



HAL
open science

Functionality as a key concept for integrated project planning and scheduling methods

Moslem Sheikhhoshkar, Hind Bril El-Haouzi, Alexis Aubry, Farook Hamzeh

► To cite this version:

Moslem Sheikhhoshkar, Hind Bril El-Haouzi, Alexis Aubry, Farook Hamzeh. Functionality as a key concept for integrated project planning and scheduling methods. *Journal of Construction Engineering and Management*, 2023, 149 (7), pp.13427. 10.1061/JCEMD4.COENG-13427 . hal-04042433

HAL Id: hal-04042433

<https://hal.univ-lorraine.fr/hal-04042433v1>

Submitted on 14 Jun 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

31 in the integrated scheduling methods. Eventually, this study will aid project stakeholders in better
32 understanding of integrated scheduling methods by defining the functionality concept of
33 scheduling methods.

34 **Keywords:** Functionality Concept, Integrated Scheduling Methods, Common Scheduling
35 Methods, Social Network Analysis (SNA), Pareto Chart Analysis

36 **Introduction**

37 McKinsey group estimated that 98% of construction projects experience more than 30% cost
38 overruns, and 77% are at least 40% late (Ashcraft 2022). Lack of effective planning and scheduling
39 (Salama et al. 2021), inefficient constraint management (Wu et al. 2021), the multi-organizational
40 structure of the construction sector (Mota et al. 2010), the shortage of collaboration between
41 stakeholders (Mota et al. 2010; Viklund Tallgren et al. 2020) and the presence of many
42 uncertainties in the projects (Tokdemir et al. 2019) are some of the significant factors
43 contributing to this rise in project cost and time. Over the previous decades, a vast range of
44 planning and scheduling methodologies, methods, and tools have been developed and used to
45 deal with these challenges (Pellerin and Perrier 2019). Examples of practical methods include the
46 Critical Path Method (CPM) (Antill and Woodhead 1991), Critical Chain Project Management
47 (CCPM) (Raz et al. 2003), Line of Balance (LOB) (Arditi and Albulak 1986), Linear Scheduling Model
48 (LSM) (Yamin and Harmelink 2001), Location-based Management System (LBMS) (Seppänen et
49 al. 2014), Last Planner System (LPS) (Ballard and Tommelein 2016), Takt Time Planning (TTP)
50 (Frandsen et al. 2013), 4DBIM (Martins et al. 2020), Simulation-based Methods (SM) (Zhang et
51 al. 2002), and Tri-Constraint Method (TCM) (Morkos 2014). In this paper, these methods are
52 defined as common scheduling methods. Another approach is mathematical and algorithmic

53 methods (Ansari et al. 2022; Milat et al. 2021) which were used to model the scheduling
54 problems. In these methods, the defined scheduling problems were solved by one or more
55 objective functions with several constraints. They also applied different meta-heuristic
56 algorithms, including Genetic Algorithms (GA), Simulated Annealing (SA), Particle Swarm
57 Optimization (PSO), and others, to optimize different types of project scheduling problems. This
58 approach is more research-oriented, and their application in a complex construction
59 environment is still challenging.

60 Although the mentioned methods separately have pros, their cons lead to ineffective planning
61 and scheduling (Olivieri et al. 2016). To address this issue, some researchers have tried to
62 combine classical planning and scheduling methods and lean tools and principles with a wide
63 range of objectives to cover the disadvantages of the existing methods. In this line, several studies
64 integrated the Last Planner System (LPS) with Building Information Modelling (BIM) to meet lean
65 principles such as workflow stability, facilitating negotiation and team commitment, pull
66 planning, flow visualization, addressing spatiotemporal conflicts, reducing the time waste of
67 urban highway projects, enhancing process management and flow of work on the construction
68 site, promoting continuous improvement, and enhancing project stakeholder understanding
69 (Bhatla and Leite 2012; Igwe et al. 2019; Sacks et al. 2010; Schimanski et al. 2021). Moreover,
70 some researchers focused on integrating LBMS, LPS, and CPM to address some gaps in
71 conventional scheduling methods, improve planning and control processes, and fulfil lean
72 objectives of reducing waste, increasing productivity, minimizing variability, supporting
73 managers in analyzing delays, and determining the most influential critical path strategy (Olivieri
74 et al. 2016; Seppänen et al. 2010). In modular construction, Salama et al. (2021) developed a new

75 approach for monitoring and controlling of integrated offsite and on-site activities. The proposed
76 technique combines the last planner system (LPS), critical chain project management (CCPM),
77 and linear scheduling method (LSM)in a structured manner that addresses student syndrome in
78 CCPM, public commitments, non-completion reasons, and monitoring of task completion.
79 Furthermore, to increase productivity, the suggested integrated scheduling method followed the
80 principle of takt time (TT) and Just in Time (JIT). Integration of Building Information Modeling
81 (BIM) and LPS have received the most attention in the literature (Al Hussein 2016; Barkokebas et
82 al. 2021; Burguete 2018; Heigermoser et al. 2019; McHugh et al. 2019; Sacks et al. 2010; Toledo
83 et al. 2016). Moreover, BIM-LPS-Kanban (Sacks et al. 2010; Schimanski et al. 2021), 4D-LPS (Igwe
84 2021; Lin and Golparvar-Fard 2021), LPS-LBMS (Seppänen et al. 2010), LBMS-LPS-CPM (Olivieri et
85 al. 2016; POLIANI 2020) and BIM-TTP-SM (Abbasi et al. 2020) can be mentioned among the many
86 combined scheduling methods that have been performed in previous studies. In this study, these
87 mixed methods are considered as integrated scheduling methods. Over time, the number of
88 integrated scheduling methods contributing to project performance and success has expanded.
89 Although several integrated scheduling methods have widened the window of opportunity,
90 particularly for contractors, they have also caused confusion on which approach should be
91 chosen and which is best suited for the project. AlNasseri and Aulin (2015) highlighted that
92 despite the availability of advanced planning and scheduling tools and methods, stakeholders
93 prefer to choose traditional methods. Insufficient familiarity and information about the
94 applicability and efficiency of planning and scheduling methods are mentioned as the primary
95 cause of this issue. In order to minimize imbalances between stakeholder requirements and
96 project plans, several studies have suggested that project participants should be aware of key

97 characteristics and objectives of project scheduling methods (AlNasseri and Aulin 2015; AlNasseri
98 2015; Walker and Shen 2002). In line with this, this study defines and addresses the concept of
99 functionality to describe the goals and objectives of integrated scheduling methods. In the
100 Longman dictionary, functionality refers to "one or all of the operations that a computer,
101 software program or piece of equipment is able to perform" (Richards and Schmidt 2013).
102 According to this concept, schedule plan functionality is regarded as the operations and the
103 primary objective of each single or integrated scheduling methods. The functionality concept can
104 ease sense-making and the situation awareness of project stakeholders regarding the planning
105 and scheduling requirements.

106 This research aims to develop a comprehensive list of the functionalities of integrated scheduling
107 methods in the construction industry and guide future research efforts. Eventually, the findings
108 of this paper aim to contribute to a better understanding of integrated scheduling methods'
109 functionalities in the construction industry. Furthermore, they provide new insights for project
110 managers and practitioners regarding the new management strategies, methods, and tools
111 required to enhance the effective use of planning and scheduling concepts in current
112 construction project practices. The following sections present the research methodology,
113 analyses and results, validation, research discussion, and finally, conclusions, limitations and
114 suggestions for future research and development in this domain.

115 **Research Methodology**

116 To achieve this study's objectives, the authors proceeded with a process composed of several
117 interdependent steps, as shown in Fig. 1.

118

Fig. 1. Summary of the adopted research methodology

119 The authors (1) performed a systematic review, and content analysis of the literature on
120 integrated planning and scheduling methods in the construction industry, (2) identified the aims
121 and objectives of integrating scheduling methods and defined them as integrated scheduling
122 methods' functionalities, (3) used social network analysis (SNA) to quantify the importance of
123 each of the identified functionalities and validated the results using a simple analytic technique,
124 (4) implemented Pareto chart analysis to determine the main functions of the integrated
125 scheduling methods, (5) identified the literature gaps and determined the future directions. In
126 the following subsections, the components of the research methodology are described in depth.

127 **Conducting a Systematic Literature Review**

128 The authors conducted a systematic literature review and analysis addressing the integrated
129 scheduling methods' functionalities in the construction industry. This study is systematic in the
130 sense that it adheres to a rigorous protocol that permits replication of the selected approach in
131 accordance with the guidelines for conducting systematic reviews (Kitchenham 2004; Thomé et
132 al. 2016). This review is composed of three parts: (1) data acquisition; (2) screening based on the
133 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline(Ullah
134 2021); and (3) content analysis which is mainly characterized by a quantitative literature analysis
135 using SNA. The review procedure is illustrated in Fig. 2 and detailed in the following subsections.

136

Fig. 2. Adopted systematic review procedure

137

138

139 **Data Acquisition**

140 For the review phase of this research, peer-reviewed and reputable scholarly construction and
141 manufacturing journal papers as well as conference proceedings were considered reliable sources.
142 The list of journals and conferences taken into account for this paper is shown in Table 1. The
143 Web of Science (WoS) database was selected as the search engine, and the search string was
144 determined using the combination of scheduling methods with "AND" & "OR", as shown in Table
145 2. To ensure that the essential papers were covered, backward and forward citation searching
146 were applied. Backward reference searching is finding and analyzing the sources or publications
147 referenced in an article. In contrast, forward searching focuses on the articles published after the
148 publication of an article (Gusenbauer and Haddaway 2020). As a result of these citation
149 searching, one paper matching the inclusion criteria was added to the list. The search was
150 conducted within the title, abstract and keywords. In addition, no limitations were imposed while
151 selecting the search's date range, and any entries accessible until November 2022 were reviewed.
152 The search was conducted by the first author of this research. The first data acquisition stage
153 resulted in a total of 1499 publications.

154 Table 1. List of journals and conferences

155 Table 2. Search query

156 **Screening based on PRISMA guideline**

157 The PRISMA protocol was followed during the screening stage due to broader acceptance. The
158 authors initially considered several inclusion and exclusion criteria to decrease the sample size

159 and concentrate the review on the integrated scheduling methods. The criteria for this aim are
160 provided in Table 3. Using these criteria, the sample size was decreased to 57 publications.

161 Table 3. Inclusion and exclusion criteria for screening

162 ***Content Analysis***

163 After the screening phase, 57 retrieved publications were subjected to content analysis to
164 determine the goals, objectives, and outcomes of integrated scheduling methods. In this regard,
165 First, 26 integrated scheduling methods were found relevant and valuable for this paper's
166 purpose. Second, the retrieved articles based on 26 identified integrated scheduling methods
167 were analyzed using Nvivo Qualitative Data Analysis software since this method of analysis is one
168 of the most utilized methodologies in qualitative research (Hajirasouli and Banihashemi 2020). In
169 addition, this kind of data analysis enhances the accuracy and reliability of qualitative research
170 by using both deductive and inductive strategies to find codes and themes within the data
171 (Hajirasouli et al. 2022). Three types of codes were established to extract the functionality of
172 integrated scheduling methods: 1) aims and objectives, 2) research questions, and 3) the benefits
173 of each integrated scheduling method. In the first step, 82 objectives for integrating common
174 scheduling methods were found by analyzing and coding the content of 57 finalized papers. The
175 authors of this paper reviewed identified objectives. Similar objectives were merged, such as
176 eliminating non-value-added activities and identifying and eliminating waste. Consequently, 44
177 adjectives are collected and considered as integrated scheduling methods' functionalities for
178 further analysis. The following subsections describe the procedure for analyzing the integrated
179 scheduling methods and their functionalities in detail.

