatic generation of the as-built real-time 4D simulation
F6	Better flow of information
F7	Constructability evaluation
F8	Continuous improvement process
F9	Continuous learning
F10	Creativity, option generation, and innovation
F11	Decentralized work tracking and information communication on construction sites
F12	Detected more logical errors, more accurately, and faster, with less need for intrateam communication
F13	Dynamic collision detection and spatial-temporal conflict analysis
F14	Early involvement of key project stakeholders
F15	Easing of access and low training time
F16	Effective supply chain practices
F17	Empowering automated project progress monitoring
F18	Enabling lean construction adoption and situation awareness
F19	Enabling project performance prediction
F20	Enabling real-time collaborative 4D planning to gain a robust construction plan
F21	Enabling real-time communication with workers
F22	Enabling real-time tracking in construction site
F23	Enabling value management/engineering
F24	Enhancing transparency
F25	Experiencing and reviewing scheduled sequences on a 1:1 scale
F26	Facilitating communication with subcontractors
F27	Fosters the convergence of 4D uses with project documents
F28	Generating real-time interactive project visualization
F29	Aligning goals with owner
F30	Higher sense of immersion and interaction
F31	Highlighting the importance of short-term planning at crew level
F32	Identifying possible optimizations
F33	Identifying time-space conflicts
F34	Improving alignment of engineering & procurement with construction and commissioning
F35	Improving collaborative sensemaking
F36	Improving communication and teamworking between the project team
F37	Improving decision making among geographically dispersed industry practitioners
F38	Improving engineering curriculum
F39	Improving organizational agility
F40	Improving role description and responsibilities
F41	Improving safety management on site
F42	Improving the involvement and the commitment of all the professional groups
F43	Increasing the work-flow reliability onsite
F44	Maintaining a workable backlog
F45	Making decision under a user-centric approach
F46	Monitoring worker motion and worker location
F47	More efficient resources management.
F48	More natural and industry-adapted interactions during a collaboration session
F49	Moving participants from passive receivers of a schedules to active contributors to the schedule
F50	Permitting real-time virtual collaboration for stakeholders from different locations
F51	Providing predictive control/monitoring method to make the best decisions with forwarding simulation
F52	Providing a digital equivalence to face-to-face communication in construction projects
F53	Providing better budget control
F54	Providing enhanced awareness of ongoing work
F55	Providing ergonomic interactions with the session workflow.
F56	Pull planning effectiveness
F57	Real-time safety monitoring
F58	Reducing information loss in data exchange
F59	Reducing the change orders during construction
F60	Reducing the impacts of potential causes of delay
F61	Reducing uncertainty and risk
F62	Reshaping an individual's cognitive determinants to influence collaboration throughout project delivery
F63	Safer learning environment
F64	Sharing the knowledge and lessons learned
F65	Site lay-out and environment management
F66	Solving disputes more efficiently
F67	Solving site logistic problems
F68	Supporting the learning and process of planning of offsite construction production challenges
F69	Supporting co-navigate, co-sort, co-plan, co-simulate and co-talk
F70	Supporting collaboration through social conversations
F71	Supporting multi-functional review meetings
F72	Supporting the trust and reliable promises among the team
F73	Systematic identification and removal of constraints
F74	Visualizing alternative construction sequences based on various what-if scenario
F75	Workspace planning

