A comprehensive analysis of the benefits of integrated digital delivery in construction projects

Abstract

Purpose – Integrated digital delivery (IDD) is the use of digital technologies, data, and platforms to integrate work processes and connect all stakeholders working on the same project throughout the construction and building lifecycle. The benefits of digital technologies are often cited to justify the adoption of IDD in construction projects, but such benefits remain under-researched and unverified. The purpose of the paper is to investigate the performance improvement attributable to the IDD approach in construction projects.

Design/methodology/approach – This study combined questionnaire surveys, statistical analysis, social network analysis, and fuzzy synthetic evaluation to investigate the benefits of IDD in Hong Kong construction projects. The methodology was applied to rank the benefits of IDD, assess the benefit categories of the IDD, and model the relationships between benefits.

Findings – The results showed twenty-two (22) significant benefits of the IDD approach, grouped into design, cost, collaboration, sustainability, procurement, and productivity benefits. Design and collaboration benefits were ranked at the top and "high quality and faster preparation of designs" and "improved information exchange and management" were the most important benefits in these clusters, respectively. The weighted network model showed that the benefits of IDD are significantly correlated, and cost savings associated with digital project delivery, improved work and project quality, and high quality and faster preparation of designs and calculation were identified as the most influential benefits.

Originality – The study outcomes offer the first empirical insights into performance gains achievable with the IDD approach in construction projects. Hence, this study, for the first time, identified and assessed the benefits and benefit categories as well as formulating the relationships between the benefits to suggest the most effective benefit pipeline.

Keywords: digital technologies; digitalization; integrated digital delivery; benefits; construction industry.

Abbreviations

B1-B22	:	Benefits of integrated digital delivery
BIM	:	Building information modelling
CSV	:	Comma-separated values
FSE	:	Fuzzy synthetic evaluation
IDD	:	Integrated digital delivery
IPD	:	Integrated project delivery
MF	:	Membership function
SEM	:	Standard errors of the mean
SNA	:	Social network analysis
VDC	:	Virtual design construction
W	:	Weights
WCNA	:	Weighted correlation network analysis
WD	:	Weighted degree centralities
α	:	Cronbach's Alpha
μ	:	Mean
p	:	Probability (significance level)
σ	:	Standard deviation

1. Introduction

Integrated digital delivery (IDD) is promoted in the Hong Kong construction industry to leverage the complementary roles of building information modelling (BIM), integrated project delivery (IPD), virtual design and construction (VDC) and other digital technologies across the project lifecycle (Wuni *et al.*, 2024). IDD refers to the use of digital technologies, data, and data sharing platforms for the integration of work processes and stakeholder interactions working on the same project throughout the project lifecycle (Hwang *et al.*, 2020). It is the process of using relevant digital technologies to complement BIM, IPD, and VDC in streamlining work processes, breaking silos, and improving collaboration among various stakeholders (Building and Construction Authority, 2023). In other words, IDD is a lifecycle approach from the beginning (i.e., digitalization in design) to the end (i.e., digitalization in asset management) for construction projects (Amo Larbi *et al.*, 2024) .

IDD extends and operationalizes the design-build principles, and ensures that the entire project lifecycle, including design, fabrication, construction, and built assets management are covered in a generic platform (Liu *et al.*, 2021). It provides a single source of truth, enabling all parties along the value chain (i.e., owners, engineers, architects, project managers, estimators, and mechanical, electrical and plumbing contractors) to access the same high-quality information throughout the project lifecycle (Building and Construction Authority, 2023). IDD enables vertical and horizontal integration in construction projects, which results in fewer reworks, higher-quality outputs, lean delivery, and improved efficiency (Wuni *et al.*, 2024). In complex construction projects, IDD connects project teams, data and workflows to improve productivity and save costs (Building and Construction Authority, 2023).

The potential benefits of digital technologies are often highlighted to justify the adoption of IDD in construction projects (Love *et al.*, 2020). However, despite growing attention given to the importance of digitalization, the benefits of IDD in construction projects have rarely been empirically evaluated and documented in the literature. Currently, the benefits of IDD have been implicitly and theoretically discussed in a handful of scientific literature (Hwang *et al.*, 2020) and mostly in blogs (Building and Construction Authority, 2023). Thus, the literature is deficient in establishing the benefits that IDD would add value to a construction project.

According to Wuni et al. (2024) and Hwang et al. (2020), the use of IDD, by construction professionals is poorly understood and often confused with BIM, VDC, or IPD. Some construction stakeholders perceive IDD as too expensive to justify its use in construction projects (Liu *et al.*, 2021), while others believe that the benefits of IDD are exaggerated and even falsified in the literature (Love *et al.*, 2020). However, some project participants view IDD as a solution to many of the problems associated with collaboration, integration, information sharing, sustainability and productivity objectives in construction projects(Wuni *et al.*, 2024). Neither of these views is necessarily right or wrong. The benefits of IDD are largely dependent on project-specific conditions, the maturity of digital technologies in the local context, and the mix of building methods being used on a construction project.

Given the lack of capacity of construction projects to adopt digital technologies and limited research on the IDD approach in construction projects, this study aims to investigate the benefits of IDD in construction projects, with evidence from Hong Kong construction industry. There are three major objectives of the study: (i) to assess and rank the benefits of IDD in construction projects, (ii) to quantify the significance of various categories of the benefits, and (iii) to model the interlinkages of the benefits of IDD in construction projects using social network analysis.

The study outcomes can inform and enlighten practitioners about the benefits and performance gains achievable with IDD approach in construction projects, which can provoke its proliferation in the sector. Additionally, identifying the relationships between the benefits of IDD in construction projects helps determine the most effective ways to use IDD by following a route through a robust benefit pipeline. Such a network framework can help discover its multifaceted nature and effective use cases, leading to complete realization of its estimated benefits.

2. Literature review

The theoretical foundation of IDD is based on the complementary roles of digital technologies across the entire project lifecycle. According to the Building and Construction Authority (2023), IDD refers to an innovative project delivery approach that uses digital technologies, data, platforms, tools, and methods to integrate work processes and connect multidisciplinary project teams and value chain members. It integrates BIM, IPD, VDC, and other relevant complementary digital technologies to connect teams, data, and workflows across the entire project lifecycle (Liu *et al.*, 2021).

The benefits of IDD remain extremely under-researched and underrepresented in the literature (Wuni *et al.*, 2024). Except for Hwang et al. (2020), who evaluated the status and performance of IDD in construction projects in the context of Singapore, there is currently no empirical evaluation of the benefits of IDD in construction projects. As such, the benefits of IDD can hardly be derived directly from the existing literature, but the potential benefits of IDD have been implicitly discussed in the literature (Hwang *et al.*, 2020; Liu *et al.*, 2021; Wuni *et al.*, 2024). There are also discussions on the benefits of digitalization (Adha *et al.*, 2023), digital technologies (Love *et al.*, 2020), and digital transformation (Guandalini, 2022), which are relevant to the IDD approach in construction projects.

Table I summarizes the potential benefits of IDD in construction projects derived from the literature. These benefits can be categorized into design benefits (e.g., fewer design changes), cost benefits (e.g., cost savings), collaboration benefits (e.g., increased coordination and collaboration among team members), sustainability benefits (e.g., fewer injuries), procurement benefits (e.g., improved flexibility in the procurement process), and productivity benefits (e.g., time savings). The identification of the categories was conducted through an inductive approach. In other words, a comprehensive literature review was employed to identify benefits of IDD without any predefined categories or themes. This approach allows generation of generic and unique benefit categories for the IDD adoption. In this context, the relationships between benefits were examined and a set of categories were determined. Overall, in contrast to the deductive (i.e., theory-testing) approach, inductive (i.e., theory-building) approach was adopted since IDD is a novel and not well articulated research area (Fleischmann and Ivens, 2019). However, none of the reviewed studies empirically quantified and measured these benefits. Hence, this study fills this knowledge gap and offers a robust assessment of the benefits of IDD in construction projects in the context of Hong Kong.

[**Table I**. Potential benefits of IDD in construction projects]

3. Research methodology

The research comprised five main work packages, including comprehensive literature review, data collection, descriptive statistical analysis, weighted network analysis, and fuzzy synthetic evaluation. Figure 1 depicts these work packages and describes the salient themes.

[Figure 1. A breakdown of the research process]

3.1 Benefit measures

The study conducted a systematic literature review to extract the potential benefits of IDD in construction projects. A similar procedure adopted by Hoseinzadeh *et al.* (2023) was followed to conduct the systematic literature review. The reviewed studies include Love et al. (2020), Hwang et al. (2020), Liu et al. (2021), Chen et al. (2023), Adha et al. (2023), and Wuni et al. (2024). Full text evaluation of these studies generated a relevant set of twenty-two (22) potential benefits of IDD in construction project, which are summarized in Table I.

3.2 Data collection

In this study, a structured questionnaire survey was employed to measure the significance of the identified benefits. The survey form contained two major sections. Section 1 requested the background information of the respondents including, occupation, years of industry experience in Hong Kong, and highest academic qualification. Questions in Section 2 were administered the respondents to assess the significance of the identified benefits based on their practical experience, on a 5-point Likert scale: 1 = very insignificant, 2 = insignificant, 3 = slightly significant, 4 = significant, and 5 = very significant. The 5-point scale is widely used in construction management research due to its simplicity, clarity and familiarity to respondents (Wuni and Shen, 2020).

Subsequently, the study used the purposive sampling approach and the snowballing technique (i.e., chain referral) to form the relevant sample frame. These are the most suitable techniques for sampling under three conditions: (i) when the investigated subject is new, (ii) when there is no central database of the relevant population, and (iii) when the investigators have adequate knowledge of relevant subject matter (i.e., to start with and initiate the chain referral). These conditions prevailed in the context of this study and rendered the two methods the most appropriate ones to identify relevant respondents. After a period of 4 months, the study contacted hundred (100) practitioners in the Hong Kong construction industry and received sixty-three (63: 63%) valid responses, which is higher than some of sample sizes (i.e., both number and percentile) identified in the literature such as 41 (41%) (Hwang *et al.*, 2018) and 62 (10%) (Hwang *et al.*, 2020). Figure 2 summarizes the background information of the respondents.

[**Figure 2**. Relevant information of the survey participants]

3.3 Data analysis

The data analysis comprised three analytical techniques: descriptive statistical analysis, weighted correlation network analysis, and fuzzy synthetic evaluation analysis. All statistical tests in the study were conducted at the default 95% significance level.