180 ***Literature Quantitative Analysis***

181 After collecting the publications and conducting a content analysis, the authors identified the
182 functionality of integrated scheduling methods in the construction industry. For the purpose of
183 analyzing the highlighted functionalities, the authors created reference matrix **M**. In this matrix,
184 the rows indicate the recognized functionalities, while the columns represent the integrated
185 scheduling methods. If functionality is included in an integrated method, a value of 1 is entered
186 into the corresponding cell; otherwise, a value of 0 is inserted. Fig. 3 is an example to illustrate
187 the notion of a reference matrix. In this article, F_i is an identified functionality, and T_j is the
188 integrated scheduling method. As seen in Fig. 3, functionality F_k is described in integrated
189 scheduling methods T_j and T_j ; thus, a value of 1 is recorded in the relevant cells, but a value of 0
190 is recorded for cells below the other integrated scheduling methods. For the generated reference
191 matrix **M**, the authors performed quantitative analysis using the SNA method and validated the
192 findings with the simplified analysis technique. The following subsections give further
193 information on these two methods for analysis.

194  Fig. 3. An example of a reference matrix

195 ***Social Network Analysis***

196 ***Application of SNA in Quantitative Literature Analysis in Construction Management***

197 Recently, the network analysis method has obtained considerable interest and built outstanding
198 expertise in the knowledge extraction of the construction management fields of study (Assaad
199 and El-Adaway 2020). SNA enables academics to undertake systematic literature-related findings
200 by connecting ideas overlooked in manual review analyses (Hosseini et al. 2018). A current

201 example of SNA applications in the quantitative literature analysis in the construction
202 management field is the research of (Elsayegh and El-adaway 2021), who studied the factors
203 affecting collaborative planning in the construction industry. Another example is the study of
204 Abdul Nabi and El-adaway (2020), who analyzed a detailed set of decision-making factors and
205 determined future research requirements for modular construction. In addition, Abdul Nabi and
206 El-adaway (2022) utilized SNA for quantitative analysis of the most frequent sources of disputes
207 and their interactions in modular construction projects (Abdul Nabi and El-adaway 2022). Other
208 instances comprise research conducted on construction business failure factors (Assaad and El-
209 Adaway 2020), critical review of off-site construction studies (Hosseini et al. 2018), application of
210 cognitive science focusing on electroencephalography in construction (Saedi et al. 2022), and a
211 study of the literature on the use of dynamic modeling in construction management systems to
212 achieve a holistic view of the direct and indirect effects of various project parameters (Abotaleb
213 and El-adaway 2018).

214 ***Justifications for SNA Selection***

215 Meanwhile, several methods have been suggested for extracting relevant characteristics, factors,
216 features, attributes and functionalities from accessible previous research findings. Existing
217 methods for identifying factors in the literature rely on qualitative assessments, while SNA
218 emphasizes a quantitative approach. To do this, SNA was used because of its (1) quantitative
219 strength, (2) capability to examine the interrelationships among the various factors (Elsayegh and
220 El-adaway 2021), (3) value in comparing the relative importance of the factors, and (4) value in
221 identifying understudied domains that could benefit from further research (Assaad and El-
222 Adaway 2020). The primary objective of this study is to determine the essential functionalities

223 utilized in integrated scheduling methods by analyzing their interdependence. The authors
224 ultimately selected SNA as the best approach to find the most prevalent functionalities leading
225 to integrated scheduling methods in construction projects.

226 ***Developing the Social Network***

227 SNA was utilized to discover knowledge gaps and determine factors' importance in many
228 applications and domains (Abdul Nabi and El-adaway 2020). In this study, the same methodology
229 is applied to understand the functionality of integrated scheduling methods. To do this, The
230 authors sought a metric that can quantify the importance of integrated scheduling methods'
231 functionalities based on their frequency of integration and co-occurrences with other
232 functionalities. Consequently, the Degree Centrality (DC) was used since it reflects the number
233 of instances in which it happened in combination with other functionality in the same integrated
234 scheduling method (Freeman 1980). Computing the DC of SNA nodes implies creating a weighted
235 adjacency matrix (WAM) for the network under study.

236 Therefore, the authors developed a WAM for network **M**, constructed during the functionalities'
237 analysis (**M**_{44×26}). Multiplying the reference matrix **M** by its transpose and then eliminating and
238 replacing the values in the diagonal cells of the resultant matrix with zeros generates a WAM.
239 The WAM is a matrix representation of a network in which (1) the matrix columns and rows
240 represent n nodes representing the functionality of integrated scheduling methods and (2) the
241 matrix records represent a set of edge weights which correspond to the strength of the
242 connection between each pair of functionalities. This matrix is calculated using Equation (1).

$$243 \quad WAM_{f \times f} = \begin{cases} M_{f \times t} \times M_{f \times t}^T & \text{for } k \neq j \\ 0 & \text{for } k = j \end{cases} \quad (1)$$

244 where $WAM_{f \times f}$ = weighted adjacency matrix; $M_{f \times t}$ = reference matrix; $M_{f \times t}^T$ = transpose of the
 245 reference matrix; f = number of identified functionalities(i.e., 44); and t = number of integrated
 246 scheduling methods (i.e., 26). Fig. 4 and Fig. 5 show an example of creating and visualizing a WAM
 247 for a reference matrix with four integrated methods and four functionalities. Fig. 4 illustrates
 248 how the adjacency matrix is developed, while Fig. 5 presents a visual representation of the
 249 references and adjacency matrix. As can be seen in the reference matrix, for instance, the
 250 functionality F1 and F4 are addressed in integrated method 1. Therefore, these functionalities
 251 are linked by an edge when a diagram of this integrated method is created. An adjacency matrix
 252 is used to depict a single network for the reference matrix rather than a network for each
 253 functionality in the reference matrix. The adjacency matrix shows the interconnections between
 254 the functionalities. It demonstrates that F1 is referenced simultaneously with F4 twice and F2
 255 simultaneously with F3 once. The adjacency matrix's calculated values, also referred to as the
 256 link strength, indicate how directly connected the functionalities are to one another.

257 Fig. 4. An illustration of an adjacency matrix

258 Fig. 5. Visual representation of reference and adjacency matrix

259
 260 After developing the WAM, The DC for each functionality of integrated scheduling methods is
 261 calculated based on Equation 2.

$$262 \quad DC_k = \sum_{j; j \neq k} M_{k,j} \quad (2)$$

263 Where DC_k indicates the degree centrality for functionality k and $M_{k,j}$ is the cell's value in row k
 264 and column j of the investigated adjacency matrix. Moreover, as the calculated DC depends on
 265 the relevant network's size, the authors decided to normalize it. As shown in Equation3., the

266 normalized DC of a functionality k in a network is simply the DC of the evaluated functionality
267 divided by the highest DC in the studied network.

$$268 \quad \overline{DC}_k = \frac{DC_k}{\max\{DC_k\}} \quad (3)$$

269 Thus, the normalized DC_k range from 0 to 1 for all functionalities.

270 ***Validation Method: Simplified Analysis***

271 The simplified analysis was considered in the research of Elsayegh and El-adaway (2021) for
272 validation of SNA results. In this research, the same approach was carried out to verify the SNA
273 and assess whether or not it is working as expected. In this method, a score for each identified
274 functionality is calculated by summing up all the cells in the row that belong to that functionality
275 using Equation 4. For instance, a score of 11 for a functionality F15 in matrix **M** indicates that this
276 functionality is addressed in 15 integrated scheduling methods.

$$277 \quad Score_k = \sum_{z=1}^{26} M_{k,z} \quad (4)$$

278 where $Score_k$ is the frequency of referencing functionality k, $M_{k,z}$ is the cell's value in the
279 reference matrix (either 0 or 1) that corresponds to functionality k and the integrated scheduling
280 method z. Similar to SNA normalization according to Equation 5, functionalities are assigned a
281 normalized score in the simplified analysis method. Therefore, the normalized score varies from
282 0 to 1 for each functionality in the reference matrix.

$$283 \quad \overline{Score}_k = \frac{Score_k}{\max\{Score_k\}} \quad (5)$$

284

285

286 ***Pareto Chart Analysis***

287 After analyzing the functionality of integrated scheduling methods in the construction project
288 using the SNA approach, a statistical analysis using Pareto diagrams was conducted to determine
289 the most important functionalities of integrating scheduling methods. The Pareto chart is a
290 commonly adopted approach primarily used to identify the most significant issues and assist
291 management and decision-makers in decision-making (Moktadir et al. 2021). A Pareto chart
292 comprises both a bar graph and a line graph. The bar in this study displayed analyzed
293 functionalities using SNA, and the line reflects the cumulative percentage of the occurrence of
294 the functionalities. When there are a significant number of functions to be evaluated, such as in
295 this research, the benefit of employing Pareto chart analysis is that it helps emphasize the most
296 significant ones. Second, the diagrammatic depiction is straightforward to comprehend and
297 allows researchers to concentrate on the few most critical functionalities by directly displaying
298 their degree of influence (Viles et al. 2019). Thus, Pareto chart analysis was implemented to
299 understand the essential functionalities of integrated scheduling methods.

300 **Results and Analysis**

301 ***Data Collection Efforts***

302 As described in the methodology, the authors used a systematic approach based on search
303 queries to extract journal and conference publications relating to integrated scheduling methods
304 in the construction industry. This meta-analysis search and screening efforts retrieved 57 journal
305 and conference articles are shown in Table 4 and were approved for further analysis. Table 4
306 reveals the published papers in three decades and shows that most publications were carried out

307 after 2013. This highlights that current research efforts in this domain have focused on
308 integrating scheduling methods. The shortcomings of scheduling methods, such as ignoring
309 uncertainties in some methods (Al Nasser et al. 2016), inadequate management of daily activities
310 (Olivieri et al. 2016), lack of integration between different levels of the schedule plan (Dave et al.
311 2016), lack of supply chain integration (Aslam et al. 2020), lack of consideration to all flows (Aslam
312 et al. 2020), high effort and investment requirements to produce a sufficiently detailed 4D model
313 (Ortenburger and Hartmann 2021) and the popularity of off-site construction (Salama et al. 2021)
314 have increased interests on integrated scheduling methods (POLIANI 2020).

315 Table 4. Full-text reviewed articles

316 Fig. 6 more clearly depicts the distribution of the papers across the years of the research period.
317 The number of papers addressing integrated scheduling methods in the construction industry has
318 been on a trend since 2014 and reached its peak in 2021.

319 Fig. 6. Distribution of the papers across the years

320 ***Integrated Scheduling Methods and their Functionalities in the Construction Industry***

321 By analyzing the content of the publications in Table 4, the authors identified 26 integrated
322 scheduling methods and 44 scheduling methods' functionalities listed in Table 5 and Table 6. The
323 26 identified integrated scheduling methods were developed by combining 14 common
324 scheduling methods and lean principles illustrated in a Sankey diagram in Fig. 7. Also, Fig. 8 clearly
325 indicates the distribution of utilized common scheduling methods in integrated scheduling
326 methods. As it can be seen, the Last Planner System (LPS), Building Information Modeling (BIM),
327 Simulation Modeling (SM) and Location-based Management System (LBMS) have been

328 considered the most with 24%, 16%, 13% and 9%, respectively. Furthermore, BIM-LPS was the
329 most used integrated scheduling method in the literature. Notably, although 4D is one of the BIM
330 applications, some researchers have just utilized it as a visual representation tool. Thus, the
331 authors distinguish between 4D, and BIM approaches in project scheduling.

332 Moreover, Fig. 9, matrix **M**, represents the mapping between the identified project scheduling
333 methods' functionalities and the analyzed integrated scheduling methods based on the
334 literature. A red-colored cell indicates that the respective integrated scheduling methods have
335 addressed the functionalities. As can be seen, the integrated scheduling methods, including BIM-
336 LPS, BIM-LPS-Kanban, LBMS-LPS-CPM and BIM-LPS-SM, have the most combination of
337 functionalities in their structure. Furthermore, F1(improving the reliability of the planning),
338 F39(increasing transparency), F15(improving managerial practices), and F19 (managing
339 uncertainties) are the most utilized functionalities in the integrated scheduling methods.