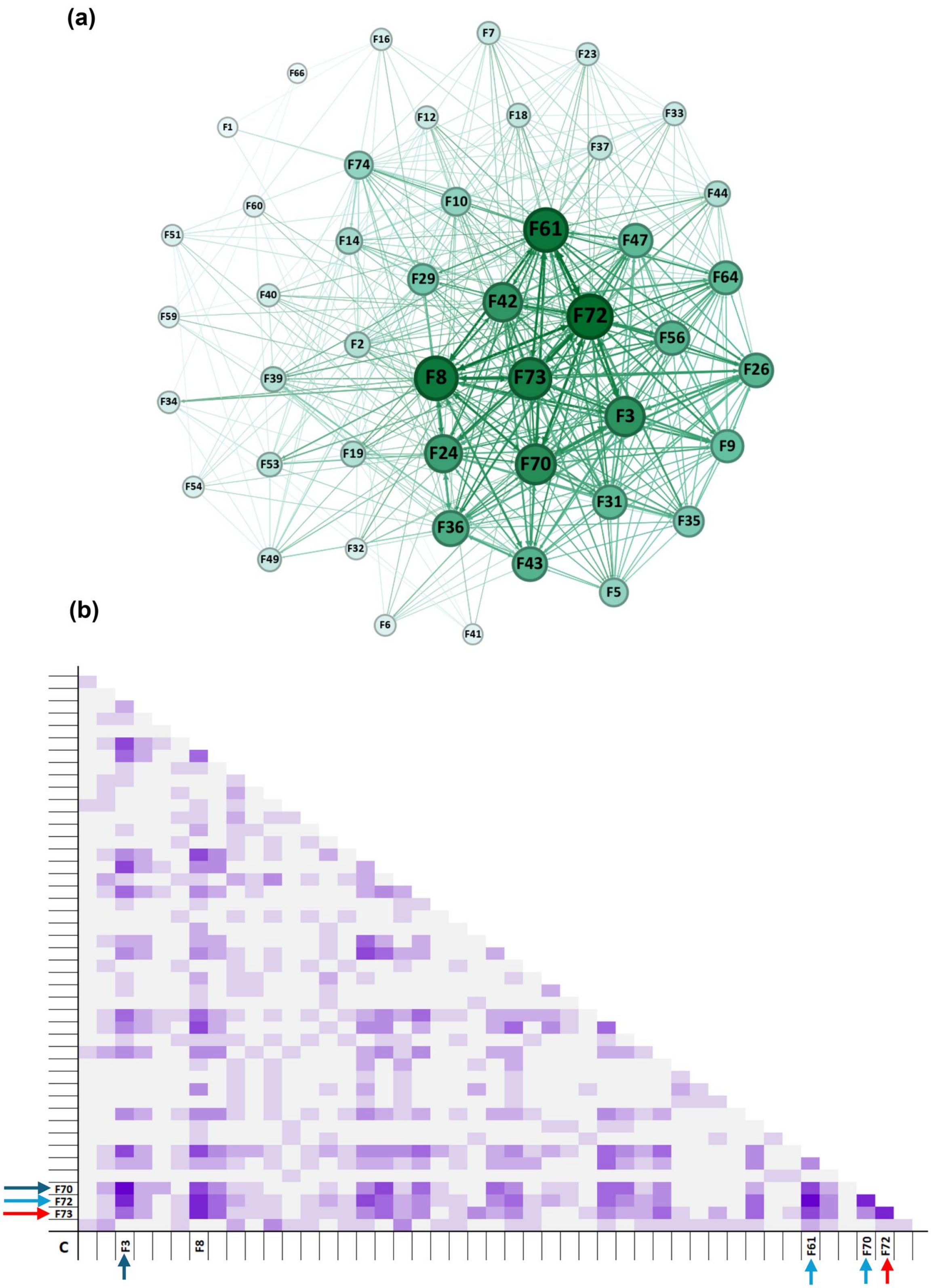

Figure 5. (a) Process-based collaborative planning methods' functionalities network, (b) colour-coded matrix of functionalities.

monitoring) are received the most co-occurrence in technology-driven collaborative planning methods.

Figure 7 illustrates the derived differences of normalized DC (C-T) for the functionalities of collaborative planning methods in the construction industry to better make sense of and visualize the differences between the most utilized functionalities presented in Figures 5 and 6. Large positive values in Figure 7 indicate that process-based collaborative planning methods have emphasized the respective functionalities more. Large negative values, on the other hand, indicate those associated functionalities have been supported more by technology-driven collaborative planning methods.