3.3.1 Descriptive statistical analysis

The descriptive statistical analyses were conducted in the Statistical Package for the Social Sciences (IBM SPSS v.27). The study conducted a reliability analysis using Cronbach's Alpha (α) to measure the internal consistency of the survey responses. Cronbach's Alpha takes values between 0 (no consistency) and 1(excellent consistency), and the minimum threshold value is 0.7, indicating an acceptable consistency level. The study further calculated the arithmetic mean scores, standard deviations, and standard errors of the means of the benefits to capture the ranking of the benefits. When two or more benefits obtain equal mean scores, the one with the lowest standard deviation is ranked higher (Wuni *et al.*, 2024). If two or more benefits obtain equal mean scores and standard deviations, the one with the lowest standard error of mean is ranked higher.

3.3.2 Weighted correlation network analysis

Social network analysis (SNA) is a modelling techniques used to investigate the structure and relationship of social actors in a network (Saqr and Alamro, 2019). It uses nodes to represent the social actors and edges to depict the links between the social actors (Zheng *et al.*, 2016). It has been used extensively in construction managements to investigate risks (Hosseini *et al.*, 2020) and barriers (Wuni *et al.*, 2024). One of the crucial step in SNA is defining the technique for capturing the relationships between the various entities and one of the widely used methods is the Spearman rank correlation method (Hosseini *et al.*, 2020).

The weighted correlation network analysis (WCNA), which uses correlation analysis, defines the weight and directions of the relationships between the nodes. The WCNA has been used to construct a network model of corruption risks (Hosseini *et al.*, 2020) and barriers to the adoption of digital technologies in construction (Wuni *et al.*, 2024). The WCNA is used in this study to construct a network model to explore the interlinkages of the benefits of IDD in construction projects. The WCNA is conducted in four steps:

Step 1. *Generating the relationship values*: The study used the Spearman rank method to calculate the pairwise correlation coefficients of the benefits of IDD in construction projects. The Spearman correlation method is the most widely used statistical relationship determination technique in WCNA because it can handle all data distributions and is insensitive to outliers(Hosseini *et al.*, 2020). Only statistically significant correlations at 95% and 99% confidence levels were considered in the network model.

Step 2. *Creation of adjacency matrix*: The correlation analysis generated an adjacency matrix of the benefits. An adjacency matrix is a square matrix of m x m where m is the number of nodes in the graph and was used to generate the connections or edges of the network model. The adjacency matrix contained 231 correlations between the benefits, of which 174 were significant at p = 0.05 or 0.01 and were retained in the network. Following the works of

Hosseini et al. (2020), the significant correlation coefficients were raised to the power of β (β=4) to deepen the gap between strong and weak correlations (i.e., links) in the matrix.

Step 3. *Network formation*: Networks are formed from matrices of nodes and edges. The network formation was conducted in Gephi, an open-source network visualization tool (Bastian *et al.*, 2009) which can form networks based on matrices of nodes and edges. The study generated a nodes table in Microsoft Excel, which contained the IDs and description of the benefits in two separate columns and saved in a comma-separated values (CSV) format. An edges table was also generated in Excel, which contained the pairwise links between the nodes (i.e., benefits) derived from the correlation matrix. It contained four separate columns including the source, target, type, and weight for the 174 significant links of the benefits.

Step 4. *Network analysis*: The study used various metrics, including degree centrality, weighted degree (node strength), betweenness centrality, closeness centrality, clustering coefficient, and eigenvector centrality to analyze and explain the structure of the weighted correlation network model of the benefits generated in Gephi software.

3.3.3 Fuzzy synthetic evaluation

The fuzzy synthetic evaluation (FSE), derived from fuzzy sets theory, combines weighting functions, membership functions and grade alternatives of a Likert scale to quantify the significance of a cluster of factors in a survey-based study (Wuni *et al.*, 2024). This study developed an FSE model to quantify the impact of various groups of benefits using the following steps.

Step 1. *Specification of the fuzzy evaluation index system*.

Step 2. *Calculating weightings of the benefits*

Step 3. *Determining the membership functions of the benefits*

Step 4. *Defuzzification*

4. Results

4.1 Reliability of the dataset

The reliability analysis generated a Cronbach's Alpha of 0.914 for the responses to the 22 benefits and Cronbach's Alpha of 0.916 based on the standardized items. These values are higher than the minimum threshold value of 0.70, and indicate excellent internal consistencies in the responses (Cronbach, 1951). The higher value also means that the questionnaire survey measured the significance of the benefits accurately and generated consistent outcomes (Tang *et al.*, 2014).

4.2 Mean score ranking of the benefits

Table II reports the arithmetic mean scores (μ), standard errors of the mean (SEM) scores, standard deviations (σ), and ranking of the benefits of IDD in construction projects. The mean scores ranged between 3.67 and 4.43, on the 5-point Likert scale, indicating that each of the benefits was averagely rated significant, reflecting and corroborating the distributions of the responses in Figure 3. The SEM of the responses to the benefits ranged between 0.08 and 0.16, indicating very minimal discrepancy between the sample mean and the population mean. The standard deviations of the responses to the benefits ranged between 0.64 and 1.24, suggesting minimal dispersions of the responses around the mean scores.

[**Table II**. Mean scores of the benefits of IDD in construction projects]

According to the analysis results, the top 10 most significant benefits of IDD in construction projects include: high quality and faster preparation of designs and calculations (μ = 4.43), improved efficiency and productivity (μ = 4.41), real time simulation and visualization of project designs (μ = 4.30), improved information exchange and management (μ = 4.27), improved communication among project team (μ = 4.25), digital construction saves time (μ = 4.22), improved work and project quality due to fewer reworks (μ = 4.13), cost savings associated with digital project delivery (μ = 4.11), improved flexibility in the procurement process (μ = 4.10), and improved risk management (μ = 4.08).

4.3 Weighted correlation network model

Figure 3 represents a weighted correlation network model of the benefits of IDD in construction projects. The nodes represent the benefits and the edges depicts the linkages between two benefits in the network. The size of a node (i.e., benefit) depicts its weighted degree centrality, indicating the influence power of the benefit in the network. The various colors represent six (6) communities (i.e., groups) of the benefits, including design, cost, collaboration, sustainability, procurement, and productivity group of benefits.

[**Figure 3**. Weighted correlation network model of the benefits of IDD in construction projects]

Table III reports the performance measures of the network model, including degree, weighted degree, closeness centrality, betweenness centrality, eigenvector centrality, clustering coefficient, and relative importance ranking. The network model shows that the set of investigated benefits are significantly correlated. The degree centrality scores indicate that each benefit is significantly correlated with at least 8 (e.g., B1) other benefits and at most 20 other benefits in the dataset (e.g., B4, B5, B10). For example, cost savings associated with digital project delivery (B4), improved work and project quality (B5), and high quality and faster preparation of designs and calculation (B10) are the most influential benefits, with each linked to 20 other benefits in the network. Waste reduction in office or on construction site (B1) is the least influential benefit with a significant correlation with 8 other benefits in the network.

[**Table III**. Node measures of the network model of the benefits of IDD in construction projects]

Based on the weighted degree centralities (WD), the top five most influential benefits in the network include improved work and project quality (B5, WD = 0.759, rank= 1), cost savings associated with digital project delivery (B4, WD= 0.753, rank= 2), project whole life costing from digital asset management (B16, WD= 0.751, rank= 3), ease of updating and applying design instructions at anytime (B12, WD= 0.703, rank= 4), and improved service to project administrator and consultants (B14, WD= 0.692, rank= 5). This set of influential benefits bring the design, cost, and productivity benefits of the IDD approach to the forefront in construction projects.

The five least influential benefits in the network include improved efficiency and productivity (B2, WD= 0.330, rank= 18), accurate project cost estimation (B11, WD= 0.257, rank= 19), fewer injuries on-site during digital construction (B9, WD= 0.228, rank= 20), waste reduction in office or on construction site (B1, WD= 0.186, rank = 21), and real-time simulation and visualization of project designs (B22, WD= 0.161, rank = 22). These suggest that the specific productivity (B2), cost (B11), sustainability (B1, B9), and design (B22) benefits, though independently significant, have limited influence on the significance of other benefits.

4.4 Fuzzy synthetic evaluation model

4.4.1 Mean weighted scores and membership functions

Table IV summarizes the weightings of the various groups of the benefits. The weightings of the individual benefits and the groups were derived from the mean scores and total mean scores, respectively. It is observed that the total mean scores (Σμ) and weights (W) are sensitive to the number of benefits in each group. Thus, groups with more sets of benefits are likely to be weightier than those with fewer.

However, it can be observed that there are an equal number of benefits (i.e., 3) in four of the groups (i.e., cost, sustainability, procurement, and productivity), but they have different total mean scores and weights. As such, the weightings can be used to rank the groups of the benefits. Based on the weightings, the ordered importance of the groups of benefits include collaboration benefits (Σμ= 20.44, W= 0.227), design benefits (Σμ= 20.39, W= 0.227), productivity benefits (Σμ= 12.76, W= 0.142), cost benefits (Σμ= 12.22, W= 0.136), procurement benefits (Σμ= 12.12, W= 0.135), and sustainability benefits (Σμ= 11.97, W= 0.133).

[**Table IV**. Mean weightings and membership functions of the benefits of IDD]

Table IV also summarizes the membership functions (MFs) of the benefits (i.e., B1 – B22) and groups (i.e., design, cost, collaboration, sustainability, procurement, and productivity) of the benefits. The MFs (level 1) of B1 – B22 were derived directly from the responses of the respondents and the sum of the MFs of each benefit is equal to 1. The MFs of the groups (level 2) were derived as a product of the weightings and MFs of the set of benefits in each group and the sum of the MFs of each group is also equal to 1.

4.4.2 Significance indices and coefficients

Table V summarizes the MFs (level 3) of the overall set of benefits. It also shows the significance indices, significance coefficients, and ranking of the groups of benefits.

[**Table V**. Significance indices and coefficients of the groups of benefits of IDD]

The significance index of the overall set of benefits is 4.09, on a 5-point scale, indicating that the benefits were collectively assessed at significant merits and outcomes of IDD in construction projects. The significance indices of the six groups of benefits ranged between 3.99 (≈4.00) and 4.26, indicating that each group was rated as a significant performance improvement in construction projects attributable to the IDD approach. Based on the significance indices and coefficients, the order of importance of the groups of benefits include productivity benefits (index= 4.26, rank= 1), collaboration benefits (index= 4.09, rank= 2), design benefits (index= 4.09, rank= 2), cost benefits (index= 4.07, rank= 4), procurement benefits (index= 4.04, rank= 5), and sustainability benefits (index= 3.99, rank= 6).