340 Table 5. Identified integrated scheduling methods

341 Table 6. Scheduling methods' functionalities

342 Fig. 7. Sankey diagram of integrated scheduling methods

343 Fig. 8. Distribution of utilized common scheduling methods in integrated scheduling methods

344 Fig. 9. Mapping between the identified functionalities and analyzed integrated scheduling methods

345 As mentioned earlier, several papers integrated common scheduling methods to address the
346 challenges of low construction productivity resulting from inefficient planning and scheduling.

347 Some investigations were conducted at the level of the conceptual framework, and implementing
348 a case study for validation. In addition to the conceptual model and case study, some have

349 developed tools, software, or decision support systems (DSS) for practical deployment in the
350 construction industry. Analyzing the various abstraction levels of common scheduling methods
351 utilized in integrated ones from a conceptual framework to implementation can be advantageous
352 in two dimensions. On the one hand, having information about methods with conceptual models
353 and promoting them into practical tools and software may substantially aid researchers in
354 selecting future research directions. On the other hand, it can help the industry to adopt more
355 practical methods for project scheduling and planning. To do this, the final articles considered for
356 content analysis were classified as follows:

357 Class 1 (C1): These articles give either a conceptual framework, a case study implementation, or
358 a mix of both. The study conducted by Abdelmegid et al. (2021) is regarded as class 1 since it
359 addressed the connections between simulation modelling and construction production planning
360 and control by developing a conceptual framework and putting it to the validation in a case study.

361 Class 2 (C2): These papers concentrate on developing a model/tools/ Decision Support
362 System(DSS) or integrating existing tools and software solutions combined with a conceptual
363 framework or case study implementation. The research project by Heigermoser et al. (2019) is
364 categorized as class 2 since it developed a BIM-based Last Planner System tool for construction
365 management throughout the construction phase.

366 After classifying the papers into two classes, 26 integrated scheduling methods were studied
367 within each class, and the number of papers associated with each integrated method was
368 determined. The number of articles that addressed each common scheduling method in
369 integrated methods was used to calculate the normalized score for each common scheduling

370 method within each class. Fig. 10 displays the findings of the analysis's common scheduling
371 methods used in each class based on differences between class 2 and class 1 (C2-C1). For each
372 method, a positive value in Fig. 10 shows that it is used more often in class 2 research, which is
373 primarily concerned with creating a model, tool, or decision-support tool for integrating the
374 common scheduling methods.

375 In contrast, a negative score indicates that the scheduling method is used more in class 1 with an
376 emphasis on conceptual model development. As can be seen, BIM and Simulation Methods (SM)
377 are considered more in conceptual framework-based studies. The applications of Takt time
378 planning (TTP), Last Planner System (LPS), and Location-based Management System (LBMS) in
379 integrated scheduling methods are almost identical for both classes. Moreover, Critical Chain
380 Project Management (CCPM) and Linear Scheduling Methods (LSM) are used more in studies
381 focusing on developing tools/models and decision-support systems or integrating existing tools
382 and software solutions. This finding may be due to the fact that, even though BIM and SM have
383 received a great deal of attention in recent years in scientific studies, the maturity and readiness
384 of construction companies to use these technologies, particularly during the construction phase,
385 is still low. Therefore, researchers who have concentrated more on the practical aspects of
386 scheduling methods have paid less attention to BIM and SM and given more emphasis to
387 conventional methods such as CCPM, LSM, and CPM.

388 Fig. 10. Derived differences in the scores of C1 and C2 studies for common scheduling methods

389
390
391

392 ***Quantitative Analysis of the Integrated Scheduling Methods' Functionalities***

393 After reviewing the publications listed in Table 3 and finding the integrated scheduling methods'
394 functionalities, the authors developed a reference matrix **M** based on the identified
395 functionalities and integrated scheduling methods based on the described detail in the
396 methodology. The reference matrix **M** has a dimension of 44 by 26 and comprises 26 integrated
397 scheduling methods and 44 functionalities. The following subsections provide a detailed
398 explanation of the findings.

399 ***Social Network Analysis***

400 After evaluating the acquired data and developing the reference matrix **M_{44×26}**, the authors
401 produced the weighted adjacency matrix **WAM_{44×44}** to calculate the DCs of the indicated
402 functionalities. The DCs measure, as was previously mentioned, highlights the value of a given
403 functionality by emphasizing its frequency and mention alongside other functionality in
404 integrated scheduling methods. The functionalities network shown in Fig. 11 consists of 44 nodes
405 (representing 44 integrated scheduling methods' functionalities) and 1248 corresponding edges.
406 The network's nodes represent the functionality, while the edges reflect the interconnection or
407 co-occurrence between each pair of functionalities. The node's radial location is inversely
408 proportional to the normalized DC of the respective functionality. In other words, when the node
409 moves closer to the center, the normalized DC of this functionality increases compared to other
410 nodes that are farther from the center. The color difference of the nodes is proportional to the
411 calculated normalized DC of each functionality in terms of radial position. Another way of putting
412 it, red, orange, and yellow nodes are linked with greater DC values than nodes of other colors.

413 Clearly, the network has a significant number of nodes and connections. As a result, a color-coded
414 matrix was provided in Fig. 12 to illustrate the degree of connectivity between nodes. Both rows
415 and columns of the matrix represent the functionality of integrated planning methods.

416 The matrix is color-coded according to the intensity of the link between any two functionalities.
417 As shown in Fig.12, the white-colored cells for a pair of functionalities imply that they have never
418 co-occurred in any of the studied integrated scheduling methods. On the other hand, some pairs
419 of functionalities contain dark purple cells, suggesting high weights and, thereby, a high
420 frequency of co-occurrence in the integrated scheduling methods. An example of the former
421 would be F3 (considering the continuous flow of work) and F44 (applying creativity techniques
422 to planning and scheduling). The latter is represented in the weights of edges between F1
423 (improving the reliability of the planning) and F39 (increasing transparency).

424 The functionalities can be discussed from two points of view: (1) the functionalities that have
425 been applied the most in the integrated scheduling methods and (2) the functionalities that have
426 received the least attention in the integrated scheduling methods.

427 Concerning the first perspective, Fig. 11 shows that F1 (improving the reliability of the planning),
428 F39 (increasing transparency), F11 (identifying and eliminating wastes), and F3 (considering the
429 continuous flow of work) are the most often used functionalities of integrated scheduling
430 methods in combination with other functionalities in construction projects. As also seen in Fig. 9,
431 F15 (improving managerial practices) and F19 (managing uncertainties) have been among the top
432 four used functionalities in integrated scheduling methods. Nevertheless, according to SNA
433 analysis, F11 (identifying and eliminating wastes) and F3 (considering the continuous flow of

434 work) have gotten the most DC, showing greater interconnectivity with other functionalities.
435 Here, the significance of SNA analysis in this study is fully acknowledged. Considering the multi-
436 functional nature of integrated scheduling methods, it can be claimed that functionalities that
437 interact more with other functionalities are more valuable in these methods. Since, as previously
438 indicated, the primary objective of integrated scheduling methods is to combine the
439 functionalities of conventional scheduling methods to compensate for their deficiencies,
440 assessing the combination of functionalities employed in integrated scheduling methods
441 conducted in this research is necessary. Regarding the combination analysis of functionalities,
442 according to Fig. 12, the combination of F1 (improving the reliability of the planning) and F39
443 (increasing transparency), F3 (considering the continuous flow of work) and F4 (decreasing
444 workflow variability), F15 (improving managerial practices) and F4 (decreasing workflow
445 variability), F14 (detecting and solving spatiotemporal conflicts) and F40 (enabling the
446 coordination of the look-ahead plans), and F27 (applying analytical method) and F15 (improving
447 managerial practices) have been utilized the most in integrated scheduling methods.

448 Following the second perspective, Fig. 11 illustrates that F30 (eliminating the root causes of
449 variability), F38 (increasing safety on construction sites), F24 (scheduling of modular and offsite
450 construction), and F31 (integrating offsite and onsite planning for modular and offsite
451 construction) have earned the least consideration in the integrated scheduling methods.

452 Fig. 11. Functionalities network

453 Fig. 12. Color-coded matrix of functionalities

454

455 ***Pareto Analysis of Main Functionalities***

456 For the Pareto analysis, the score for each functionality was calculated using SNA, and after that,
457 the cumulative percentage was derived. 43% of the forty-four functionalities are employed in
458 80% of integrated scheduling methods, as illustrated by the Pareto chart in Fig. 13. As shown in
459 Figure 9, integrated scheduling methods and even conventional scheduling methods (CPM, LPS,
460 LBMS, and so on) are multi-functional. In addition, the construction industry's multi-
461 organizational nature and its complexities and uncertainties have led to using a combination of
462 functionalities in project scheduling. This argument may explain why the proportion of crucial
463 functionalities exceeds the Pareto principle (80/20).

464 F1(improving the reliability of the planning), F39 (increasing transparency), F11 (identifying and
465 eliminating wastes), F3 (considering the continuous flow of work), F14 (detecting and solving
466 spatiotemporal conflicts), F15 (improving managerial practices), F4 (decreasing workflow
467 variability), F40 (enabling the coordination of the look-ahead plans), F28 (supporting human
468 decision making), F10 (increasing teamwork, and communication between all stakeholders), F5
469 (Analyzing constraints more effectively), F7(visualizing of the schedules to understand and
470 communicate content to a variety of stakeholders), F16(considering the supply chain instability),
471 F18(understanding of the subprocesses more accurately), and F33 (linking the supply chain and
472 construction process) are considered in 60% of integrated scheduling methods.

473 Fig. 13. Pareto Analysis of Functionalities

474

475

476

477 **Validation**

478 This study used a simplified analysis to verify the SNA values. After analyzing the normalized DC
479 values for the functionalities outlined in the methodology, the authors calculated the normalized
480 scores using simplified analysis to compare the findings of these two approaches. The differences
481 in normalized scores between the SNA and the simplified analysis are shown in Fig. 14. The results
482 indicate that the simplified analysis outputs are comparable to those of the SNA. The slight
483 deviations between the outcomes of the two kinds of analysis may be explained by the fact that
484 the SNA employs more sophisticated criteria to examine the interrelationships and
485 interdependencies between the various functionalities (Elsayegh and El-adaway 2021). On the
486 contrary, the simplified analysis is calculated mainly on the simple frequency of the co-
487 occurrence of functionalities in the analyzed integrated scheduling methods. In Table 7,
488 Spearman correlation, variance, and standard deviation have been applied to examine the
489 relationship between these two approaches' outcomes and validate the SNA values. Given the
490 fundamental features of the two investigations and the statistical test results, the differences are
491 thus deemed acceptable. Accordingly, the findings shown in Table 7 demonstrate that the SNA is
492 acting as anticipated. For a thorough validation of the results, however, the authors suggest that
493 future research investigates the interactions between the 44 functionalities using real case
494 studies or experts' points of view.

495 Table 7. Statistical test results on the simplified analysis and SNA

496 Fig. 14. Comparison results between simplified analysis and SNA

497

498 **Discussions of the Research Findings**

499 Using the insights from the literature analysis of this study, this section describes in-depth
500 discussions of the main findings of this article in light of the recognized integrated scheduling
501 methods' functionalities. This is conducted by highlighting areas where the extensive focus has
502 previously been received, as well as those that have paid the least attention to lead the future
503 directions.

504 This study identified and analyzed the integrated scheduling methods' functionalities to the
505 project team can choose the project scheduling method according to the needs and
506 characteristics of the project with a better understanding. Functionalities were considered due
507 to the insufficient understanding and awareness of project scheduling theories and methods on
508 behalf of project stakeholders and participants (AlNasseri and Aulin 2015). This implies that these
509 methods address a broader range of project planning, scheduling, and control issues. Between
510 identified integrated scheduling methods, BIM-LPS, BIM-LPS-Kanban, LBMS-LPS-CPM and BIM-
511 LPS-SM have utilized the most combination of functionalities. The combination of common
512 scheduling methods with BIM demonstrates the attention of researchers and the industry to the
513 use of semantic information of BIM models as well as its visualization capability in the form of 4D
514 modeling to improve communication between stakeholders in the project. Furthermore, the last
515 planner system is employed more often, according to the distribution of common scheduling
516 methods in integrated scheduling methods.