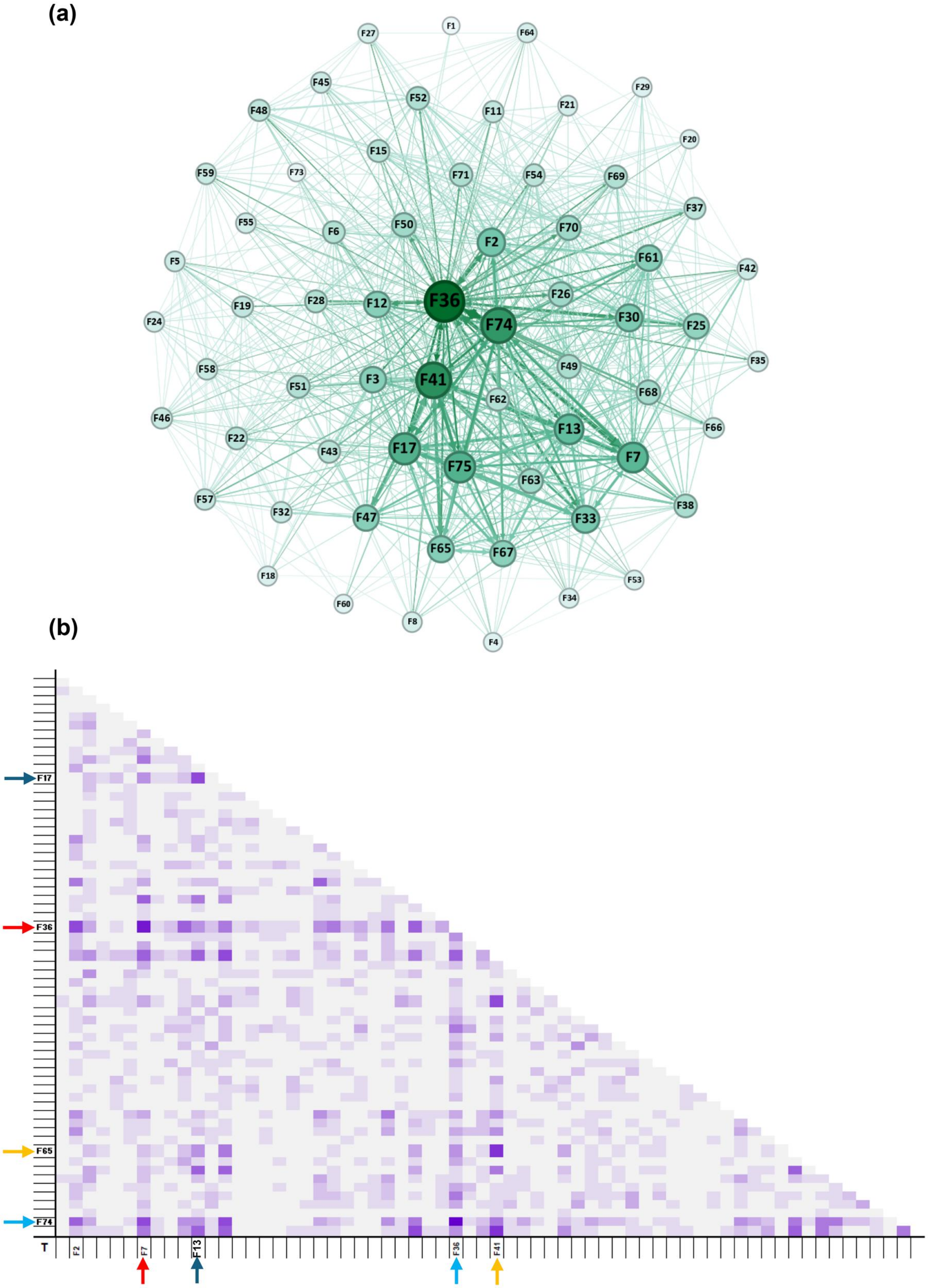

Figure 6. (a) Technology-driven collaborative planning methods' functionalities network, (b) colour-coded matrix of functionalities.

As can be seen in Figure 7, Only four out of 75 functionalities have closely comparable DC scores in process-based and technology-driven collaborative planning methods, which are F37 (improving decision-making among geographically dispersed industry practitioners), F1 (allowing just-in-time (JIT) purchasing and delivery of material), F34 (improving alignment of engineering & procurement with construction and commissioning), and F60 (reducing the impacts of potential causes of delay). These functionalities are among the least considered in both methods. Moreover, although the technology-driven methods have covered more functionalities, as seen in the C&T network in Figure 5(a) and Figure 6(a), the network

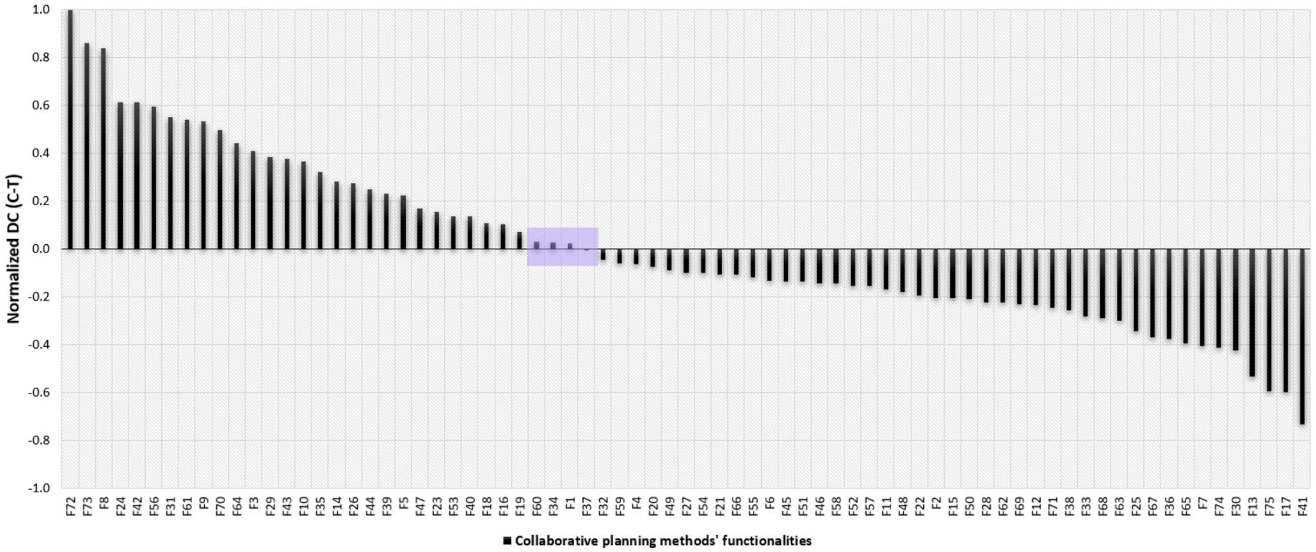

Figure 7. Difference between network C and network T normalized DCs.

corresponding to the process-based methods is denser, and functionalities have obtained more DC values. To discover the reason for this, collaborative planning methods for each group (process-based and technology-driven) were evaluated concerning their ability to support people, process and technology aspects, as depicted in Figure 8. The explanation for taking into account these three aspects is that, according to Shelbourn et al. (2007) and Dave et al. (2008), effective collaborative works in construction, including collaborative planning, can be performed by bringing together and integrating these three strategic areas of process, people, and technology.

As seen in Figure 8, process and people aspects have received considerable attention in process-based collaborative planning methods, while in technology-driven collaborative planning methods, the emphasis has been on people and technology. In a survey conducted by Shelbourn et al. (2007) regarding the significance of three essential strategies for effective collaboration, respondents assigned 40% importance to people, 34% value to processes, and 26% to technology. Moreover, Wilkinson (2005) argued that for adopting and implementing any collaboration technologies in the construction industry, people, process, and technology should be considered in proportions of 40%, 40%, and 20%, respectively. These findings reveal that current collaborative planning methods, whether process-based or technology-driven are ineffective since the necessary and sufficient attention has not been paid to integrate the aspects of people, process, and technology in their development, adoption, and implementation. For instance, in technology-driven collaborative planning methods, a great deal of effort has been spent on developing functionalities by focusing on the visible aspect, technology, while the process side has received less attention. Also, the technology dimension is almost ignored in process-based collaborative planning methods. Considering previous studies' findings (Dave et al. 2008) and based on the beliefs of this paper's authors, the collaborative planning methods could be more effective by a paradigm shift and bringing together and leveraging the people, process, and technology components by following this order and putting a greater emphasis on the people and process aspects first. These findings offer a transformative opportunity for construction projects by facilitating customized implementations tailored precisely to the unique needs of each project. This personalized approach enhances overall efficiency and contributes significantly to project success. It achieves this by fostering collaborative decision-making and actively involving project stakeholders and considering their skills and knowledge in the planning and control process. In summary, these insights empower construction projects to make informed decisions, fostering a holistic and adaptive approaches, optimizing resource allocation for adoption and implementation of more fitted collaborative planning methods that improve efficiency, reduce risks, and enhance collaboration during the project lifecycle.