5. Discussions and implications

This study investigated the host of process and performance improvements in construction projects by implementing the IDD approach, based on the survey data from Hong Kong. The results indicated that there are multiple perceived benefits of the IDD approach in construction projects. The analysis results revealed that industry practitioners consider the overall set of twenty-two benefits investigated to be significant performance improvements attributable to the IDD approach in construction projects. The SNA established that there are considerable interlinkages among the benefits of IDD in construction projects, suggesting that the realization of some benefits could trigger other benefits. The FSE model also concluded that each of the six groups is a significant benefit group. These groups of benefits are described and discussed in the following sub-sections in the order of importance based on the significance indices.

5.1 Productivity benefits (index= 4.26, rank= 1)

The findings indicate that the IDD approach offers the most significant gains in productivity improvements in construction projects, with a significance index of 4.26 (Table V). The productivity benefits of IDD in construction projects include improved efficiency, fewer reworks, improved work and project quality, and time savings. The integrated approach of IDD enables the relevant project team members to accurately design specifications that are understood by all involved. The integrated project team work collaboratively to review drawings, documentations, and specifications that proactively address intractable downstream constraints to minimize rework and associated wastes (Hwang *et al.*, 2020). More specifically, IDD uses clash detection technologies and BIM-based defect management systems to eliminate abortive works and avoid duplication of tasks. Given the fewer changes and reworks, IDD significantly saves design and construction time.

However, the theoretical position of digital technologies offering productivity gains is not well-established in the literature. There are mixed findings regarding the productivity gains of digital technologies in construction projects. Even though the findings of this study are consistent with Love et al. (2020) who observed significant productivity gains attributable to digital technologies in construction, it diverges from Brynjolfsson (1993), who observed that overuse of digital technologies decreases the productivity of workers, arising from mismeasurement of outputs and inputs, lags due to learning and adjustment, redistribution and dissipation of profits, and mismanagement of information and technology.

5.2 Collaboration benefits (index= 4.09, rank= 2)

The second most significant group is the collaboration benefits, represented by five (5) sets of benefits and with a significance index of 4.09. IDD usually records and stores project data and information in a single digital platform (e.g., a digital cloud-based system such as BIM360), providing a single source of truth, where all project participants, including architects, engineers, contractors, subcontractors and clients have access to the same information (Liu *et al.*, 2021). This improvement enables all project teams to observe the status of the projects and with full knowledge of the progress and responsibilities of all parties involved. Thus, IDD reduces the risk of ambiguity and miscommunication that can occur with scattered information and fragmented teams (Hwang *et al.*, 2020).

The theoretical position of the collaboration benefits arising from digital technologies (e.g., BIM, VDC) and IPD are well-established in the literature (Love *et al.*, 2020). Thus, the optimum mix and dose of IDD technologies addresses the collaboration deficits and closes the communication and information-sharing gaps in the design, fabrication, construction, and operation stages of construction projects. The collaboration benefits arise from five sources, including improved communication among project teams (B6), improved information exchange and management (B7), increased coordination and collaboration among team members (B8), improved service to project coordinator and consultants (B14), and collaborative fabrication from digital manufacturing (B19). Hence, it can be deduced that collaboration through proper communication among included parties is one of the most apparent benefits of IDD approach.

5.3 Design benefits (index= 4.09, rank= 2)

The third most significant group is the design benefits, represented by five (5) sets of benefits and with a significance index of 4.09. According to Hwang et al. (2020), IDD improves and optimizes the speed, accuracy, adequacy, cost, and quality of design in construction projects. IDD offers a suite for digital software deploying advanced computational and artificial intelligence techniques to facilitate fabrication-aware generative design solutions. Generative design in IDD facilitates quicker generation of conceptual designs, which can capture the aesthetic, form, and structure requirements of clients (Baduge *et al.*, 2022). Similarly, digital design software in IDD allows designers to quickly and efficiently modify and update project designs to meet changes requested by the client. IDD also deploys cloud-based technologies to create a single and shared model or design of the project, accessible to all team members in real-time. Thus, changes or updates made to the design are immediately updated and visible to everyone. This centralized and synchronized approach eliminates the risk of working on outdated or duplicated designs, ensuring that every member collaborates and works on the most current version of the project design (Hwang *et al.*, 2020).

5.4 Cost benefits (index= 4.07, rank= 4)

The study positioned cost benefits as the fourth most significant gain of the IDD approach in construction projects, with a significance index of 4.07. The literature established a significant link between digital technologies and cost reductions in construction projects (Love *et al.*, 2020). After evaluating the status of 149 construction projects that adopted the IDD approach in Singapore, Hwang et al. (2020) observed that IDD generated a mean cost reduction by 3.76%. The Building and Construction Authority (2023) also documented the lifecycle cost savings achievable with the IDD approach in construction projects. The cost savings associated with IDD solutions arise from the reduced rework, optimized procurement, efficient design, and streamlined workflows (Love *et al.*, 2020). Also, IDD leverages digital platforms for estimation, such as Cubit Pro estimating software, Navisworks, Synchro Pro, and BIM360 to simplify and improve the accuracy of project cost estimates. These digital estimating solutions enable the project teams to measure designs directly within the digital prints and select objects from the digital space. These digital tools can be programmed to capture particular dimensions in accordance with the chosen measurement method. Also, the data collected and generated at each project phase forms the basis for estimating the necessary whole-life project costs.

5.5 Procurement benefits (index= 4.04, rank= 5)

The fifth most significant group is the procurement benefits, represented by three (3) benefits and with a significance index of 4.04. This outcome is consistent with Yevu et al. (2021), who documented that digital technologies generate significant procurement gains in terms of reduced procurement costs, improved transparency and efficiency, reduced supplier risk, and improved supply resiliency. The IDD approach lowers procurement risks and improves risk management in construction projects. A major source of procurement challenges is design errors. IDD deploys BIM to detect design anomalies through clash detection analysis, which unveils all potential risks occurring between the designs from various project teams across all the design disciplines. The real-time design reviews provide the opportunity for issues to be identified and resolved to proactively avoid intractable fabrication and construction problems. IDD technologies (e.g., BIM360, Bluebeam Revu, and SharePoint) improves contract and project documentation through the conversion of documents such as plans, specifications, change orders, contracts and revisions into manageable digital files and units. IDD has revolutionized the procurement process, enabling unprecedented flexibility. It reduces the cost of manual paperwork and facilitates fair and transparent issuance of addenda to potential applicants. It takes individuals to create accounts to access any work package from a digital platform. Response to project tendering is digitally submitted, and the analytics are made available to the procurement entity. The evaluation panel can work on submitted bids through paperless projects to select a responsive tender.

5.6 Sustainability benefits (index= 3.99, rank= 6)

The least significant group is the sustainability benefits of IDD with a significance index of 3.99. The theoretical position of the sustainability benefits of digital technologies in construction remains contested. While IDD improves social sustainability (e.g., fewer injuries, minimized disputes, improved human relationships) (Grybauskas *et al.*, 2022), the adverse environmental impact of digital technologies such as energy consumption, e-waste generation, carbon emissions, and landfill issues remain grave concerns regarding IDD approach (Adha *et al.*, 2023). Therefore, developing strategies and measures that minimize the adverse impact of the IDD approach on sustainability can enable IDD to be adopted by wider audiences for its adoption in the construction industry.

6. Novelty and contributions

This study has a merit in providing a robust assessment of the benefits of the IDD approach in construction projects. There are several novelties that differ this study from its counterparts. First, IDD is an emerging concept and potential benefits of IDD have not been documented systematically in the literature. According to a comprehensive literature review, a list of IDD benefits was identified and grouped into six groups to clearly show the contributions of the IDD approach. Theoretically, the derived six constructs (i.e., design, cost, collaboration, procurement, productivity, and sustainability) explain the host of performance improvements attributable to the IDD approach. These constructs represent the building blocks to theorize the benefits of IDD, including digital technologies in construction projects. Additionally, this study combines FSE and SNA to computationally measure the relationship between the benefits of IDD, addressing performance improvements achievable with the IDD approach. Combination of FSE and SNA approach is not only a unique approach in the IDD literature, but also one of the initial attempts in other fields of project management. By developing a robust and reliable network map, the impacts of benefits on others can help identify the most effective managerial pipeline for the overall performance improvements in construction projects.

Practically, the study findings have made several distinct contributions. First, this study found that the IDD approach can offer significant advantages in construction productivity, especially in design optimization and advanced work packaging. Thus, it establishes that the IDD approach should be prioritized in projects where productivity, which is at its poorest levels in the construction industry, is significantly challenged. Second, this research underscored the roles of digital technologies in addressing communication gaps, collaboration deficits, and optimization of construction project design. The findings show that IDD can offer significant gains in collaboration, communication, information sharing, and design visualization. Hence, in the era of data, IDD will be an essential component of project management to turn shared data and information into beneficial insights. Finally, the findings challenge future studies to critically evaluate the environmental consequences of digital technologies in construction projects. The study identified sustainability as the least significant benefit of IDD in construction projects. It joins the debate in questioning the sustainability of digital technologies in construction projects and invokes the necessity to develop sustainable digital technologies in the construction industry.

Project managers in construction can use the most critical benefits in each category based on the project-specific requirements or issues. For instance, if there is collaboration-based issues in a project, the project manager can ensure that communication among project team members and information exchange can be ameliorated through the IDD approach. Many technological solutions (e.g., IDD, BIM) can therefore be evaluated by project managers to select the most suitable. In addition, the identified benefits, their categorization, and order of importance can be used to formulate guideline routes and policies for the IDD adoption. Here, the relationships between benefits can be used to develop the most effective policy development pipeline since some of the benefits can emerge as a result of other benefits. In this way, only the causal benefits can be focused on, ensuring the most effective process for the policy and guideline development. A prototype application of the IDD approach can also be presented to the pioneers in the sector and performance improvements and benefits can be documented systematically to show the materialization of the benefits to a wider extent.

7. Conclusions

This study investigates the benefits of integrated digital delivery in Hong Kong construction projects. Relevant survey data was collected to measure the importance of a set of twenty-two (22) benefits of the IDD approach and the resulting data was analyzed using descriptive statistics, social network analysis, and fuzzy synthetic evaluation. Overall, there were three major objectives of the study as (i) ranking the benefits of IDD in construction projects, (ii) assessing the benefit categories of IDD approach, and (iii) modelling the relationship between the benefits.