517 Although simulation methods are not practical project scheduling methods, different types of it
518 (such as System Dynamic (SD), Discrete Event Simulation (DES), Agent-based Modeling (ABM)

519 and Monte Carlo) have contributed several functions to common scheduling methods, including
520 uncertainty modeling (Alhussein et al. 2022; Himmiche et al. 2018; Tokdemir et al. 2019),
521 applying creativity techniques to planning and scheduling (Abdelmegid et al. 2019; Abdelmegid
522 et al. 2021), understanding the behaviour of the performance indicators (Shehab et al. 2020) and
523 scenario analysis (König 2011).

524 The results of the network analysis indicated that F1 (improving the reliability of the planning),
525 F39 (increasing transparency), F11 (identifying and eliminating wastes), and F3 (considering the
526 continuous flow of work) are the most often used functionalities of integrated scheduling
527 methods in combination with other functionalities in construction projects. These findings
528 significantly emphasize lean construction principles, such as planning reliability, transparency,
529 waste elimination, and continuous workflow in integrated scheduling methods. In other words,
530 these methods have integrated lean thinking into the planning and control process. Therefore,
531 lean planners must address the planning and control process before the project execution
532 process. In addition, these functionalities are remarkable for enhancing medium-term and short-
533 term planning (Emdanat and Azambuja 2016; Soman and Molina-Solana 2022; Tezel et al. 2020),
534 indicating that integrated scheduling methods pay greater attention to these two planning levels.
535 Integrated methods that have included CPM in their structure have emphasized long-term
536 planning and management. Hence, despite the efforts of academics to compensate for the
537 shortcomings of common scheduling methods by using integrated scheduling methods, there is
538 still a research gap between the alignment of short-term and long-term planning (Amer et al.
539 2021; Emdanat and Azambuja 2016; Tezel et al. 2020).

540 Regarding the combination analysis of integrated scheduling methods' functionalities, the
541 combination of F1 (improving the reliability of the planning) and F39 (increasing transparency),
542 F3 (considering the continuous flow of work) and F4 (decreasing workflow variability), F15
543 (improving managerial practices) and F4 (decreasing workflow variability), F14 (detecting and
544 solving spatiotemporal conflicts) and F40 (enabling the coordination of the look-ahead plans),
545 and F27 (applying analytical method) and F15 (improving managerial practices) have been
546 considered the most in integrated scheduling methods. These analyses demonstrate that
547 integrated scheduling methods are developed to address the aforementioned concerns
548 regarding low productivity caused by inefficient construction planning and scheduling. In
549 addition, they will be able to manage the whole scheduling process, including long-term,
550 medium-term, and short-term planning.

551 The SNA analysis shows that little attention had been paid to the required functionalities in the
552 scheduling methods for offsite construction. This issue can be concluded from the lack of
553 consideration given to F24 (scheduling of modular and offsite construction) and F31 (integrating
554 offsite and onsite planning for modular and offsite construction). Although there have been
555 advances in industrialization and offsite construction in the industry and academic studies, more
556 attention should be paid to scheduling methods and the associated functionalities of integrated
557 scheduling methods.

558 Following the results in Figures 7 and 8, the last planner system has gained the most attention
559 among integrated scheduling methods. Several integrated scheduling technologies, such as LPS-
560 BIM and LPS-CPM-LBMS, have attempted to account for the shortcomings of the last planner
561 system, which included inadequate visualization capabilities (Aslam et al. 2020) and a lack of

562 involvement in the management of construction delays, changes, and contracts (Olivieri et al.
563 2019). However, Integrated scheduling methods have paid little attention to one of the LPS' key
564 drawbacks, namely the nonperformance of root cause analysis and corrective actions (Aslam et
565 al. 2020). This finding is evident from the network in Fig. 11, which demonstrates that F30
566 (eliminating the root causes of variability) had the lowest DC between integrated scheduling
567 methods' functionalities. This functionality is only considered in LPS-SS integrated methods.
568 Consequently, there is a need for further study in this area.

569 **Conclusion, Limitations, and Future Directions**

570 Understanding the functionality of integrated scheduling methods in the construction industry is
571 necessary for selecting the most appropriate planning and scheduling approach based on the
572 required project's goals and objectives. As such, this research conducted a multi-step
573 methodology to collect and analyze 26 integrated scheduling methods and 44 associated
574 functionalities using SNA. Accordingly, 14 common scheduling methods and lean principles were
575 included to create 26 identified integrated scheduling methods. The Last Planner System (LPS),
576 Building Information Modeling (BIM), Simulation Modeling (SM) and Location-based
577 Management System (LBMS) are utilized , as common scheduling methods, more often in
578 integrated scheduling methods. Moreover, It has been demonstrated, as well, that studies
579 focusing on the practical application of scheduling methods have tended to emphasize traditional
580 methods such as CCPM, LSM, and CPM while focusing less on BIM and SM. Regarding the
581 integrated scheduling methods, BIM-LPS, BIM-LPS-Kanban, LBMS-LPS-CPM, and BIM-LPS-SM
582 have used the highest combination of functionalities. Also, the findings revealed that F1
583 (improving planning reliability), F39 (increasing transparency), F11 (identifying and eliminating

584 wastes), and F3 (considering the continuous flow of work) are the main functionalities employed
585 in integrated scheduling methods. These results also underline the importance of lean
586 construction principles, such as planning reliability, transparency, waste elimination, and
587 continuous workflow in integrated scheduling techniques. In contrast, the findings indicate that
588 integrated scheduling methods need to pay more attention to one of the LPS's significant flaws,
589 non-performance of root cause analysis and corrective actions. Furthermore, although offsite
590 and modular construction is receiving a great deal of attention in practice and academia, more
591 focus should be given to the required functionalities of the scheduling methods for offsite
592 construction.

593 Another finding illustrates several combinations of functionalities have been considered most
594 often. These include F1 (improving the reliability of the planning) and F39 (increasing
595 transparency), F3 (considering the continuous flow of work) and F4 (decreasing workflow
596 variability), F15 (improving managerial practices) and F4 (decreasing workflow variability), F14
597 (detecting and solving spatiotemporal conflicts) and F40 (enabling the coordination of the look-
598 ahead plans), and F27 (applying analytical method) and F15 (improving managerial practices).
599 These results indicate that integrated scheduling methods can handle the requirement of multi-
600 levels of schedule plan, including long-term, medium-term, and short-term planning. Moreover,
601 the pareto chart analysis applied to determine the most important functionalities in integrated
602 scheduling methods. 80% of integrated scheduling methods utilize 43% of the forty-four
603 functionalities. To validate the SNA method's findings, a simplified analysis approach is used. The
604 spearman correlation, variance, and standard deviation results reveal that minor differences
605 between the two approaches are acceptable.

606 Ultimately, this research contributes to the body of knowledge by providing a better
607 understanding the integrated scheduling methods' functionalities in the construction sector.

608 One of the limitations of this article is that the analyses were conducted solely based on the
609 literature review; however, given the practical aspect of project planning and scheduling, it is
610 crucial to consider experts' opinions for a more effective and comprehensive analysis. In this
611 regard, Future research should focus on studying the understanding of scheduling methods in
612 light of the perspectives of experts. In addition, Due to a large number of identified functionalities
613 and some conceptual overlap between them, their clustering and sorting out according to
614 underlying concepts and taking expert opinion into account could be another future direction.

615 **Data Availability Statement**

616 All data and code generated or used during the study appear in the published article.

617 **Acknowledgements**

618 This study was conducted at the Nancy Automation Research Center (CRAN) laboratory through
619 the financial support provided by the National Research Agency of France (ANR-20-CE10-0011)
620 for the ISoBIM project.

621 **References**

- 622 Abbasi, S., Taghizade, K., and Noorzai, E. (2020). "BIM-based combination of takt time and discrete event
623 simulation for implementing just in time in construction scheduling under constraints." *Journal of*
624 *construction engineering and management*, 146(12), 04020143.
- 625 Abdelmegid, M. A., González, V. A., O'Sullivan, M., Walker, C. G., Poshdar, M., and Alarcón, L. F.
626 "Establishing a link between the last planner system and simulation: a conceptual framework."
627 *Proc., 27th Annual Conference of the International Group for Lean Construction (IGLC)*, 335-246.
- 628 Abdelmegid, M. A., González, V. A., O'Sullivan, M., Walker, C. G., Poshdar, M., and Alarcón, L. F. (2021).
629 "Exploring the links between simulation modelling and construction production planning and
630 control: a case study on the last planner system." *Production Planning & Control*, 1-18.

631 Abdul Nabi, M., and El-adaway, I. H. (2020). "Modular construction: Determining decision-making factors
632 and future research needs." *Journal of management in engineering*, 36(6), 04020085.

633 Abdul Nabi, M., and El-adaway, I. H. (2022). "Understanding Disputes in Modular Construction Projects:
634 Key Common Causes and Their Associations." *Journal of Construction Engineering and
635 Management*, 148(1), 04021184.

636 Abotaleb, I. S., and El-adaway, I. H. (2018). "Managing construction projects through dynamic modeling:
637 Reviewing the existing body of knowledge and deriving future research directions." *Journal of
638 management in engineering*, 34(6), 04018033.

639 Al Hussein, Z. K. (2016). "Using Building Information Modeling (BIM) and the Last Planner System (LPS) to
640 Reduce Construction Process Delay." Masters Thesis, Western Kentucky University.

641 Ajweh, Z. (2014). "A framework for design of panelized wood framing prefabrication utilizing multi-panels
642 and crew balancing." Master of Science, University of Alberta.

643 Al Nasser, H. A., Widen, K., and Aulin, R. (2016). "A taxonomy of planning and scheduling methods to
644 support their more efficient use in construction project management." *Journal of Engineering,
645 Design and Technology*.

646 Alhussein, H., Shehab, L., and Hamzeh, F. (2022). "Improvisation in Construction Planning: An Agent-Based
647 Simulation Approach." *Buildings*, 12(10), 1608.

648 AlNasser, H., and Aulin, R. (2015). "Assessing understanding of planning and scheduling theory and
649 practice on construction projects." *Engineering Management Journal*, 27(2), 58-72.

650 AlNasser, H. A. (2015). *Understanding applications of project planning and scheduling in construction
651 projects*, Department of Construction Sciences, Lund University.

652 Amer, F., Jung, Y., and Golparvar-Fard, M. (2021). "Transformer machine learning language model for
653 auto-alignment of long-term and short-term plans in construction." *Automation in Construction*,
654 132, 103929.

655 Ammar, M. A. (2013). "LOB and CPM integrated method for scheduling repetitive projects." *Journal of
656 construction engineering and management*, 139(1).

657 Andújar-Montoya, M. D., Galiano-Garrigós, A., Echarri-Iribarren, V., and Rizo-Maestre, C. (2020). "BIM-
658 LEAN as a Methodology to Save Execution Costs in Building Construction—An Experience under
659 the Spanish Framework." *Applied Sciences*, 10(6), 1913.

660 Ansari, R., Khalilzadeh, M., and Hosseini, M. R. (2022). "A Multi-objective Dynamic Optimization Approach
661 to Project Schedule Management: A Case Study of a Gas Field Construction." *KSCE Journal of Civil
662 Engineering*, 26(3), 1005-1013.

663 Antill, J. M., and Woodhead, R. W. (1991). *Critical path methods in construction practice*, John Wiley &
664 Sons.

665 Arditi, D., and Albulak, M. Z. (1986). "Line-of-balance scheduling in pavement construction." *Journal of
666 Construction Engineering and Management*, 112(3), 411-424.