Validation of SNA results

This study uses a simplified analysis to verify the SNA outcomes. The normalized scores were computed to compare with the DC values for two reference matrices. Based on normalized degree centrality values for the SNA and normalized score for simplified analysis, Pearson correlation, variance, and standard deviation, the same as Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh (2023), have been utilized to evaluate the correlation between the findings of these two methodologies and validate the SNA results. The Pearson correlation is a statistical measure used to assess linear relationships between variables. Using a scale of −1 to +1, it calculates the strength and direction of their association, where −1 means a perfect negative correlation, +1 means a perfect positive correlation, and 0 indicates no correlation at all. Furthermore, variance and standard deviation are measures of how far the values of a dataset deviate from the mean. In this manner, they are able to quantify the degree of variability or dispersion within the data points. Table 6 displays the outcomes of the aforementioned statistical tests. In addition,

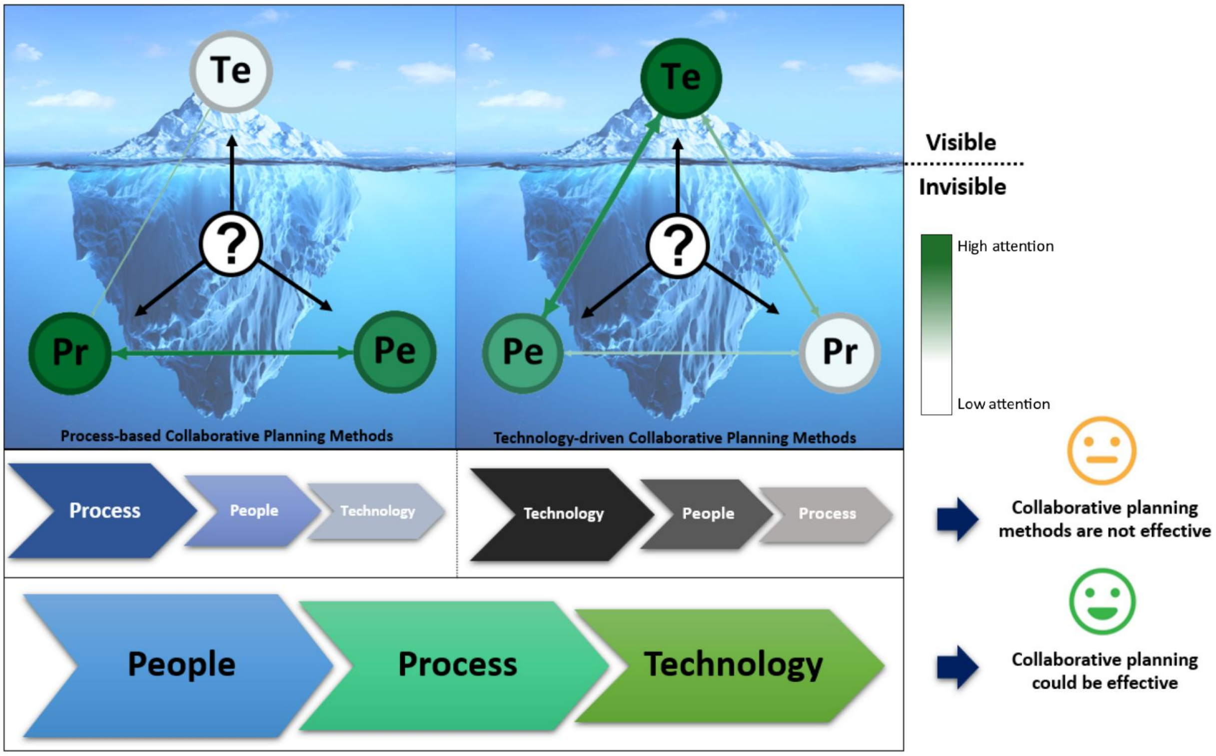

Figure 8. Evaluating collaborative planning methods in view of people, process and technology.

Table 6. Results of statistical tests on the simplified analysis and SNA.

	Matrix C		Matrix T	
Statistics tests	Simplified Analysis	SNA	Simplified Analysis	SNA
Mean	0.333	0.255	0.16	0.206
Variance	0.061	0.080	0.047	0.037
Standard Deviation	0.246	0.282	0.217	0.192
Pearson Correlation	0.928		0.966	

to visualize the statistical tests' results, violin plots for the findings of two techniques are provided in Figure 9. A violin plot integrates a box plot and a kernel density plot to present summary statistics and distribution shapes of the data. For instance, in the case of violin plots for matrix T, both violin plots (simplified analysis and SNA) exhibit similar distribution shapes, as indicated by smooth and symmetric kernel density curves. Thus, the data points are concentrated around similar values, resulting in comparable distribution patterns. In addition, based on the similarities between the box plots of the two violin plots, we can conclude that the data sets have comparable measures of central tendency, spread, and overall distribution. In light of this, it is reasonable to conclude that the two methods being compared have similar characteristics and statistical properties.