(i) The results showed that the investigated benefits were perceived as significant performance improvements attributable to the IDD approach. The mean score analysis showed that the most prominent benefits of IDD arise from higher quality and faster preparation of designs, improved efficiency, real-time simulation and visualization of project designs, better information exchange and management as well as improved communication among project teams. Thus, it is perceived among industry practitioners that the IDD approach can address many design challenges, communication gaps, collaboration deficits, rework, inefficiencies, procurement problems, and risks in construction projects.

(ii) The study further derived six constructs to classify the project gains from the IDD approach, including design, cost, collaboration, sustainability, procurement, and productivity benefits. It is identified that the set of investigated benefits are collectively perceived as significant gains from the IDD approach. Each of the constructs of the benefits was also perceived as a significant cluster in the IDD approach, with significance indices ranging between 3.99 and 4.26, on a 5-point scale. However, the study found the least significant group to be the sustainability construct and silhouetted the concerns about the environmental impact of digital technologies in construction projects.

(iii) It is established that the set of investigated benefits of IDD are significantly correlated, with each benefit influencing the significance of between 8 and 20 other benefits in the network. Particularly cost savings associated with digital project delivery, improved work and project quality, and high quality and faster preparation of designs and calculation were the most influential benefits, related with 20 other benefits in the network. Hence, it can be concluded that each element in the iron triangle, i.e., cost (cost savings with digital delivery), time (faster preparation of designs and calculation), and quality (improved work and project quality) can be addressed explicitly by adopting the IDD approach.

The study outcomes offer a comprehensive assessment of the benefits of the IDD approach and deepen the understanding of the perceived performance gains achievable with the IDD approach. Still, there are two noteworthy limitations of the study. First, the sample size, although representative of Hong Kong, limits the generalizability of the findings. Second, the list of benefits investigated may not exhaustive and may have not captured all the possible benefits of the IDD approach in construction projects.

Based on the study limitations the following future works are recommended. First, increasing the sample size can further enhance the generalizability of the research outputs. Besides, a more comprehensive set of benefits can be identified through focus group discussions that help the emergence of new ideas through synergistic data collection process. Additionally, this study assessed the benefits of the IDD approach. In future research, a set of

IDD applications can be listed, and the most effective ones can be selected based on their perceived benefits using a multi-criteria decision approach. Still, the perceived benefits may differ according to cultural characteristics of the respondents. Hence, country-based comparisons can be conducted to consider the changes in the perceived benefits in different countries. Overall, the model proposed in the study can be used by professionals who want to gain a competitive advantage in the sector using IDD, to determine what advantages IDD will provide in their projects.

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A comprehensive analysis of the benefits of integrated digital delivery in construction projects

Abstract

Purpose – Integrated digital delivery (IDD) is the use of digital technologies, data, and platforms to integrate work processes and connect all stakeholders working on the same project throughout the construction and building lifecycle. The benefits of digital technologies are often cited to justify the adoption of IDD in construction projects, but such benefits remain under-researched and unverified. The purpose of the paper is to investigate the performance improvement attributable to the IDD approach in construction projects.

Design/methodology/approach – This study combined questionnaire surveys, statistical analysis, social network analysis, and fuzzy synthetic evaluation to investigate the benefits of IDD in Hong Kong construction projects. The methodology was applied to rank the benefits of IDD, assess the benefit categories of the IDD, and model the relationships between benefits.

Findings – The results showed twenty-two (22) significant benefits of the IDD approach, grouped into design, cost, collaboration, sustainability, procurement, and productivity benefits. Design and collaboration benefits were ranked at the top and "high quality and faster preparation of designs" and "improved information exchange and management" were the most important benefits in these clusters, respectively. The weighted network model showed that the benefits of IDD are significantly correlated, and cost savings associated with digital project delivery, improved work and project quality, and high quality and faster preparation of designs and calculation were identified as the most influential benefits.

Originality – The study outcomes offer the first empirical insights into performance gains achievable with the IDD approach in construction projects. Hence, this study, for the first time, identified and assessed the benefits and benefit categories as well as formulating the relationships between the benefits to suggest the most effective benefit pipeline.

Keywords: digital technologies; digitalization; integrated digital delivery; benefits; construction industry.

Abbreviations

B1-B22	:	Benefits of integrated digital delivery
BIM	:	Building information modelling
CSV	:	Comma-separated values
FSE	:	Fuzzy synthetic evaluation
IDD	:	Integrated digital delivery
IPD	:	Integrated project delivery
MF	:	Membership function
SEM	:	Standard errors of the mean
SNA	:	Social network analysis
VDC	:	Virtual design construction
W	:	Weights
WCNA	:	Weighted correlation network analysis
WD	:	Weighted degree centralities
α	:	Cronbach's Alpha
μ	:	Mean
p	:	Probability (significance level)
σ	:	Standard deviation

1. Introduction

Integrated digital delivery (IDD) is promoted in the Hong Kong construction industry to leverage the complementary roles of building information modelling (BIM), integrated project delivery (IPD), virtual design and construction (VDC) and other digital technologies across the project lifecycle (Wuni *et al.*, 2024). IDD refers to the use of digital technologies, data, and data sharing platforms for the integration of work processes and stakeholder interactions working on the same project throughout the project lifecycle (Hwang *et al.*, 2020). It is the process of using relevant digital technologies to complement BIM, IPD, and VDC in streamlining work processes, breaking silos, and improving collaboration among various stakeholders (Building and Construction Authority, 2023). In other words, IDD is a lifecycle approach from the beginning (i.e., digitalization in design) to the end (i.e., digitalization in asset management) for construction projects (Amo Larbi *et al.*, 2024) .

IDD extends and operationalizes the design-build principles, and ensures that the entire project lifecycle, including design, fabrication, construction, and built assets management are covered in a generic platform (Liu *et al.*, 2021). It provides a single source of truth, enabling all parties along the value chain (i.e., owners, engineers, architects, project managers, estimators, and mechanical, electrical and plumbing contractors) to access the same high-quality information throughout the project lifecycle (Building and Construction Authority, 2023). IDD enables vertical and horizontal integration in construction projects, which results in fewer reworks, higher-quality outputs, lean delivery, and improved efficiency (Wuni *et al.*, 2024). In complex construction projects, IDD connects project teams, data and workflows to improve productivity and save costs (Building and Construction Authority, 2023).

The potential benefits of digital technologies are often highlighted to justify the adoption of IDD in construction projects (Love *et al.*, 2020). However, despite growing attention given to the importance of digitalization, the benefits of IDD in construction projects have rarely been empirically evaluated and documented in the literature. Currently, the benefits of IDD have been implicitly and theoretically discussed in a handful of scientific literature (Hwang *et al.*, 2020) and mostly in blogs (Building and Construction Authority, 2023). Thus, the literature is deficient in establishing the benefits that IDD would add value to a construction project.

According to Wuni et al. (2024) and Hwang et al. (2020), the use of IDD, by construction professionals is poorly understood and often confused with BIM, VDC, or IPD. Some construction stakeholders perceive IDD as too expensive to justify its use in construction projects (Liu *et al.*, 2021), while others believe that the benefits of IDD are exaggerated and even falsified in the literature (Love *et al.*, 2020). However, some project participants view IDD as a solution to many of the problems associated with collaboration, integration, information sharing, sustainability and productivity objectives in construction projects(Wuni *et al.*, 2024). Neither of these views is necessarily right or wrong. The benefits of IDD are largely dependent on project-specific conditions, the maturity of digital technologies in the local context, and the mix of building methods being used on a construction project.

Given the lack of capacity of construction projects to adopt digital technologies and limited research on the IDD approach in construction projects, this study aims to investigate the benefits of IDD in construction projects, with evidence from Hong Kong construction industry. There are three major objectives of the study: (i) to assess and rank the benefits of IDD in construction projects, (ii) to quantify the significance of various categories of the benefits, and (iii) to model the interlinkages of the benefits of IDD in construction projects using social network analysis.

The study outcomes can inform and enlighten practitioners about the benefits and performance gains achievable with IDD approach in construction projects, which can provoke its proliferation in the sector. Additionally, identifying the relationships between the benefits of IDD in construction projects helps determine the most effective ways to use IDD by following a route through a robust benefit pipeline. Such a network framework can help discover its multifaceted nature and effective use cases, leading to complete realization of its estimated benefits.

2. Literature review

The theoretical foundation of IDD is based on the complementary roles of digital technologies across the entire project lifecycle. According to the Building and Construction Authority (2023), IDD refers to an innovative project delivery approach that uses digital technologies, data, platforms, tools, and methods to integrate work processes and connect multidisciplinary project teams and value chain members. It integrates BIM, IPD, VDC, and other relevant complementary digital technologies to connect teams, data, and workflows across the entire project lifecycle (Liu *et al.*, 2021).

The benefits of IDD remain extremely under-researched and underrepresented in the literature (Wuni *et al.*, 2024). Except for Hwang et al. (2020), who evaluated the status and performance of IDD in construction projects in the context of Singapore, there is currently no empirical evaluation of the benefits of IDD in construction projects. As such, the benefits of IDD can hardly be derived directly from the existing literature, but the potential benefits of IDD have been implicitly discussed in the literature (Hwang *et al.*, 2020; Liu *et al.*, 2021; Wuni *et al.*, 2024). There are also discussions on the benefits of digitalization (Adha *et al.*, 2023), digital technologies (Love *et al.*, 2020), and digital transformation (Guandalini, 2022), which are relevant to the IDD approach in construction projects.

Table I summarizes the potential benefits of IDD in construction projects derived from the literature. These benefits can be categorized into design benefits (e.g., fewer design changes), cost benefits (e.g., cost savings), collaboration benefits (e.g., increased coordination and collaboration among team members), sustainability benefits (e.g., fewer injuries), procurement benefits (e.g., improved flexibility in the procurement process), and productivity benefits (e.g., time savings). The identification of the categories was conducted through an inductive approach. In other words, a comprehensive literature review was employed to identify benefits of IDD without any predefined categories or themes. This approach allows generation of generic and unique benefit categories for the IDD adoption. In this context, the relationships between benefits were examined and a set of categories were determined. Overall, in contrast to the deductive (i.e., theory-testing) approach, inductive (i.e., theory-building) approach was adopted since IDD is a novel and not well articulated research area (Fleischmann and Ivens, 2019). However, none of the reviewed studies empirically quantified and measured these benefits. Hence, this study fills this knowledge gap and offers a robust assessment of the benefits of IDD in construction projects in the context of Hong Kong.

[**Table I**. Potential benefits of IDD in construction projects]

3. Research methodology

The research comprised five main work packages, including comprehensive literature review, data collection, descriptive statistical analysis, weighted network analysis, and fuzzy synthetic evaluation. Figure 1 depicts these work packages and describes the salient themes.