667 Ashcraft, H. (2022). "Transforming project delivery: integrated project delivery." *Oxford Review of
668 Economic Policy*, 38(2), 369-384.

669 Aslam, M., Gao, Z., and Smith, G. (2020). "Development of innovative integrated last planner system
670 (ILPS)." *International Journal of Civil Engineering*, 18(6), 701-715.

671 Assaad, R., and El-Adaway, I. H. (2020). "Enhancing the knowledge of construction business failure: A social
672 network analysis approach." *Journal of construction engineering and management*, 146(6),
673 04020052.

674 Ballard, G., and Tommelein, I. (2016). "Current process benchmark for the last planner system." *Lean
675 Construction Journal*, 89, 57-89.

676 Barkokebas, B., Khalife, S., Al-Hussein, M., and Hamzeh, F. (2021). "A BIM-lean framework for digitalisation
677 of premanufacturing phases in offsite construction." *Engineering, Construction and Architectural
678 Management*, 28(8), 2155-2175.

679 Bhatla, A., and Leite, F. "Integration framework of bim with the last planner systemtm." *Proc., IGLC 2012-*
680 *20th Conference of the International Group for Lean Construction.*

681 Botton, C., Pitti, Y., Forgues, D., and Iordanova, I. (2021). "Investigating the challenges related to combining
682 BIM and Last Planner System on construction sites." *Frontiers of Engineering Management*, 8(2),
683 172-182.

684 Büchmann-Slorup, R. (2014). "Applying critical chain buffer management theory in location-based
685 management." *Construction management and economics*, 32(6), 506-519.

686 Burguete, M. G. (2018). "Project optimization through the combination of BIM and last planner system."
687 Aalborg University.

688 Dave, B., Seppänen, O., and Modrich, R.-U. "Modeling information flows between last planner and
689 location based management system." *Proc., Proceedings of the 24th Annual Conference of the*
690 *International Group for Lean Construction, Boston, EE. UU.*

691 Elsayegh, A., and El-adaway, I. H. (2021). "Holistic study and analysis of factors affecting collaborative
692 planning in construction." *Journal of Construction Engineering and Management*, 147(4),
693 04021023.

694 Emdanat, S., and Azambuja, M. (2016). "Aligning near and Long Term Planning for LPS implementations:
695 a review of existing and new metrics." *Lean Construction Journal*, 101, 90-101.

696 Etges, B. M., Reck, R. H., Fireman, M. T., Rodrigues, J. L., and Isatto, E. L. (2020). "USING BIM WITH THE
697 LAST PLANNER® SYSTEM TO IMPROVE CONSTRAINTS ANALYSIS." *28th Annual Conference of the*
698 *International Group for Lean Construction (IGLC28)*Berkeley, California.

699 Frandson, A. (2019). "Takt time planning as a work structuring method to improve construction work
700 flow." University of California, Berkeley.

701 Frandson, A., Berghede, K., and Tommelein, I. D. "Takt time planning for construction of exterior cladding."
702 *Proc., 21st Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil,*
703 *Citeseer*, 21-22.

704 Freeman, L. C. (1980). "A Set of Measures of Centrality Based on Betweenness." *Sociometry* 40: 35-41.
705 1979." *Centrality in Social Networks: Conceptual Clarification.*" *Social Networks*, 1, 215-239.

706 Gusenbauer, M., and Haddaway, N. R. (2020). "Which academic search systems are suitable for systematic
707 reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other
708 resources." *Research synthesis methods*, 11(2), 181-217.

709 Hajirasouli, A., and Banihashemi, S. (2020). "The Unfolding Tragedy of Kandovan: The Loss of the last
710 inhabited cone-shaped settlement in the world." *Habitat International*, 102, 102211.

711 Hajirasouli, A., Banihashemi, S., Drogemuller, R., Fazeli, A., and Mohandes, S. R. (2022). "Augmented
712 reality in design and construction: thematic analysis and conceptual frameworks." *Construction*
713 *Innovation*(ahead-of-print).

714 Hamzeh, F. R., Saab, I., Tommelein, I. D., and Ballard, G. (2015). "Understanding the role of "tasks
715 anticipated" in lookahead planning through simulation." *Automation in Construction*, 49, 18-26.

716 Hamzeh, F. R., Zankoul, E., and Rouhana, C. (2015). "How can 'tasks made ready'during lookahead
717 planning impact reliable workflow and project duration?" *Construction management and*
718 *economics*, 33(4), 243-258.

719 Heigermoser, D., de Soto, B. G., Abbott, E. L. S., and Chua, D. K. H. (2019). "BIM-based Last Planner System
720 tool for improving construction project management." *Automation in Construction*, 104, 246-254.

721 Himmiche, S., Aubry, A., Marangé, P., DufLOT-Kremer, M., and Pétin, J.-F. (2018). "Using statistical-model-
722 checking-based simulation for evaluating the robustness of a production schedule." *Service*
723 *Orientation in Holonic and Multi-Agent Manufacturing*, Springer, 345-357.

724 Hosseini, M. R., Martek, I., Zavadskas, E. K., Aibinu, A. A., Arashpour, M., and Chileshe, N. (2018). "Critical
725 evaluation of off-site construction research: A Scientometric analysis." *Automation in*
726 *Construction*, 87, 235-247.

727 Huber, B., and Reiser, P. "The marriage of CPM and lean construction." *Proc., ANNUAL CONFERENCE OF*
728 *THE INTERNATIONAL GROUP FOR LEAN CONSTRUCTION*, Citeseer.

729 Igwe, C., Hammad, A., and Nasiri, F. (2019). "USING LEAN CONSTRUCTION TOOLS AND 4D MODELLING
730 FOR EQUIPMENT WORKSPACE PLANNING." *CSCCE Annual Conference*.

731 Igwe, C. N. (2021). "A Process-Based Approach for Integrating the Last Planner System In 4D Modeling for
732 Equipment Workspace Planning in Elevated Urban Highway." Concordia University.

733 Jeong, W., Chang, S., Son, J., and Yi, J.-S. (2016). "BIM-integrated construction operation simulation for
734 just-in-time production management." *Sustainability*, 8(11), 1106.

735 Jongeling, R., and Olofsson, T. (2007). "A method for planning of work-flow by combined use of location-
736 based scheduling and 4D CAD." *Automation in construction*, 16(2), 189-198.

737 Kim, Y.-W., and Ballard, G. (2010). "Management thinking in the earned value method system and the last
738 planner system." *Journal of management in engineering*, 26(4), 223.

739 Kitchenham, B. (2004). "Procedures for performing systematic reviews." *Keele, UK, Keele University*,
740 33(2004), 1-26.

741 König, M. (2011). "Robust construction scheduling using discrete-event simulation." *Computing in Civil*
742 *Engineering (2011)*, 446-453.

743 König, M., Koch, C., Habenicht, I., and Spieckermann, S. "Intelligent BIM-based construction scheduling
744 using discrete event simulation." *Proc., Proceedings of the 2012 Winter Simulation Conference*
745 *(WSC)*, IEEE, 1-12.

746 Lin, J. J., and Golparvar-Fard, M. (2021). "Visual and virtual production management system for proactive
747 project controls." *Journal of Construction Engineering and Management*, 147(7), 04021058.

748 Lu, M., and AbouRizk, S. (2000). "Simplified CPM/PERT simulation model." *Journal of Construction*
749 *Engineering and Management*, 126(3), 219-226.

750 Lu, W., and Olofsson, T. (2014). "Building information modeling and discrete event simulation: Towards
751 an integrated framework." *Automation in Construction*, 44, 73-83.

752 Martins, S. S., Evangelista, A. C. J., Hammad, A. W., Tam, V. W., and Haddad, A. (2020). "Evaluation of 4D
753 BIM tools applicability in construction planning efficiency." *International Journal of Construction*
754 *Management*, 1-14.

755 McHugh, K., Dave, B., and Craig, R. "Integrated lean and BIM processes for modularised construction."
756 *Proc., 27th Annual Conference of the International Group for Lean Construction*

757 Melzner, J. "BIM-based takt-time planning and takt control: Requirements for digital construction process
758 management." *Proc., ISARC. Proceedings of the International Symposium on Automation and*
759 *Robotics in Construction*, IAARC Publications, 50-56.

760 Milat, M., Knezić, S., and Sedlar, J. (2021). "Resilient scheduling as a response to uncertainty in
761 construction projects." *Applied Sciences*, 11(14), 6493.

762 Muktadir, M. A., Dwivedi, A., Khan, N. S., Paul, S. K., Khan, S. A., Ahmed, S., and Sultana, R. (2021). "Analysis
763 of risk factors in sustainable supply chain management in an emerging economy of leather
764 industry." *Journal of Cleaner Production*, 283, 124641.

765 Morkos, R. (2014). *Operational efficiency frontier: Visualizing, manipulating, and navigating the*
766 *construction scheduling state space with precedence, discrete, and disjunctive constraints*,
767 Stanford University.

768 Mota, B. P., Viana, D. D., and Isatto, E. L. "Simulating the last planner with systems dynamic." *Proc.,*
769 *ANNUAL CONFERENCE OF THE INTERNATIONAL GROUP FOR LEAN CONSTRUCTION*, Citeseer.

770 Novinsky, M., Nesensohn, C., Ihwas, N., and Haghsheno, S. "Combined application of earned value
771 management and last planner system in construction projects." *Proc., Proceedings of the 26th*
772 *Annual Conference of the International Group for Lean Construction, Chennai, India*, 16-22.

773 Olivieri, H., Seppänen, O., Alves, T. d. C., Scala, N. M., Schiavone, V., Liu, M., and Granja, A. D. (2019).
774 "Survey comparing critical path method, last planner system, and location-based techniques."
775 *Journal of construction engineering and management*, 145(12), 04019077.

776 Olivieri, H., Seppänen, O., and Denis Granja, A. (2018). "Improving workflow and resource usage in
777 construction schedules through location-based management system (LBMS)." *Construction*
778 *management and economics*, 36(2), 109-124.

779 Olivieri, H., Seppänen, O., and Granja, A. D. "Integrating Lbms, Lps and Cpm: a practical process." *Proc.,*
780 *Proceedings of the 24th Annual Conference of the International Group for Lean Construction,*
781 *Boston, EE. UU.*

782 Ortenburger, S., and Hartmann, T. (2021). "Supporting the Last Planner System with 4D BIM." *Technische*
783 *Universität Berlin.*

784 Pellerin, R., and Perrier, N. (2019). "A review of methods, techniques and tools for project planning and
785 control." *International Journal of Production Research*, 57(7), 2160-2178.

786 POLIANI, R. (2020). "Planning and control in construction: analysis and integrations of three
787 methodological approaches. Location-based management system (LBMS), last planner system
788 (LPS) and critical path method (CPM)." POLITECNICO DI MILANO.

789 Ratajczak, J., Riedl, M., and Matt, D. T. (2019). "BIM-based and AR application combined with location-
790 based management system for the improvement of the construction performance." *Buildings,*
791 9(5), 118.

792 Raz, T., Barnes, R., and Dvir, D. (2003). "A critical look at critical chain project management." *Project*
793 *management journal*, 34(4), 24-32.

794 Richards, J. C., and Schmidt, R. W. (2013). *Longman dictionary of language teaching and applied linguistics,*
795 Routledge.

796 Russell, A., Staub-French, S., Tran, N., and Wong, W. (2009). "Visualizing high-rise building construction
797 strategies using linear scheduling and 4D CAD." *Automation in Construction*, 18(2), 219-236.

798 Sacks, R., Radosavljevic, M., and Barak, R. (2010). "Requirements for building information modeling based
799 lean production management systems for construction." *Automation in construction*, 19(5), 641-
800 655.

801 Saedi, S., Fini, A. A. F., Khanzadi, M., Wong, J., Sheikhhoshkar, M., and Banaei, M. (2022). "Applications
802 of electroencephalography in construction." *Automation in Construction*, 133, 103985.