There are minor differences in the results of the two analytical techniques when considering the box plots, distribution shapes, and statistical test scores for each matrix. The fact that SNA employs more sophisticated criteria to evaluate the functionalities' interrelationships may help explain this slight variation (Elsayegh and El-adaway 2021; Sheikhkhoshkar, El-Haouzi, Aubry, and Hamzeh 2023). Therefore, the statistics and violin plots in Table 6 and Figure 9 confirm that the SNA functions as anticipated.

Discussion, and future directions

This study contributes to the body of collaborative planning methods knowledge by identifying and analysing the collaborative planning methods and their functionalities in the construction industry. In this regard, the analysis of collaborative planning methods indicates that in recent years, with technological advancement, particularly industry 4.0 technologies, researchers and the market have focused on developing technology-driven solutions, including virtual reality, web-based platforms, multi-user touch screens, digital twins and metaverse for collaborative project planning and control in the construction industry. Even though these technologies facilitate communication, collaboration, and processes among project stakeholders for planning and control, several studies (Dave et al. 2008; Shelbourn et al. 2007; Wilkinson 2005) revealed that for effective collaborative planning, people and process aspects are more crucial than technology. Indeed, for effective collaborative planning, focusing on technology-first approaches is difficult to successfully implement if the human resource challenges are not considered. Thus, before determining the appropriate technology for the particular needs of the collaboration, it is necessary to identify the staff's challenges, define a process, and then decide which technology would be most appropriate. It is worth noting that although BIM, especially 4D, has been utilized in all technology-driven collaborative planning methods to improve collaboration, communication and visualization of what-if scenarios, it has only been used as a tool. However, BIM is not only a tool; rather, it is a process that can support all three aspects of people, process, and technology. As a result, it is recommended that future research and market platforms integrate people and process characteristics in process-based methods

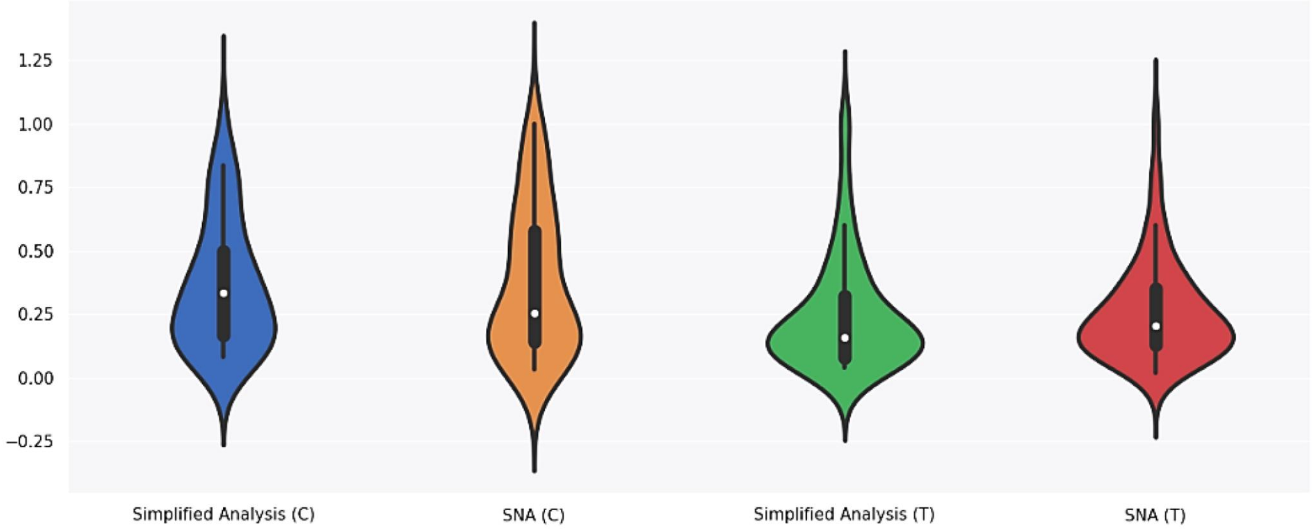

Figure 9. Violin plots for the simplified analysis and SNA.

such as the last planner system with new technologies to have more effective collaborative planning methods.

Concerning the collaborative planning methods' functionalities, the analysis followed by highlighting functionalities that have gotten the most attention and the ones that have received the least in both process-based and technology-driven collaborative planning methods. In light of this, the results of process-based collaborative planning methods' functionalities network indicated that supporting the trust and reliable promises among the team, reducing uncertainty and risk, continuous improvement process, systematic identification and removal of constraints, supporting collaboration through social conversations, and assisting in reducing waste are the most often employed functionalities in process-based collaborative planning methods. These outcomes reflect a special focus on process and people-related characteristics such as team trust and promise, systematic identification and elimination of constraints, and collaboration via social interactions. Moreover, solving disputes more efficiently, allowing just-in-time (JIT) purchasing and delivery of material, improving safety management on site, and reducing the change orders during construction are the least received focus in process-based collaborative planning methods. Since project planning, scheduling, and control is a complex and dynamic process, it must integrate numerous concepts, including safety, supply chain, cost, quality, teamwork, and so forth, to be successful. As a practical matter, contractors and owners tend to pay more attention to contractual, legal, and technical concerns, and these should be included in the fundamental functionalities of project planning and control methods. However, the results of the functionalities analysis revealed that in both process-based and technology-driven collaborative planning methods, little attention is paid to the essential aspects of project planning and control, such as effective delay and claim management, change order management, procurement and supply chain management, and site safety management. These issues have the potential to be studied in the future.