[**Figure 1**. A breakdown of the research process]

3.1 Benefit measures

The study conducted a systematic literature review to extract the potential benefits of IDD in construction projects. A similar procedure adopted by Hoseinzadeh *et al.* (2023) was followed to conduct the systematic literature review. The reviewed studies include Love et al. (2020), Hwang et al. (2020), Liu et al. (2021), Chen et al. (2023), Adha et al. (2023), and Wuni et al. (2024). Full text evaluation of these studies generated a relevant set of twenty-two (22) potential benefits of IDD in construction project, which are summarized in Table I.

3.2 Data collection

In this study, a structured questionnaire survey was employed to measure the significance of the identified benefits. The survey form contained two major sections. Section 1 requested the background information of the respondents including, occupation, years of industry experience in Hong Kong, and highest academic qualification. Questions in Section 2 were administered the respondents to assess the significance of the identified benefits based on their practical experience, on a 5-point Likert scale: 1 = very insignificant, 2 = insignificant, 3 = slightly significant, 4 = significant, and 5 = very significant. The 5-point scale is widely used in construction management research due to its simplicity, clarity and familiarity to respondents (Wuni and Shen, 2020).

Subsequently, the study used the purposive sampling approach and the snowballing technique (i.e., chain referral) to form the relevant sample frame. These are the most suitable techniques for sampling under three conditions: (i) when the investigated subject is new, (ii) when there is no central database of the relevant population, and (iii) when the investigators have adequate knowledge of relevant subject matter (i.e., to start with and initiate the chain referral). These conditions prevailed in the context of this study and rendered the two methods the most appropriate ones to identify relevant respondents. After a period of 4 months, the study contacted hundred (100) practitioners in the Hong Kong construction industry and received sixty-three (63: 63%) valid responses, which is higher than some of sample sizes (i.e., both number and percentile) identified in the literature such as 41 (41%) (Hwang *et al.*, 2018) and 62 (10%) (Hwang *et al.*, 2020). Figure 2 summarizes the background information of the respondents.

[**Figure 2**. Relevant information of the survey participants]

3.3 Data analysis

The data analysis comprised three analytical techniques: descriptive statistical analysis, weighted correlation network analysis, and fuzzy synthetic evaluation analysis. All statistical tests in the study were conducted at the default 95% significance level.

3.3.1 Descriptive statistical analysis

The descriptive statistical analyses were conducted in the Statistical Package for the Social Sciences (IBM SPSS v.27). The study conducted a reliability analysis using Cronbach's Alpha (α) to measure the internal consistency of the survey responses. Cronbach's Alpha takes values between 0 (no consistency) and 1(excellent consistency), and the minimum threshold value is 0.7, indicating an acceptable consistency level. The study further calculated the arithmetic mean scores, standard deviations, and standard errors of the means of the benefits to capture the ranking of the benefits. When two or more benefits obtain equal mean scores, the one with the lowest standard deviation is ranked higher (Wuni *et al.*, 2024). If two or more benefits obtain equal mean scores and standard deviations, the one with the lowest standard error of mean is ranked higher.

3.3.2 Weighted correlation network analysis

Social network analysis (SNA) is a modelling techniques used to investigate the structure and relationship of social actors in a network (Saqr and Alamro, 2019). It uses nodes to represent the social actors and edges to depict the links between the social actors (Zheng *et al.*, 2016). It has been used extensively in construction managements to investigate risks (Hosseini *et al.*, 2020) and barriers (Wuni *et al.*, 2024). One of the crucial step in SNA is defining the technique for capturing the relationships between the various entities and one of the widely used methods is the Spearman rank correlation method (Hosseini *et al.*, 2020).

The weighted correlation network analysis (WCNA), which uses correlation analysis, defines the weight and directions of the relationships between the nodes. The WCNA has been used to construct a network model of corruption risks (Hosseini *et al.*, 2020) and barriers to the adoption of digital technologies in construction (Wuni *et al.*, 2024). The WCNA is used in this study to construct a network model to explore the interlinkages of the benefits of IDD in construction projects. The WCNA is conducted in four steps:

Step 1. *Generating the relationship values*: The study used the Spearman rank method to calculate the pairwise correlation coefficients of the benefits of IDD in construction projects. The Spearman correlation method is the most widely used statistical relationship determination technique in WCNA because it can handle all data distributions and is insensitive to outliers(Hosseini *et al.*, 2020). Only statistically significant correlations at 95% and 99% confidence levels were considered in the network model.

Step 2. *Creation of adjacency matrix*: The correlation analysis generated an adjacency matrix of the benefits. An adjacency matrix is a square matrix of m x m where m is the number of nodes in the graph and was used to generate the connections or edges of the network model. The adjacency matrix contained 231 correlations between the benefits, of which 174 were significant at p = 0.05 or 0.01 and were retained in the network. Following the works of

Hosseini et al. (2020), the significant correlation coefficients were raised to the power of β (β=4) to deepen the gap between strong and weak correlations (i.e., links) in the matrix.

Step 3. *Network formation*: Networks are formed from matrices of nodes and edges. The network formation was conducted in Gephi, an open-source network visualization tool (Bastian *et al.*, 2009) which can form networks based on matrices of nodes and edges. The study generated a nodes table in Microsoft Excel, which contained the IDs and description of the benefits in two separate columns and saved in a comma-separated values (CSV) format. An edges table was also generated in Excel, which contained the pairwise links between the nodes (i.e., benefits) derived from the correlation matrix. It contained four separate columns including the source, target, type, and weight for the 174 significant links of the benefits.

Step 4. *Network analysis*: The study used various metrics, including degree centrality, weighted degree (node strength), betweenness centrality, closeness centrality, clustering coefficient, and eigenvector centrality to analyze and explain the structure of the weighted correlation network model of the benefits generated in Gephi software.

3.3.3 Fuzzy synthetic evaluation

The fuzzy synthetic evaluation (FSE), derived from fuzzy sets theory, combines weighting functions, membership functions and grade alternatives of a Likert scale to quantify the significance of a cluster of factors in a survey-based study (Wuni *et al.*, 2024). This study developed an FSE model to quantify the impact of various groups of benefits using the following steps.

Step 1. *Specification of the fuzzy evaluation index system.*

Step 2. *Calculating weightings of the benefits*

Step 3. *Determining the membership functions of the benefits*

Step 4. *Defuzzification*

4. Results

4.1 Reliability of the dataset

The reliability analysis generated a Cronbach's Alpha of 0.914 for the responses to the 22 benefits and Cronbach's Alpha of 0.916 based on the standardized items. These values are higher than the minimum threshold value of 0.70, and indicate excellent internal consistencies in the responses (Cronbach, 1951). The higher value also means that the questionnaire survey measured the significance of the benefits accurately and generated consistent outcomes (Tang *et al.*, 2014).

4.2 Mean score ranking of the benefits

Table II reports the arithmetic mean scores (μ), standard errors of the mean (SEM) scores, standard deviations (σ), and ranking of the benefits of IDD in construction projects. The mean scores ranged between 3.67 and 4.43, on the 5-point Likert scale, indicating that each of the benefits was averagely rated significant, reflecting and corroborating the distributions of the responses in Figure 3. The SEM of the responses to the benefits ranged between 0.08 and 0.16, indicating very minimal discrepancy between the sample mean and the population mean. The standard deviations of the responses to the benefits ranged between 0.64 and 1.24, suggesting minimal dispersions of the responses around the mean scores.

[**Table II**. Mean scores of the benefits of IDD in construction projects]

According to the analysis results, the top 10 most significant benefits of IDD in construction projects include: high quality and faster preparation of designs and calculations (μ = 4.43), improved efficiency and productivity (μ = 4.41), real time simulation and visualization of project designs (μ = 4.30), improved information exchange and management (μ = 4.27), improved communication among project team (μ = 4.25), digital construction saves time (μ = 4.22), improved work and project quality due to fewer reworks (μ = 4.13), cost savings associated with digital project delivery (μ = 4.11), improved flexibility in the procurement process (μ = 4.10), and improved risk management (μ = 4.08).

4.3 Weighted correlation network model

Figure 3 represents a weighted correlation network model of the benefits of IDD in construction projects. The nodes represent the benefits and the edges depicts the linkages between two benefits in the network. The size of a node (i.e., benefit) depicts its weighted degree centrality, indicating the influence power of the benefit in the network. The various colors represent six (6) communities (i.e., groups) of the benefits, including design, cost, collaboration, sustainability, procurement, and productivity group of benefits.

[**Figure 3**. Weighted correlation network model of the benefits of IDD in construction projects]

Table III reports the performance measures of the network model, including degree, weighted degree, closeness centrality, betweenness centrality, eigenvector centrality, clustering coefficient, and relative importance ranking. The network model shows that the set of investigated benefits are significantly correlated. The degree centrality scores indicate that each benefit is significantly correlated with at least 8 (e.g., B1) other benefits and at most 20 other benefits in the dataset (e.g., B4, B5, B10). For example, cost savings associated with digital project delivery (B4), improved work and project quality (B5), and high quality and faster preparation of designs and calculation (B10) are the most influential benefits, with each linked to 20 other benefits in the network. Waste reduction in office or on construction site (B1) is the least influential benefit with a significant correlation with 8 other benefits in the network.

[**Table III**. Node measures of the network model of the benefits of IDD in construction projects]

Based on the weighted degree centralities (WD), the top five most influential benefits in the network include improved work and project quality (B5, WD = 0.759, rank= 1), cost savings associated with digital project delivery (B4, WD= 0.753, rank= 2), project whole life costing from digital asset management (B16, WD= 0.751, rank= 3), ease of updating and applying design instructions at anytime (B12, WD= 0.703, rank= 4), and improved service to project administrator and consultants (B14, WD= 0.692, rank= 5). This set of influential benefits bring the design, cost, and productivity benefits of the IDD approach to the forefront in construction projects.

The five least influential benefits in the network include improved efficiency and productivity (B2, WD= 0.330, rank= 18), accurate project cost estimation (B11, WD= 0.257, rank= 19), fewer injuries on-site during digital construction (B9, WD= 0.228, rank= 20), waste reduction in office or on construction site (B1, WD= 0.186, rank = 21), and real-time simulation and visualization of project designs (B22, WD= 0.161, rank = 22). These suggest that the specific productivity (B2), cost (B11), sustainability (B1, B9), and design (B22) benefits, though independently significant, have limited influence on the significance of other benefits.