803 Salama, T., Salah, A., and Moselhi, O. "Alternative scheduling and planning processes for hybrid offsite
804 construction." *Proc., Proceedings of the 33rd International Symposium on Automation and*
805 *Robotics in Construction, International Association for Automation and Robotics in Construction,*
806 *Auburn, AL, USA, 18-21.*

807 Salama, T., Salah, A., and Moselhi, O. (2018). "Integration of linear scheduling method and the critical
808 chain project management." *Canadian Journal of Civil Engineering*, 45(1), 30-40.

809 Salama, T., Salah, A., and Moselhi, O. (2021). "Integrating critical chain project management with last
810 planner system for linear scheduling of modular construction." *Construction Innovation.*

811 Sbiti, M., Beddiar, K., Beladjine, D., Perrault, R., and Mazari, B. (2021). "Toward BIM and LPS Data
812 Integration for Lean Site Project Management: A State-of-the-Art Review and Recommendations."
813 *Buildings*, 11(5), 196.

814 Schimanski, C. P., Marcher, C., Pasetti Monizza, G., and Matt, D. T. (2020). "The Last Planner® system and
815 building information modeling in construction execution: From an integrative review to a
816 conceptual model for integration." *Applied Sciences*, 10(3), 821.

817 Schimanski, C. P., Pasetti Monizza, G., Marcher, C., and Matt, D. T. (2021). "Development of a BIM-based
818 production planning and control system for Lean Construction through advancement and
819 integration of existing management techniques." *Frontiers of engineering management*, 8(3),
820 429-441.

821 Schimanski, C. P., Pradhan, N. L., Chaltsev, D., Monizza, G. P., and Matt, D. T. (2021). "Integrating BIM with
822 Lean Construction approach: Functional requirements and production management software."
823 *Automation in Construction*, 132, 103969.

824 Seppänen, O., Ballard, G., and Pesonen, S. (2010). "The combination of last planner system and location-
825 based management system." *Lean construction journal*.

826 Seppänen, O., Evinger, J., and Mouflard, C. (2014). "Effects of the location-based management system on
827 production rates and productivity." *Construction management and economics*, 32(6), 608-624.

828 Shehab, L., Ezzeddine, A., Hamzeh, F., Power, W., Tommelein, I., and Daniel, E. "Agent-Based Modelling
829 and Simulation of Construction Crew Performance." *Proc., Proc. 28th Annual Conference of the
830 International Group for Lean Construction (IGLC28)*.

831 Shen, L., and Chua, D. K. (2008). "An investigation of critical chain and lean project scheduling." *16th
832 Annual Conference of the International Group for Lean Construction (IGLC16)*.

833 Silveira, B. F., and Costa, D. B. (2023). "Method for automating the processes of generating and using 4D
834 BIM models integrated with location-based planning and Last Planner® System." *Construction
835 Innovation*(ahead-of-print).

836 Simmons, L. F. "Project management-critical path method (CPM) and PERT simulated with ProcessModel."
837 *Proc., Proceedings of the Winter Simulation Conference, IEEE*, 1786-1788.

838 Soman, R. K., and Molina-Solana, M. (2022). "Automating look-ahead schedule generation for
839 construction using linked-data based constraint checking and reinforcement learning."
840 *Automation in Construction*, 134, 104069.

841 Sriprasert, E., and Dawood, N. (2002). "Next generation of construction planning and control system: the
842 LEWIS approach." *Z. Turk. & R. Scherer, eWork and eBusiness in Architecture, Engineering and
843 Construction*, 175-182.

844 Sriprasert, E., and Dawood, N. (2003). "Multi-constraint information management and visualisation for
845 collaborative planning and control in construction." *Journal of Information Technology in
846 Construction*, 8, 341-366.

847 Staub-French, S., Russell, A., and Tran, N. (2008). "Linear scheduling and 4D visualization." *Journal of
848 Computing in Civil Engineering*, 22(3), 192-205.

849 Suhail, S. A., and Neale, R. H. (1994). "CPM/LOB: New methodology to integrate CPM and line of balance."
850 *Journal of construction Engineering and management*, 120(3), 667-684.

851 Tezel, A., Taggart, M., Koskela, L., Tzortzopoulos, P., Hanahoe, J., and Kelly, M. (2020). "Lean construction
852 and BIM in small and medium-sized enterprises (SMEs) in construction: a systematic literature
853 review." *Canadian journal of civil engineering*, 47(2), 186-201.

854 Thomé, A. M. T., Scavarda, L. F., and Scavarda, A. J. (2016). "Conducting systematic literature review in
855 operations management." *Production Planning & Control*, 27(5), 408-420.

856 Tokdemir, O. B., Erol, H., and Dikmen, I. (2019). "Delay risk assessment of repetitive construction projects
857 using line-of-balance scheduling and Monte Carlo simulation." *Journal of Construction
858 Engineering and Management*, 145(2), 04018132.

859 Toledo, M., Olivares, K., and González, V. "Exploration of a Lean-BIM planning framework: A Last Planner
860 System and BIM-based case study." *Proc., 24th Annual Conference of the International Group for
861 Lean Construction*, Citeseer, 2016.

862 Ullah, F. (2021). "A beginner's guide to developing review-based conceptual frameworks in the built
863 environment." *Architecture*, 1(1), 5-24.

864 Viklund Tallgren, M., Roupé, M., Johansson, M., and Bosch-Sijtsema, P. (2020). "BIM-tool development
865 enhancing collaborative scheduling for pre-construction." *J. Inf. Technol. Constr.(ITcon)*, 25, 374-
866 397.

867 Viles, E., Rudeli, N. C., and Santilli, A. (2019). "Causes of delay in construction projects: a quantitative
868 analysis." *Engineering, Construction and Architectural Management*.

869 Walker, D. H., and Shen, Y. J. (2002). "Project understanding, planning, flexibility of management action
870 and construction time performance: two Australian case studies." *Construction Management &
871 Economics*, 20(1), 31-44.

872 Wickramasekara, A. N., Gonzalez, V., O'Sullivan, M., Walker, C., Poshdar, M., and Ying, F. "Exploring the
873 Integration of Last Planner® System, Bim, and Construction Simulation." *Proc., Annual Conference
874 of the International. Group for Lean Construction*.

875 Wu, C., Wang, X., Wu, P., Wang, J., Jiang, R., Chen, M., and Swapan, M. (2021). "Hybrid deep learning
876 model for automating constraint modelling in advanced working packaging." *Automation in
877 Construction*, 127, 103733.

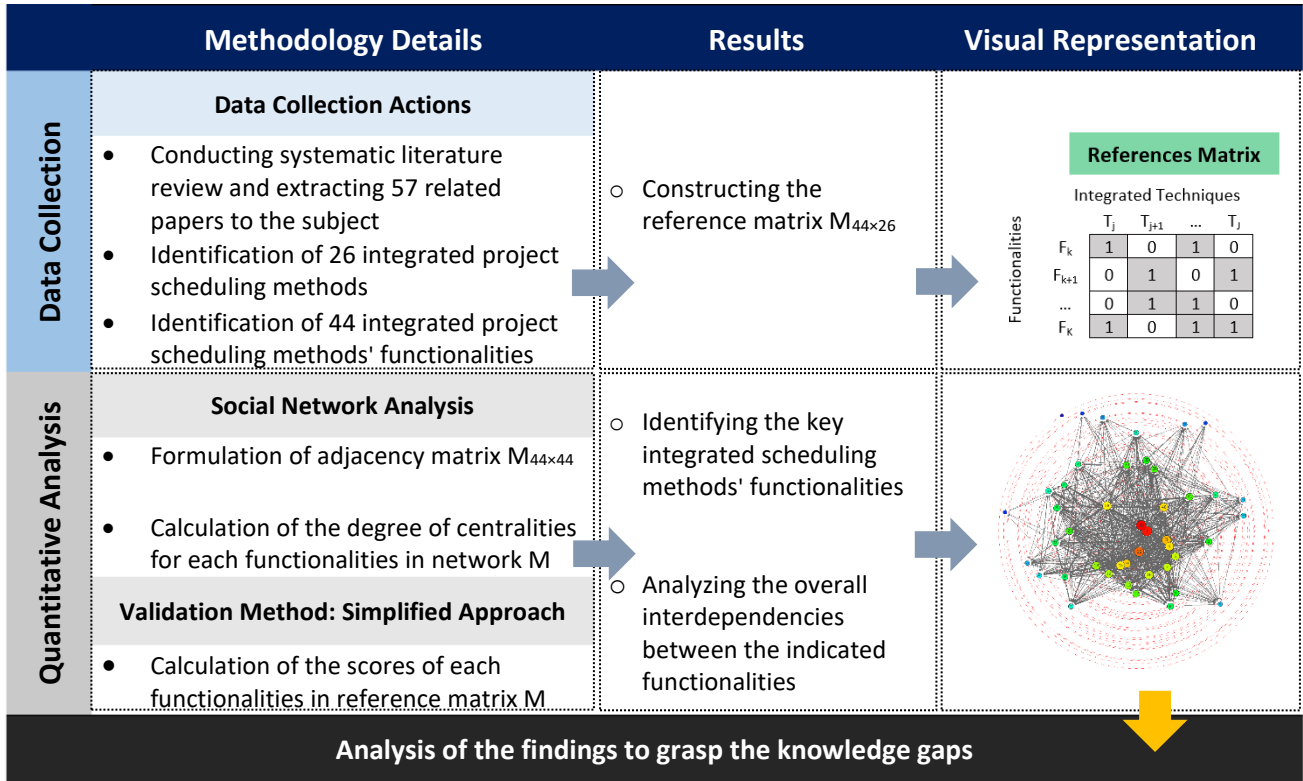
878 Yamın, R. A., and Harmelink, D. J. (2001). "Comparison of linear scheduling model (LSM) and critical path
879 method (CPM)." *Journal of construction engineering and management*, 112(4), 476-491.

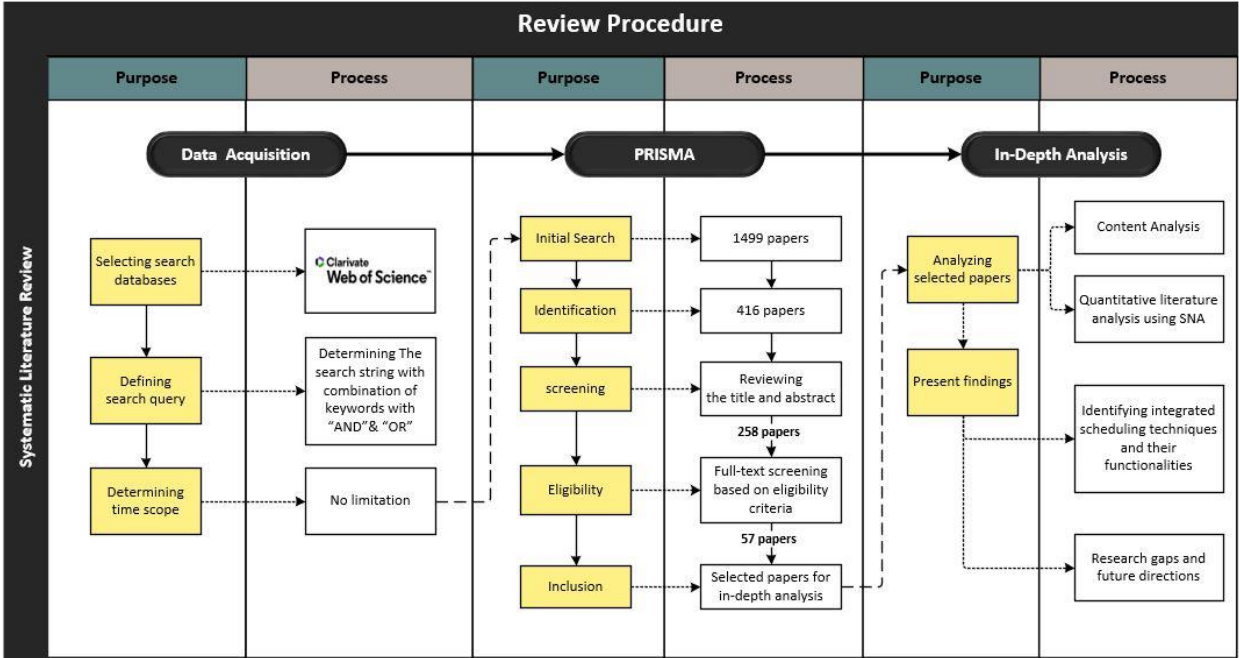
880 Zhang, H., Tam, C., and Shi, J. J. (2002). "Simulation-based methodology for project scheduling."
881 *Construction Management & Economics*, 20(8), 667-678.