Addressing the findings of technology-driven collaborative planning methods' functionalities, improving communication and teamwork between the project team, improving safety management on site, and visualizing alternative construction sequences based on various what-if scenarios have been considered frequently used functionalities. This analysis highlights that although technology-driven collaborative planning methods cover more functionalities than process-based methods, there is still confusion regarding the functionalities that must be prioritized to develop an effective collaborative planning method. This is due to the fact that only 3 out of 64 functionalities achieved high degree centrality scores in technology-driven methods. Furthermore, besides concentrating on collaboration and communication among stakeholders, these methods have significantly emphasized visualization as a central function in collaborative planning. Visualization examples include utilizing fourth dimension (4D) simulation, Virtual Reality (VR), digital twins, multi-user VR experiences, and interactive touch table and touch wall screens. These tools enable stakeholders to immerse themselves in the project environment, explore scenarios, and gain a comprehensive view of construction processes. Visualization fosters better communication, facilitates real-time collaboration, and aids in identifying potential issues early in the planning phase, contributing to more efficient and informed decision-making throughout the project lifecycle.

Additionally, the outcomes illustrate that allowing just-in-time (JIT) material purchasing and delivery, improving decision-making among geographically dispersed industry practitioners, reducing the impacts of potential causes of delay, and enabling real-time collaborative 4D planning to gain a robust construction plan are functionalities that acquire least scores in technology-driven collaborative planning methods. It can be discovered that despite the necessity of geographically dispersed and real-time communication and collaboration throughout the COVID period and thereafter, they are still in infantile maturity in collaborative planning methods. Focusing on technologies such as digital twins and metaverse can considerably improve the possibility of practical implementation of these two functions. Future studies can investigate this concern as well. Also, technology-driven collaborative methods often focus on the technology, such as real-time solutions, without taking full advantage of their collaborative potential.

Due to the growing interest in using integrated project delivery (IPD) and other collaborative project delivery methods such as early contractor involvement or progressive Design-Build (DB) and prefabrication methods in the construction industry (Hosseini, Maghrebi, et al. 2018; Rashed and Mutis 2023), there will be an increased demand to develop integrated project planning, scheduling and control methods to combine planning and control of design and engineering, procurement and construction phases. While the functionalities analysis in this article reveals that in both collaborative planning methods, the functionalities related to the supply chain and procurement, allowing just-in-time (JIT) material purchasing and delivery, have been neglected, highlighting the need for more research in the future.

The implications of the findings

The implications of the findings are thoroughly discussed in this section concerning the identified collaborative planning methods and their functionalities from both theoretical and practical standpoints.

Theoretical implications

The findings of this study significantly contribute to the body of production planning and control knowledge within the construction management domain. This contribution is achieved by the identification and thorough examination of both process-based and technology-driven collaborative planning methods, along with a comprehensive analysis of their respective functionalities. In particular, this examination sheds light on the functionalities that have garnered the greatest attention, as well as those that have received comparatively less focus within both process-based and technology-driven collaborative planning approaches. Theoretical implications underscore a shift towards a more people-centric and process-oriented perspective, harmonized with emerging technologies in collaborative planning within construction. They also highlight the need for further exploration and development of methodologies that incorporate crucial aspects like dispute resolution, change order management, and the integration of dimensions such as delay management, claim resolution, and supply chain optimization into collaborative planning methods. Moreover, the emphasis on visualization in technology-driven collaborative planning methods indicates a move towards data-driven decision-making and improved project visualization.

In summary, these theoretical implications not only guide future research endeavours but also reflect the evolving nature of collaborative planning in construction, emphasizing the importance of human dynamics, process considerations, and technological integration in shaping the industry's practices.

Practical implications

This research also holds substantial practical implications for the construction industry. Firstly, it provides and analyzes a comprehensive list of collaborative planning methods' functionalities, enhancing various stakeholders' understanding, sensemaking, and situational awareness, including designers, contractors, owners, and project participants. This, in turn, empowers these stakeholders to make informed decisions when selecting the most suitable collaborative planning methods for their construction projects. In addition, the result's emphasis on trust-building, collaboration through social conversations, continuous improvement, and constraint removal suggests that organizations should priorities fostering a collaborative culture that encourages open communication, and trustworthiness among team members. Additionally, the research illuminates a significant challenge in technology adoption within organizations and construction companies. Often, decisions regarding technology adoption are driven by upper-level management in construction companies (Alinaitwe, Mwakali, and Hansson 2007; Elsayegh 2021) without considering the perspectives and needs of engineers responsible for on-site implementation. This top-down approach has led to fragmented and inefficient technology utilization, including collaborative planning methods and tools. To address this challenge effectively, this study emphasizes the importance of thoroughly assessing human resource challenges and establishing clear processes before implementing technology-driven solutions. Organizations are encouraged to priorities understanding their staff's specific requirements and capabilities at lower organizational levels and on construction sites. Consequently, technology adoption can be tailored to align with these unique needs. Furthermore, it is highlighted that specific areas within collaborative planning methods have received limited attention, including dispute resolution, just-in-time material procurement, safety management, and change order management. In light of these gaps, contractors and owners need to recognize these shortcomings and consider integrating appropriate strategies and tools into their collaborative planning practices.