4.4 Fuzzy synthetic evaluation model

4.4.1 Mean weighted scores and membership functions

Table IV summarizes the weightings of the various groups of the benefits. The weightings of the individual benefits and the groups were derived from the mean scores and total mean scores, respectively. It is observed that the total mean scores (Σμ) and weights (W) are sensitive to the number of benefits in each group. Thus, groups with more sets of benefits are likely to be weightier than those with fewer.

However, it can be observed that there are an equal number of benefits (i.e., 3) in four of the groups (i.e., cost, sustainability, procurement, and productivity), but they have different total mean scores and weights. As such, the weightings can be used to rank the groups of the benefits. Based on the weightings, the ordered importance of the groups of benefits include collaboration benefits (Σμ= 20.44, W= 0.227), design benefits (Σμ= 20.39, W= 0.227), productivity benefits (Σμ= 12.76, W= 0.142), cost benefits (Σμ= 12.22, W= 0.136), procurement benefits (Σμ= 12.12, W= 0.135), and sustainability benefits (Σμ= 11.97, W= 0.133).

[**Table IV**. Mean weightings and membership functions of the benefits of IDD]

Table IV also summarizes the membership functions (MFs) of the benefits (i.e., B1 – B22) and groups (i.e., design, cost, collaboration, sustainability, procurement, and productivity) of the benefits. The MFs (level 1) of B1 – B22 were derived directly from the responses of the respondents and the sum of the MFs of each benefit is equal to 1. The MFs of the groups (level 2) were derived as a product of the weightings and MFs of the set of benefits in each group and the sum of the MFs of each group is also equal to 1.

4.4.2 Significance indices and coefficients

Table V summarizes the MFs (level 3) of the overall set of benefits. It also shows the significance indices, significance coefficients, and ranking of the groups of benefits.

[**Table V**. Significance indices and coefficients of the groups of benefits of IDD]

The significance index of the overall set of benefits is 4.09, on a 5-point scale, indicating that the benefits were collectively assessed at significant merits and outcomes of IDD in construction projects. The significance indices of the six groups of benefits ranged between 3.99 (≈4.00) and 4.26, indicating that each group was rated as a significant performance improvement in construction projects attributable to the IDD approach. Based on the significance indices and coefficients, the order of importance of the groups of benefits include productivity benefits (index= 4.26, rank= 1), collaboration benefits (index= 4.09, rank= 2), design benefits (index= 4.09, rank= 2), cost benefits (index= 4.07, rank= 4), procurement benefits (index= 4.04, rank= 5), and sustainability benefits (index= 3.99, rank= 6).

5. Discussions and implications

This study investigated the host of process and performance improvements in construction projects by implementing the IDD approach, based on the survey data from Hong Kong. The results indicated that there are multiple perceived benefits of the IDD approach in construction projects. The analysis results revealed that industry practitioners consider the overall set of twenty-two benefits investigated to be significant performance improvements attributable to the IDD approach in construction projects. The SNA established that there are considerable interlinkages among the benefits of IDD in construction projects, suggesting that the realization of some benefits could trigger other benefits. The FSE model also concluded that each of the six groups is a significant benefit group. These groups of benefits are described and discussed in the following sub-sections in the order of importance based on the significance indices.

5.1 Productivity benefits (index= 4.26, rank= 1)

The findings indicate that the IDD approach offers the most significant gains in productivity improvements in construction projects, with a significance index of 4.26 (Table V). The productivity benefits of IDD in construction projects include improved efficiency, fewer reworks, improved work and project quality, and time savings. The integrated approach of IDD enables the relevant project team members to accurately design specifications that are understood by all involved. The integrated project team work collaboratively to review drawings, documentations, and specifications that proactively address intractable downstream constraints to minimize rework and associated wastes (Hwang *et al.*, 2020). More specifically, IDD uses clash detection technologies and BIM-based defect management systems to eliminate abortive works and avoid duplication of tasks. Given the fewer changes and reworks, IDD significantly saves design and construction time.

However, the theoretical position of digital technologies offering productivity gains is not well-established in the literature. There are mixed findings regarding the productivity gains of digital technologies in construction projects. Even though the findings of this study are consistent with Love et al. (2020) who observed significant productivity gains attributable to digital technologies in construction, it diverges from Brynjolfsson (1993), who observed that overuse of digital technologies decreases the productivity of workers, arising from mismeasurement of outputs and inputs, lags due to learning and adjustment, redistribution and dissipation of profits, and mismanagement of information and technology.

5.2 Collaboration benefits (index= 4.09, rank= 2)

The second most significant group is the collaboration benefits, represented by five (5) sets of benefits and with a significance index of 4.09. IDD usually records and stores project data and information in a single digital platform (e.g., a digital cloud-based system such as BIM360), providing a single source of truth, where all project participants, including architects, engineers, contractors, subcontractors and clients have access to the same information (Liu *et al.*, 2021). This improvement enables all project teams to observe the status of the projects and with full knowledge of the progress and responsibilities of all parties involved. Thus, IDD reduces the risk of ambiguity and miscommunication that can occur with scattered information and fragmented teams (Hwang *et al.*, 2020).

The theoretical position of the collaboration benefits arising from digital technologies (e.g., BIM, VDC) and IPD are well-established in the literature (Love *et al.*, 2020). Thus, the optimum mix and dose of IDD technologies addresses the collaboration deficits and closes the communication and information-sharing gaps in the design, fabrication, construction, and operation stages of construction projects. The collaboration benefits arise from five sources, including improved communication among project teams (B6), improved information exchange and management (B7), increased coordination and collaboration among team members (B8), improved service to project coordinator and consultants (B14), and collaborative fabrication from digital manufacturing (B19). Hence, it can be deduced that collaboration through proper communication among included parties is one of the most apparent benefits of IDD approach.

5.3 Design benefits (index= 4.09, rank= 2)

The third most significant group is the design benefits, represented by five (5) sets of benefits and with a significance index of 4.09. According to Hwang et al. (2020), IDD improves and optimizes the speed, accuracy, adequacy, cost, and quality of design in construction projects. IDD offers a suite for digital software deploying advanced computational and artificial intelligence techniques to facilitate fabrication-aware generative design solutions. Generative design in IDD facilitates quicker generation of conceptual designs, which can capture the aesthetic, form, and structure requirements of clients (Baduge *et al.*, 2022). Similarly, digital design software in IDD allows designers to quickly and efficiently modify and update project designs to meet changes requested by the client. IDD also deploys cloud-based technologies to create a single and shared model or design of the project, accessible to all team members in real-time. Thus, changes or updates made to the design are immediately updated and visible to everyone. This centralized and synchronized approach eliminates the risk of working on outdated or duplicated designs, ensuring that every member collaborates and works on the most current version of the project design (Hwang *et al.*, 2020).

5.4 Cost benefits (index= 4.07, rank= 4)

The study positioned cost benefits as the fourth most significant gain of the IDD approach in construction projects, with a significance index of 4.07. The literature established a significant link between digital technologies and cost reductions in construction projects (Love *et al.*, 2020). After evaluating the status of 149 construction projects that adopted the IDD approach in Singapore, Hwang et al. (2020) observed that IDD generated a mean cost reduction by 3.76%. The Building and Construction Authority (2023) also documented the lifecycle cost savings achievable with the IDD approach in construction projects. The cost savings associated with IDD solutions arise from the reduced rework, optimized procurement, efficient design, and streamlined workflows (Love *et al.*, 2020). Also, IDD leverages digital platforms for estimation, such as Cubit Pro estimating software, Navisworks, Synchro Pro, and BIM360 to simplify and improve the accuracy of project cost estimates. These digital estimating solutions enable the project teams to measure designs directly within the digital prints and select objects from the digital space. These digital tools can be programmed to capture particular dimensions in accordance with the chosen measurement method. Also, the data collected and generated at each project phase forms the basis for estimating the necessary whole-life project costs.

5.5 Procurement benefits (index= 4.04, rank= 5)

The fifth most significant group is the procurement benefits, represented by three (3) benefits and with a significance index of 4.04. This outcome is consistent with Yevu et al. (2021), who documented that digital technologies generate significant procurement gains in terms of reduced procurement costs, improved transparency and efficiency, reduced supplier risk, and improved supply resiliency. The IDD approach lowers procurement risks and improves risk management in construction projects. A major source of procurement challenges is design errors. IDD deploys BIM to detect design anomalies through clash detection analysis, which unveils all potential risks occurring between the designs from various project teams across all the design disciplines. The real-time design reviews provide the opportunity for issues to be identified and resolved to proactively avoid intractable fabrication and construction problems. IDD technologies (e.g., BIM360, Bluebeam Revu, and SharePoint) improves contract and project documentation through the conversion of documents such as plans, specifications, change orders, contracts and revisions into manageable digital files and units. IDD has revolutionized the procurement process, enabling unprecedented flexibility. It reduces the cost of manual paperwork and facilitates fair and transparent issuance of addenda to potential applicants. It takes individuals to create accounts to access any work package from a digital platform. Response to project tendering is digitally submitted, and the analytics are made available to the procurement entity. The evaluation panel can work on submitted bids through paperless projects to select a responsive tender.

5.6 Sustainability benefits (index= 3.99, rank= 6)

The least significant group is the sustainability benefits of IDD with a significance index of 3.99. The theoretical position of the sustainability benefits of digital technologies in construction remains contested. While IDD improves social sustainability (e.g., fewer injuries, minimized disputes, improved human relationships) (Grybauskas *et al.*, 2022), the adverse environmental impact of digital technologies such as energy consumption, e-waste generation, carbon emissions, and landfill issues remain grave concerns regarding IDD approach (Adha *et al.*, 2023). Therefore, developing strategies and measures that minimize the adverse impact of the IDD approach on sustainability can enable IDD to be adopted by wider audiences for its adoption in the construction industry.

6. Novelty and contributions

This study has a merit in providing a robust assessment of the benefits of the IDD approach in construction projects. There are several novelties that differ this study from its counterparts. First, IDD is an emerging concept and potential benefits of IDD have not been documented systematically in the literature. According to a comprehensive literature review, a list of IDD benefits was identified and grouped into six groups to clearly show the contributions of the IDD approach. Theoretically, the derived six constructs (i.e., design, cost, collaboration, procurement, productivity, and sustainability) explain the host of performance improvements attributable to the IDD approach. These constructs represent the building blocks to theorize the benefits of IDD, including digital technologies in construction projects. Additionally, this study combines FSE and SNA to computationally measure the relationship between the benefits of IDD, addressing performance improvements achievable with the IDD approach. Combination of FSE and SNA approach is not only a unique approach in the IDD literature, but also one of the initial attempts in other fields of project management. By developing a robust and reliable network map, the impacts of benefits on others can help identify the most effective managerial pipeline for the overall performance improvements in construction projects.