882

883 **Figures Caption List**

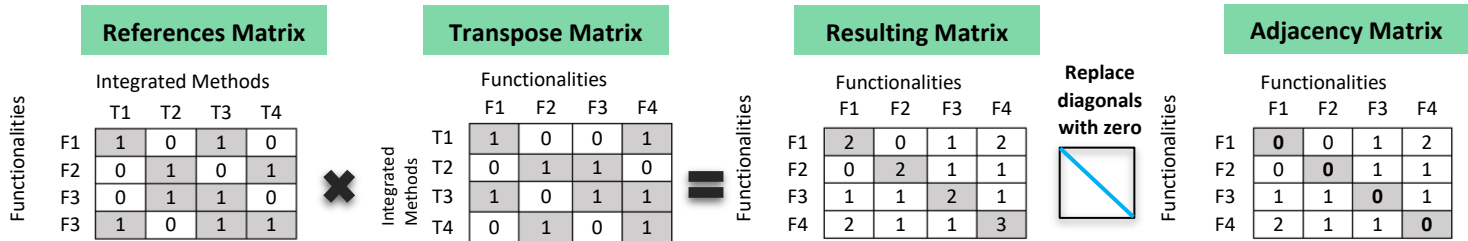
- 884 Fig. 1. Summary of the adopted research methodology
- 885 Fig. 2. Adopted systematic review procedure
- 886 Fig. 3. An example of a reference matrix
- 887 Fig. 4. An illustration of an adjacency matrix
- 888 Fig. 5. Visual representation of reference and adjacency matrix
- 889 Fig. 6. Distribution of the papers across the years
- 890 Fig. 7. Sankey diagram of integrated scheduling methods
- 891 Fig. 8. Distribution of utilized common scheduling methods in integrated scheduling methods
- 892 Fig. 9. Mapping between the identified functionalities and analyzed integrated scheduling methods
- 893 Fig. 10. Derived differences in the scores of C1 and C2 studies for common scheduling methods
- 894 Fig. 11. Functionalities network
- 895 Fig. 12. Color-coded matrix of functionalities
- 896 Fig. 13. Pareto Analysis of Functionalities
- 897 Fig. 14. Comparison results between simplified analysis and SNA
- 898





References Matrix M

		Integrated Techniques			
		T_j	T_{j+1}	...	T_J
Functionalities	F_k	1	0	1	0
	F_{k+1}	0	1	0	1
	...	0	1	1	0
	F_K	1	0	1	1



References Matrix

Integrated Methods

	T1	T2	T3	T4
F1	1	0	1	0
F2	0	1	0	1
F3	0	1	1	0
F3	1	0	1	1



Functionalities

	F1	F2	F3	F4
T1	1	0	0	1
T2	0	1	1	0
T3	1	0	1	1
T4	0	1	0	1



Resulting Matrix

Functionalities

	F1	F2	F3	F4
F1	2	0	1	2
F2	0	2	1	1
F3	1	1	2	1
F4	2	1	1	3

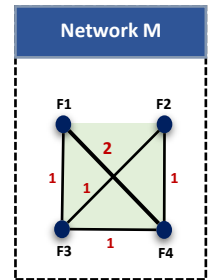
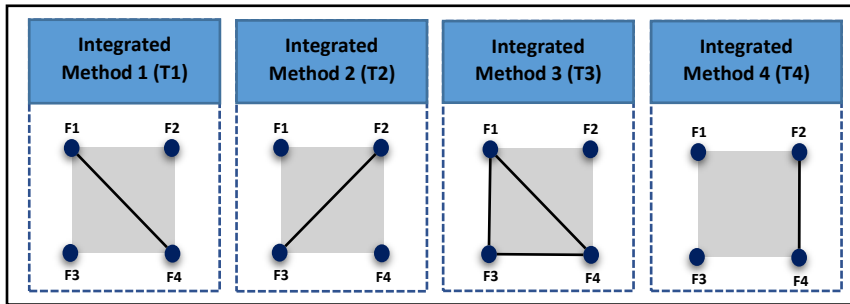
Replace diagonals with zero