Contributions to the body of collaborative planning knowledge

This study significantly advances collaborative planning methods knowledge in construction by examining both process-based and technology-driven approaches. While recognizing the increasing focus on technology-driven solutions, it emphasizes the pivotal roles of people and processes in effective collaborative planning, challenging the prevalent technology-first approach. The findings recommend a paradigm shift, prioritizing people and processes before selecting suitable technology. The analysis highlights specific strengths in process-based methods, such as trust-building and constraint removal, and in technology-driven methods, particularly communication enhancement and visualization. The study underscores the need for more attention to essential aspects like delay management, claim resolution, and procurement functions in both approaches. Practical implications stress the importance of a balanced focus on people, processes, and technology, advocating for a thorough understanding of staff requirements before technology implementation. Overall, the research guides future endeavours, emphasizing a holistic approach and clearer prioritization of functionalities for effective collaborative planning in construction.

Conclusion and limitations

This study extensively examined collaborative planning methods and their functionalities in the construction industry. Identifying ten collaborative planning methods and 75 associated functionalities, categorized into process-based and technology-driven groups, has revealed a need for a more balanced focus on people, process, and technology aspects. Process-based methods emphasize people and processes, while technology-driven methods lean towards people and technology, often overlooking the process. In this regard, to develop more effective collaborative planning methods, it is recommended to direct future studies and construction companies' strategies on thinking about a paradigm shift and bringing together and leveraging the people, process, and technology components by following this order and putting a greater emphasis on the people and process aspects first.

Additionally, Social Network Analysis (SNA) for functionality assessment has demonstrated a prevalent focus on process and people-oriented functionalities in process-based collaborative planning methods. Even so, critical aspects of project planning and control, such as delay and claim management, change order management, procurement and supply chain management, and site safety management, require additional attention. Also, the findings highlight the need for clarity when it comes to technology-driven collaborative planning methods. Even though it encompasses a broad range of functionalities, there needs to be more clarity regarding prioritizing these functionalities for effective and practical implementation. Notably, visualization plays a vital role in these methods; however, the development of geographically distributed and real-time collaboration functions remains in its infancy. Moreover, both process-based and technology-driven methods have been overlooked in supply chain and procurement functions, providing an avenue for further research.

It is also evident that the process-based methods' functionalities network is characterized by a dense network that facilitates collaborative activities. In contrast, the network of technology-driven methods' functionalities reveals a great deal of potential for more collaborative functionalities that are sometimes not harnessed. Companies often deploy technology-driven methods without understanding process-based methods, which leads to a lack of full utilization of collaboration's potential. To harness this potential fully, organizations and projects should consider integrating the foundational concepts of both process-based and technology-driven approaches.

This article's evaluation relied on data gathered through an extensive review of the existing literature. Given the practical nature of project planning and control, it is necessary to incorporate insight from industry experts to conduct a more comprehensive and pragmatic assessment. Furthermore, future investigations could explore the application of clustering algorithms and expert opinions to refine the categorization of functionalities based on their underlying knowledge domain. Moreover, while this study examined collaborative planning methods by categorizing them into process-based versus technology-driven approaches, there is potential for future research to explore additional divisions. These might include distinctions such as input versus output-focused, process versus product-focused, tools versus processes, project management versus project-focused, result versus effect-focused, people versus data-focused, visualization versus communication-focused, and quality versus time-focused, among others. This approach could pave the way for further advancements and insights in collaborative planning methods within the construction industry. Eventually, this research focuses on collaborative approaches for project planning and control, excluding collaborative delivery models and specific techniques such as Integrated Project Delivery (IPD), alliancing, co-location, big room, and so on. Although these models and techniques have been recognized for their comprehensive and stakeholder-inclusive approach, they are not explicitly explored in this study. Future research might expand on this foundation by looking at how different delivery models interact with collaborative planning and control approaches, resulting in a more complete understanding of collaboration in construction projects.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A

Table A. The results of normalized score and DC for each functionality in each matrix.