Practically, the study findings have made several distinct contributions. First, this study found that the IDD approach can offer significant advantages in construction productivity, especially in design optimization and advanced work packaging. Thus, it establishes that the IDD approach should be prioritized in projects where productivity, which is at its poorest levels in the construction industry, is significantly challenged. Second, this research underscored the roles of digital technologies in addressing communication gaps, collaboration deficits, and optimization of construction project design. The findings show that IDD can offer significant gains in collaboration, communication, information sharing, and design visualization. Hence, in the era of data, IDD will be an essential component of project management to turn shared data and information into beneficial insights. Finally, the findings challenge future studies to critically evaluate the environmental consequences of digital technologies in construction projects. The study identified sustainability as the least significant benefit of IDD in construction projects. It joins the debate in questioning the sustainability of digital technologies in construction projects and invokes the necessity to develop sustainable digital technologies in the construction industry.

Project managers in construction can use the most critical benefits in each category based on the project-specific requirements or issues. For instance, if there is collaboration-based issues in a project, the project manager can ensure that communication among project team members and information exchange can be ameliorated through the IDD approach. Many technological solutions (e.g., IDD, BIM) can therefore be evaluated by project managers to select the most suitable. In addition, the identified benefits, their categorization, and order of importance can be used to formulate guideline routes and policies for the IDD adoption. Here, the relationships between benefits can be used to develop the most effective policy development pipeline since some of the benefits can emerge as a result of other benefits. In this way, only the causal benefits can be focused on, ensuring the most effective process for the policy and guideline development. A prototype application of the IDD approach can also be presented to the pioneers in the sector and performance improvements and benefits can be documented systematically to show the materialization of the benefits to a wider extent.

7. Conclusions

This study investigates the benefits of integrated digital delivery in Hong Kong construction projects. Relevant survey data was collected to measure the importance of a set of twenty-two (22) benefits of the IDD approach and the resulting data was analyzed using descriptive statistics, social network analysis, and fuzzy synthetic evaluation. Overall, there were three major objectives of the study as (i) ranking the benefits of IDD in construction projects, (ii) assessing the benefit categories of IDD approach, and (iii) modelling the relationship between the benefits.

(i) The results showed that the investigated benefits were perceived as significant performance improvements attributable to the IDD approach. The mean score analysis showed that the most prominent benefits of IDD arise from higher quality and faster preparation of designs, improved efficiency, real-time simulation and visualization of project designs, better information exchange and management as well as improved communication among project teams. Thus, it is perceived among industry practitioners that the IDD approach can address many design challenges, communication gaps, collaboration deficits, rework, inefficiencies, procurement problems, and risks in construction projects.

(ii) The study further derived six constructs to classify the project gains from the IDD approach, including design, cost, collaboration, sustainability, procurement, and productivity benefits. It is identified that the set of investigated benefits are collectively perceived as significant gains from the IDD approach. Each of the constructs of the benefits was also perceived as a significant cluster in the IDD approach, with significance indices ranging between 3.99 and 4.26, on a 5-point scale. However, the study found the least significant group to be the sustainability construct and silhouetted the concerns about the environmental impact of digital technologies in construction projects.

(iii) It is established that the set of investigated benefits of IDD are significantly correlated, with each benefit influencing the significance of between 8 and 20 other benefits in the network. Particularly cost savings associated with digital project delivery, improved work and project quality, and high quality and faster preparation of designs and calculation were the most influential benefits, related with 20 other benefits in the network. Hence, it can be concluded that each element in the iron triangle, i.e., cost (cost savings with digital delivery), time (faster preparation of designs and calculation), and quality (improved work and project quality) can be addressed explicitly by adopting the IDD approach.

The study outcomes offer a comprehensive assessment of the benefits of the IDD approach and deepen the understanding of the perceived performance gains achievable with the IDD approach. Still, there are two noteworthy limitations of the study. First, the sample size, although representative of Hong Kong, limits the generalizability of the findings. Second, the list of benefits investigated may not exhaustive and may have not captured all the possible benefits of the IDD approach in construction projects.

Based on the study limitations the following future works are recommended. First, increasing the sample size can further enhance the generalizability of the research outputs. Besides, a more comprehensive set of benefits can be identified through focus group discussions that help the emergence of new ideas through synergistic data collection process. Additionally, this study assessed the benefits of the IDD approach. In future research, a set of

IDD applications can be listed, and the most effective ones can be selected based on their perceived benefits using a multi-criteria decision approach. Still, the perceived benefits may differ according to cultural characteristics of the respondents. Hence, country-based comparisons can be conducted to consider the changes in the perceived benefits in different countries. Overall, the model proposed in the study can be used by professionals who want to gain a competitive advantage in the sector using IDD, to determine what advantages IDD will provide in their projects.

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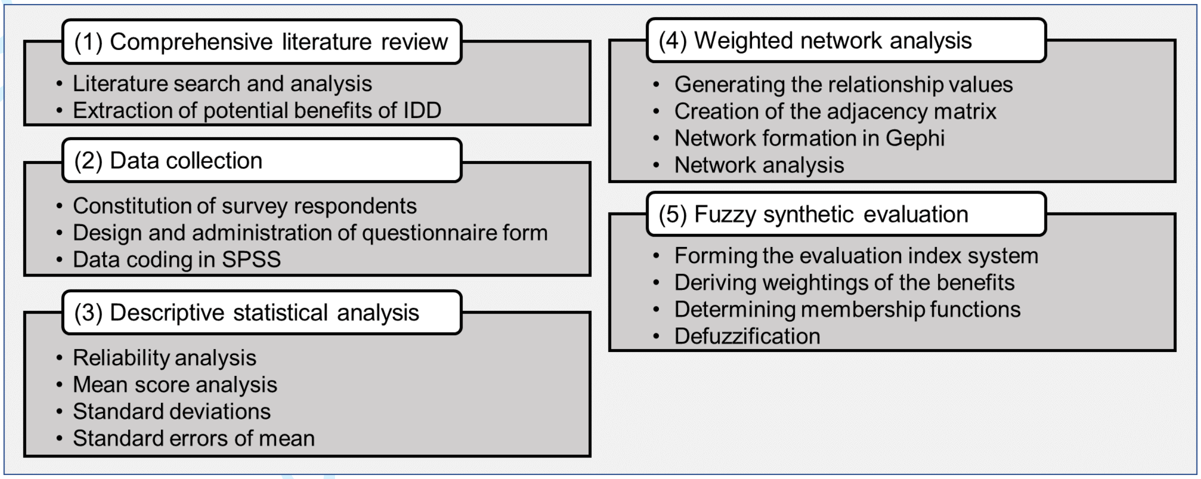