This step is to compare the results of SNA with Simplified Analysis		Using Simplified Analysis		Using SNA	
		Normalised score		Normalised DC	
Code	Functionalities	Matrix C	Matrix T	Network C	Network T
F1	Allowing just-in-time (JIT) purchasing and delivery of material	0.083	0.040	0.042	0.019
F2	Allowing the interactions of multiple team professionals and stakeholders in a common environment.	0.500	0.400	0.250	0.456
F3	Assisting in reducing waste	0.667	0.440	0.792	0.381
F4	Automated planning of concrete joint layouts	0.000	0.040	0.000	0.063
F5	Automatic generation of the as-built real-time 4D simulation	0.167	0.080	0.354	0.131
F6	Better flow of information	0.167	0.200	0.094	0.225
F7	Constructability evaluation	0.083	0.600	0.156	0.563
F8	Continuous improvement process	1.000	0.120	0.938	0.100
F9	Continuous learning	0.333	0.000	0.531	0.000
F10	Creativity, option generation, and innovation	0.333	0.000	0.365	0.000
F11	Decentralized work tracking and information communication on construction sites	0.000	0.160	0.000	0.169
F12	Detected more logical errors, more accurately, and faster, with less need for intrateam communication	0.167	0.400	0.146	0.381
F13	Dynamic collision detection and spatial-temporal conflict analysis	0.000	0.480	0.000	0.531
F14	Early involvement of key project stakeholders	0.250	0.000	0.281	0.000
F15	Easing of access and low training time	0.000	0.160	0.000	0.206
F16	Effective supply chain practices	0.250	0.000	0.104	0.000
F17	Empowering automated project progress monitoring	0.000	0.560	0.000	0.600
F18	Enabling lean construction adoption and situation awareness	0.167	0.080	0.188	0.081
F19	Enabling project performance prediction	0.333	0.120	0.240	0.169
F20	Enabling real-time collaborative 4D planning to gain a robust construction plan	0.000	0.080	0.000	0.075
F21	Enabling real-time communication with workers	0.000	0.080	0.000	0.106
F22	Enabling real-time tracking in construction site	0.000	0.120	0.000	0.194
F23	Enabling value management/engineering	0.083	0.000	0.156	0.000
F24	Enhancing transparency	0.750	0.080	0.719	0.106
F25	Experiencing and reviewing scheduled sequences on a 1:1 scale	0.000	0.240	0.000	0.344
F26	Facilitating communication with subcontractors	0.500	0.200	0.573	0.300
F27	Fosters the convergence of 4D uses with project documents	0.000	0.080	0.000	0.100
F28	Generating real-time interactive project visualisation	0.000	0.160	0.000	0.225
F29	Aligning goals with owner	0.500	0.040	0.458	0.075
F30	Higher sense of immersion and interaction	0.000	0.320	0.000	0.425
F31	Highlighting the importance of short-term planning at crew level	0.417	0.000	0.552	0.000
F32	Identifying possible optimizations	0.167	0.160	0.104	0.150
F33	Identifying time-space conflicts	0.083	0.600	0.156	0.438
F34	Improving alignment of engineering & procurement with construction and commissioning	0.250	0.040	0.115	0.088
F35	Improving collaborative sensemaking	0.417	0.120	0.427	0.106
F36	Improving communication and teamworking between the project team	0.583	1.000	0.625	1.000
F37	Improving decision making among geographically dispersed industry practitioners	0.167	0.160	0.188	0.194
F38	Improving engineering curriculum	0.000	0.240	0.000	0.256
F39	Improving organisational agility	0.333	0.000	0.229	0.000
F40	Improving role description and responsibilities	0.167	0.000	0.135	0.000
F41	Improving safety management on site	0.083	0.800	0.063	0.794
F42	Improving the involvement and the commitment of all the professional groups	0.667	0.120	0.750	0.138
F43	Increasing the work-flow reliability onsite	0.583	0.200	0.583	0.206
F44	Maintaining a workable backlog	0.167	0.000	0.250	0.000
F45	Making decision under a user-centric approach	0.000	0.120	0.000	0.138
F46	Monitoring worker motion and worker location	0.000	0.080	0.000	0.144
F47	More efficient resources management.	0.417	0.440	0.552	0.381
F48	More natural and industry-adapted interactions during a collaboration session	0.000	0.160	0.000	0.181
F49	Moving participants from passive receivers of a schedules to active contributors to the schedule	0.250	0.320	0.167	0.256
F50	Permitting real-time virtual collaboration for stakeholders from different locations	0.083	0.240	0.083	0.294
F51	Providing predictive control/monitoring method to make the best decisions with forwarding simulation	0.083	0.200	0.094	0.231

(*continued*)

Table A. Continued.

This step is to compare the results of SNA with Simplified Analysis		Using Simplified Analysis		Using SNA	
		Normalised score		Normalised DC	
Code	Functionalities	Matrix C	Matrix T	Network C	Network T
F52	Providing a digital equivalence to face-to-face communication in construction projects	0.083	0.200	0.083	0.238
F53	Providing better budget control	0.333	0.080	0.219	0.081
F54	Providing enhanced awareness of ongoing work	0.083	0.160	0.094	0.194
F55	Providing ergonomic interactions with the session workflow.	0.000	0.120	0.000	0.119
F56	Pull planning effectiveness	0.333	0.000	0.594	0.000
F57	Real-time safety monitoring	0.000	0.120	0.000	0.156
F58	Reducing information loss in data exchange	0.000	0.080	0.000	0.144
F59	Reducing the change orders during construction	0.167	0.080	0.083	0.144
F60	Reducing the impacts of potential causes of delay	0.167	0.080	0.094	0.063
F61	Reducing uncertainty and risk	0.750	0.320	0.927	0.388
F62	Reshaping an individual's cognitive determinants to influence collaboration throughout project delivery	0.000	0.200	0.000	0.225
F63	Safer learning environment	0.000	0.240	0.000	0.300
F64	Sharing the knowledge and lessons learned	0.333	0.080	0.542	0.100
F65	Site lay-out and environment management	0.000	0.440	0.000	0.394
F66	Solving disputes more efficiently	0.083	0.160	0.031	0.138
F67	Solving site logistic problems	0.000	0.360	0.000	0.369
F68	Supporting the learning and process of planning of offsite construction production challenges	0.000	0.360	0.000	0.288
F69	Supporting co-navigate, co-sort, co-plan, co-simulate and co-talk	0.000	0.200	0.000	0.231
F70	Supporting collaboration through social conversations	0.833	0.200	0.802	0.306
F71	Supporting multi-functional review meetings	0.000	0.200	0.000	0.244
F72	Supporting the trust and reliable promises among the team	0.833	0.000	1.000	0.000
F73	Systematic identification and removal of constraints	0.833	0.040	0.896	0.038
F74	Visualizing alternative construction sequences based on various what-if scenario	0.417	1.000	0.344	0.756
F75	Workspace planning	0.000	0.720	0.000	0.594