Figure 1. A breakdown of the research process

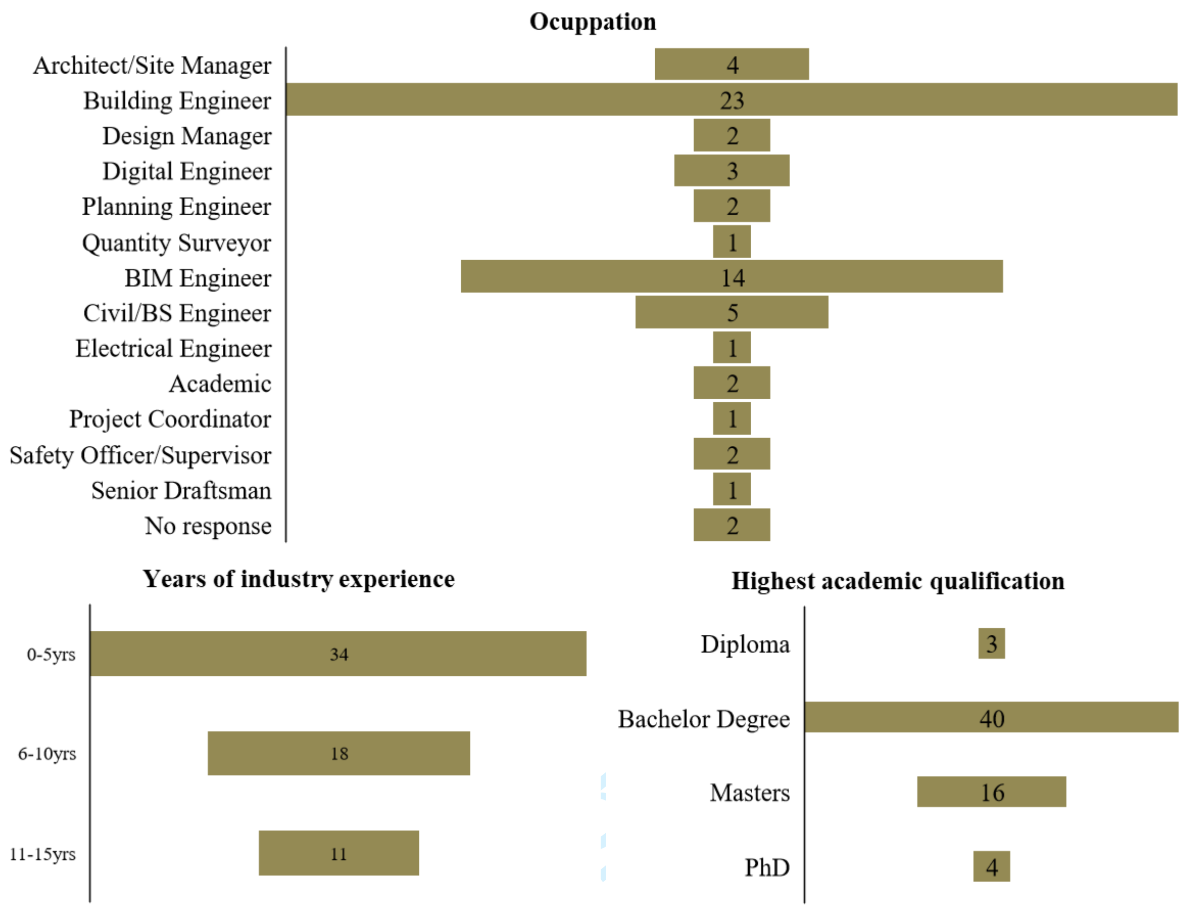

Figure 2: Relevant information of the survey participants

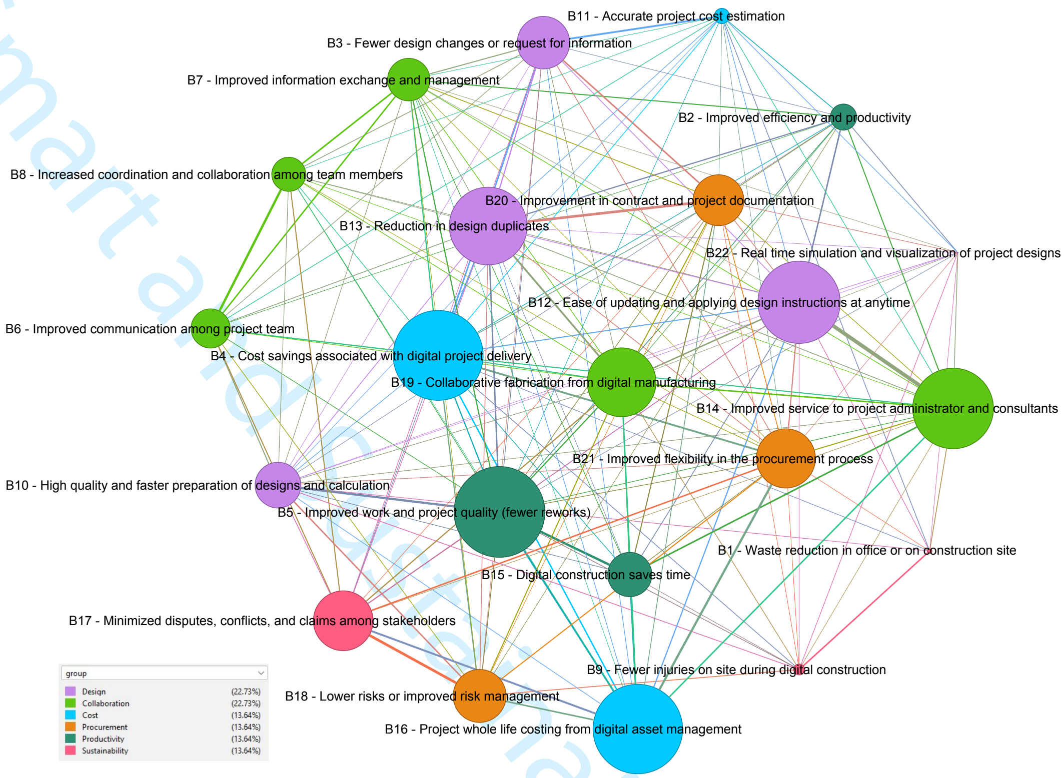

Figure 3. Weighted correlation network model of the benefits of IDD in construction projects

Table I. Potential benefits of IDD in construction projects

Code	Benefit	Sources
B1	Waste reduction in office or on construction site	(Wuni *et al.*, 2024)
B2	Improved efficiency and productivity	(Love *et al.*, 2020)
B3	Fewer design changes or request for information (RFI)	(Liu *et al.*, 2021)
B4	Cost savings associated with digital project delivery	(Love *et al.*, 2020)
B5	Improved work and project quality (fewer reworks)	(Chen *et al.*, 2023)
B6	Improved communication among project team	(Adha *et al.*, 2023)
B7	Improved information exchange and management	(Liu *et al.*, 2021)
B8	Increased coordination and collaboration among team members	(Hwang *et al.*, 2020)
B9	Fewer injuries on site during digital construction	(Wuni *et al.*, 2024)
B10	High quality and faster preparation of designs and calculation	(Wuni *et al.*, 2024)
B11	Accurate project cost estimation	(Wuni *et al.*, 2024)
B12	Ease of updating and applying design instructions at anytime	(Guandalini, 2022)
B13	Reduction in design duplicates	(Hwang *et al.*, 2020)
B14	Improved service to project administrator (PA) and consultants	(Love *et al.*, 2020)
B15	Digital construction saves time	(Hwang *et al.*, 2020)
B16	Project whole life costing from digital asset management	(Love *et al.*, 2020)
B17	Minimized disputes, conflicts, and claims among stakeholders	(Love *et al.*, 2020)
B18	Lower risks or improved risk management	(Hwang *et al.*, 2020)
B19	Collaborative fabrication from digital manufacturing	(Liu *et al.*, 2021)
B20	Improvement in contract and project documentation	(Wuni *et al.*, 2024)
B21	Improved flexibility in the procurement process	(Hwang *et al.*, 2020)
B22	Real time simulation and visualization of project designs	(Hwang *et al.*, 2020)

Table II. Mean scores of the benefits of IDD in construction projects

Code	Mean	Std. Error	Std. Dev	Rank
B1	3.98	0.131	1.039	17
B2	4.41	0.084	0.663	2
B3	3.67	0.157	1.244	22
B4	4.11	0.118	0.935	8
B5	4.13	0.110	0.871	7
B6	4.25	0.090	0.718	5
B7	4.27	0.102	0.807	4
B8	4.03	0.113	0.897	14
B9	4.02	0.121	0.959	16
B10	4.43	0.081	0.640	1
B11	4.03	0.101	0.803	12
B12	3.97	0.111	0.879	18
B13	4.02	0.116	0.924	15
B14	3.86	0.124	0.981	21
B15	4.22	0.097	0.771	6
B16	4.08	0.118	0.938	11
B17	3.97	0.113	0.897	19
B18	4.08	0.102	0.809	10
B19	4.03	0.111	0.879	13
B20	3.94	0.117	0.931	20
B21	4.10	0.115	0.911	9
B22	4.30	0.089	0.710	3

Table III. Node measures of the network model of the benefits of IDD in construction projects

ID	Degree	Weighted degree	Closeness centrality	Betweenness centrality	Clustering coefficient	Eigenvector centrality	Ranking (WD)
B1	8	0.186	0.618	0.188	0.929	0.415	21
B2	14	0.330	0.750	1.184	0.857	0.740	18
B3	16	0.504	0.808	1.466	0.858	0.836	11
B4	20	0.753	0.955	5.973	0.742	0.985	2
B5	20	0.759	0.955	4.471	0.768	1.000	1
B6	12	0.416	0.700	0.606	0.894	0.632	16
B7	18	0.438	0.875	2.910	0.804	0.922	15
B8	14	0.382	0.750	0.778	0.901	0.754	17
B9	12	0.228	0.700	1.434	0.818	0.613	20
B10	20	0.460	0.955	6.466	0.721	0.974	13
B11	15	0.257	0.778	2.614	0.800	0.765	19
B12	19	0.703	0.913	4.714	0.760	0.946	4
B13	19	0.672	0.913	3.388	0.795	0.965	6
B14	18	0.692	0.875	4.117	0.765	0.898	5
B15	12	0.450	0.700	0.341	0.939	0.662	14
B16	15	0.751	0.778	0.936	0.895	0.803	3
B17	14	0.553	0.750	0.947	0.879	0.748	8
B18	14	0.507	0.750	1.509	0.835	0.730	10
B19	19	0.612	0.913	3.895	0.778	0.956	7
B20	17	0.493	0.840	2.802	0.787	0.864	12
B21	19	0.548	0.913	4.787	0.760	0.945	9
B22	13	0.161	0.724	1.474	0.833	0.671	22

Table IV. Mean weightings and membership functions of the benefits of IDD

Code	Group	Mean	Weight	Membership functions
	Design benefits	**20.39**	**0.227**	**(0.011, 0.044, 0.182, 0.364, 0.398)**
B3		3.67	0.180	(0.063, 0.159, 0.127, 0.349, 0.302)
B10		4.43	0.217	(0.000, 0.000, 0.079, 0.413, 0.508)
B12		3.97	0.195	(0.000, 0.032, 0.302, 0.333, 0.333)
B13		4.02	0.197	(0.000, 0.048, 0.270, 0.302, 0.381)
B22		4.30	0.211	(0.000, 0.000, 0.143, 0.413, 0.444)
	Cost benefits	**12.22**	**0.136**	**(0.000, 0.069, 0.153, 0.412, 0.366)**
B4		4.11	0.336	(0.000, 0.079, 0.143, 0.365, 0.413)
B11		4.03	0.330	(0.000, 0.048, 0.159, 0.508, 0.286)
B16		4.08	0.334	(0.000, 0.079, 0.159, 0.365, 0.397)
	Collaboration benefits	**20.44**	**0.227**	**(0.000, 0.050, 0.182, 0.391, 0.376)**
B6		4.25	0.208	(0.000, 0.000, 0.159, 0.429, 0.413)
B7		4.27	0.209	(0.000, 0.032, 0.127, 0.381, 0.460)
B8		4.03	0.197	(0.000, 0.063, 0.190, 0.397, 0.349)
B14		3.86	0.189	(0.000, 0.095, 0.270, 0.317, 0.317)
B19		4.03	0.197	(0.000, 0.063, 0.175, 0.429, 0.333)
	Sustainability benefits	**11.97**	**0.133**	**(0.000, 0.095, 0.180, 0.365, 0.360)**
B1		3.98	0.332	(0.000, 0.127, 0.159, 0.317, 0.397)
B9		4.02	0.336	(0.000, 0.095, 0.159, 0.381, 0.365)
B17		3.97	0.332	(0.000, 0.063, 0.222, 0.397, 0.317)
	Procurement benefits	**12.12**	**0.135**	**(0.000, 0.048, 0.226, 0.366, 0.360)**
B18		4.08	0.337	(0.000, 0.032, 0.190, 0.444, 0.333)
B20		3.94	0.325	(0.000, 0.048, 0.317, 0.286, 0.349)
B21		4.10	0.338	(0.000, 0.063, 0.175, 0.365, 0.397)
	Productivity benefits	**12.76**	**0.142**	**(0.000, 0.015, 0.158, 0.381, 0.446)**
B2		4.41	0.346	(0.000, 0.000, 0.095, 0.397, 0.508)
B5		4.13	0.324	(0.000, 0.048, 0.175, 0.381, 0.397)
B15		4.22	0.331	(0.000, 0.000, 0.206, 0.365, 0.429)

Table V. Significance indices and coefficients of the groups of benefits of IDD

Group	Weight	Membership Function	Index	Rank
Design benefits	0.227	(0.011, 0.044, 0.182, 0.364, 0.398)	4.09	2
Cost benefits	0.136	(0.000, 0.069, 0.153, 0.412, 0.366)	4.07	4
Collaboration benefits	0.227	(0.000, 0.050, 0.182, 0.391, 0.376)	4.09	2
Sustainability benefits	0.133	(0.000, 0.095, 0.180, 0.365, 0.360)	3.99	6
Procurement benefits	0.135	(0.000, 0.048, 0.226, 0.366, 0.360)	4.04	5
Productivity benefits	0.142	(0.000, 0.015, 0.158, 0.381, 0.446)	4.26	1
Overall benefits		**(0.003, 0.052, 0.180, 0.380, 0.385)**	**4.09**	