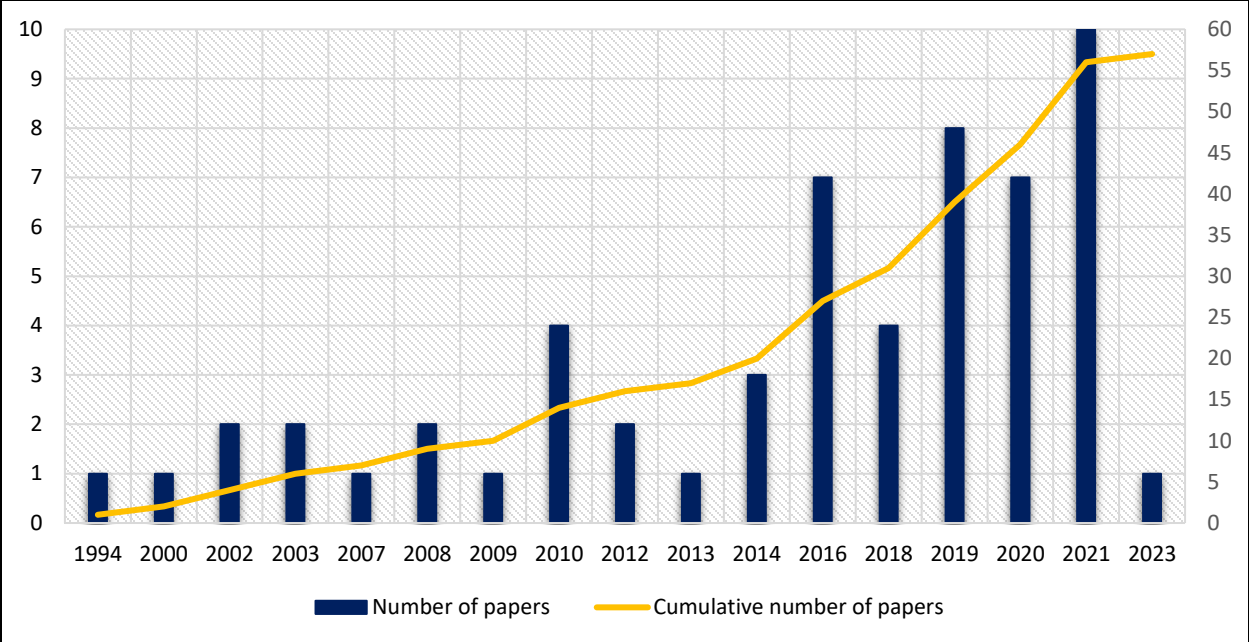


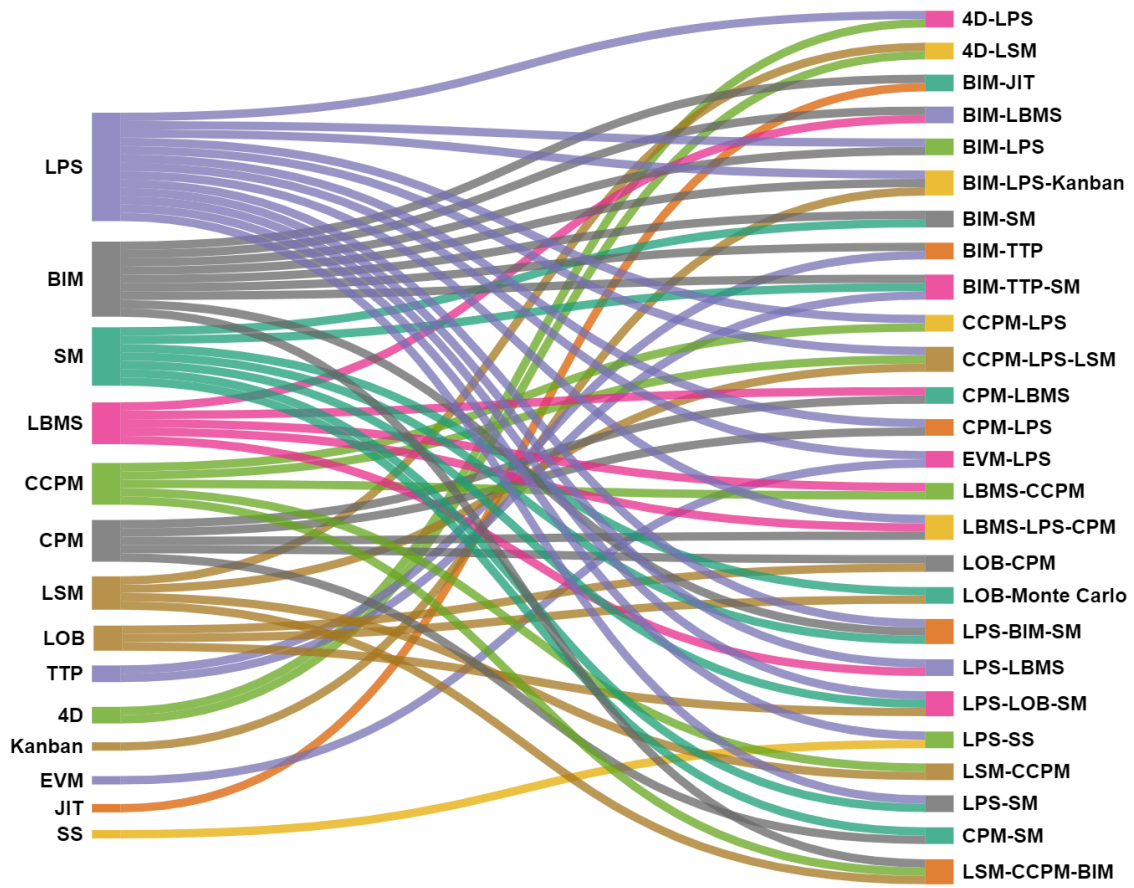
Adjacency Matrix

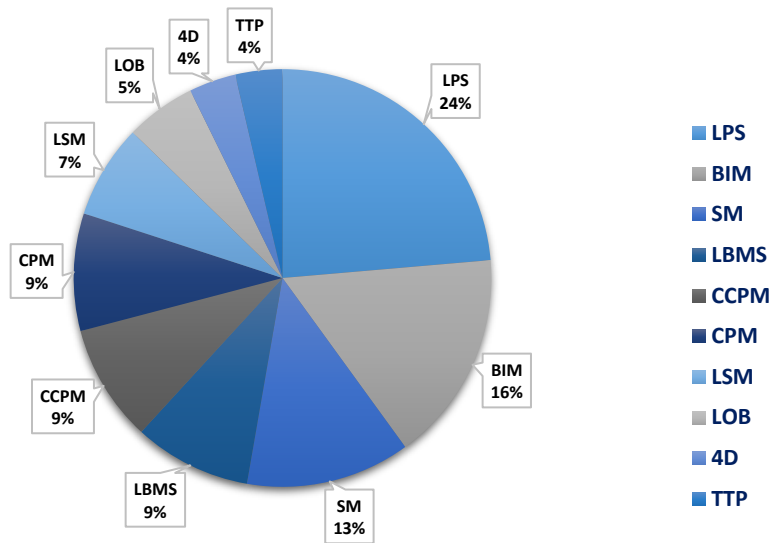
Functionalities

	F1	F2	F3	F4
F1	0	0	1	2
F2	0	0	1	1
F3	1	1	0	1
F4	2	1	1	0

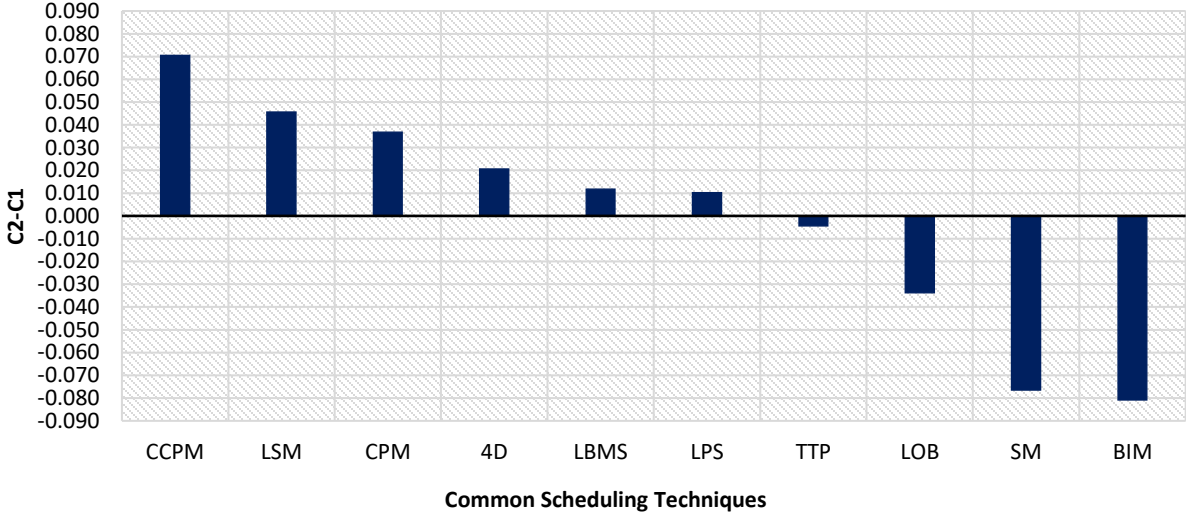


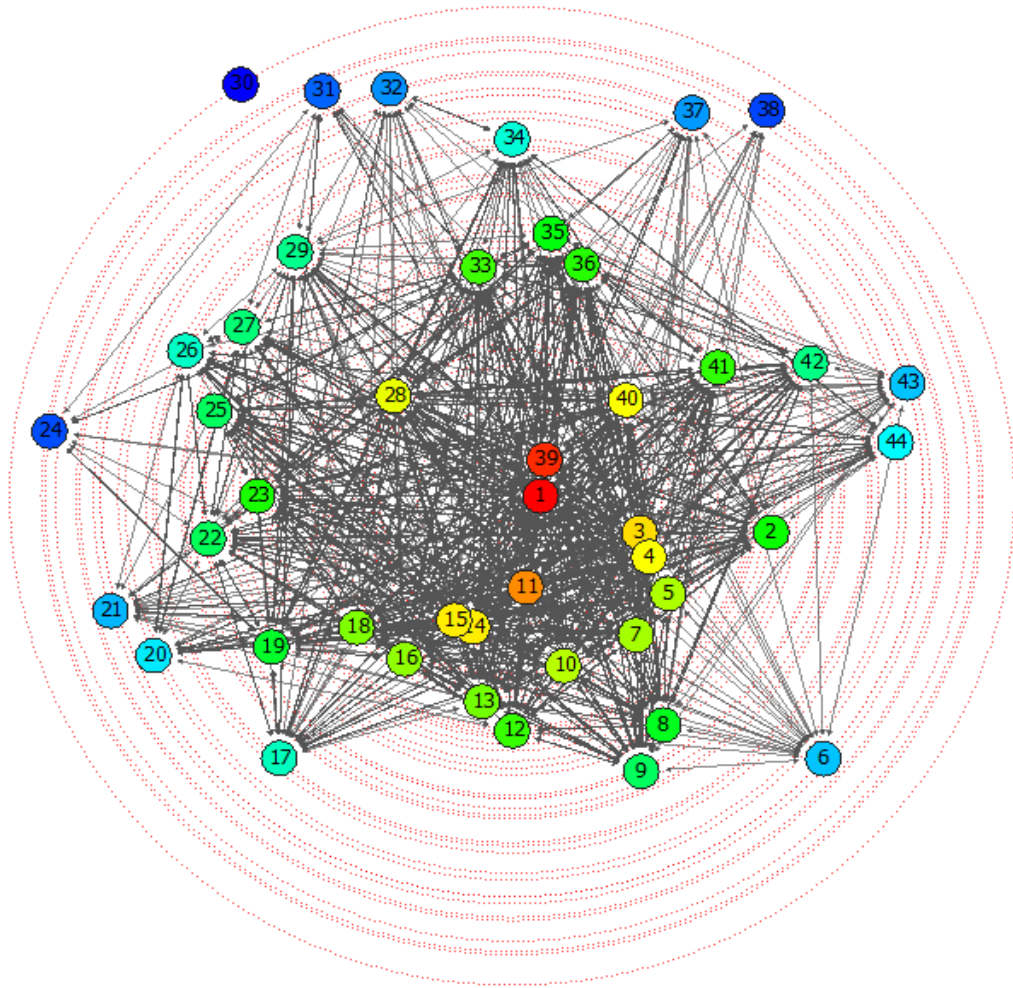


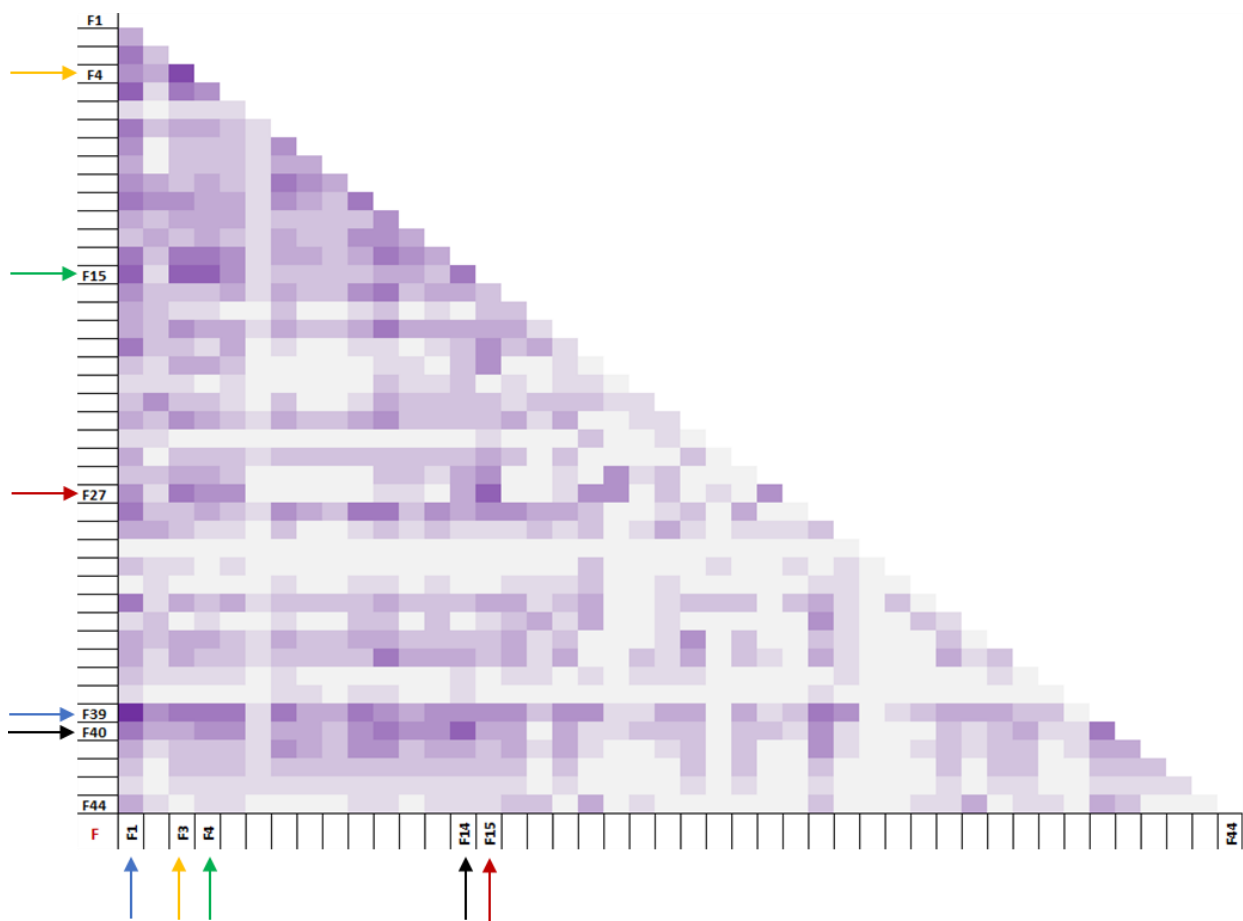


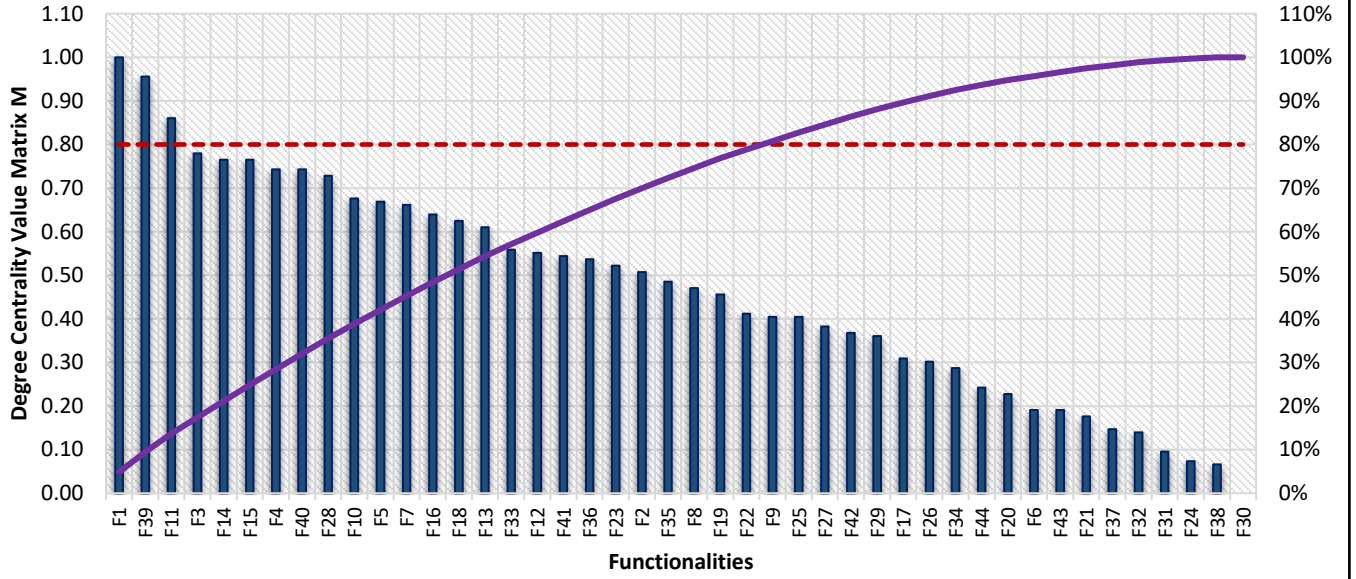


Difference between normalized C2 & C1









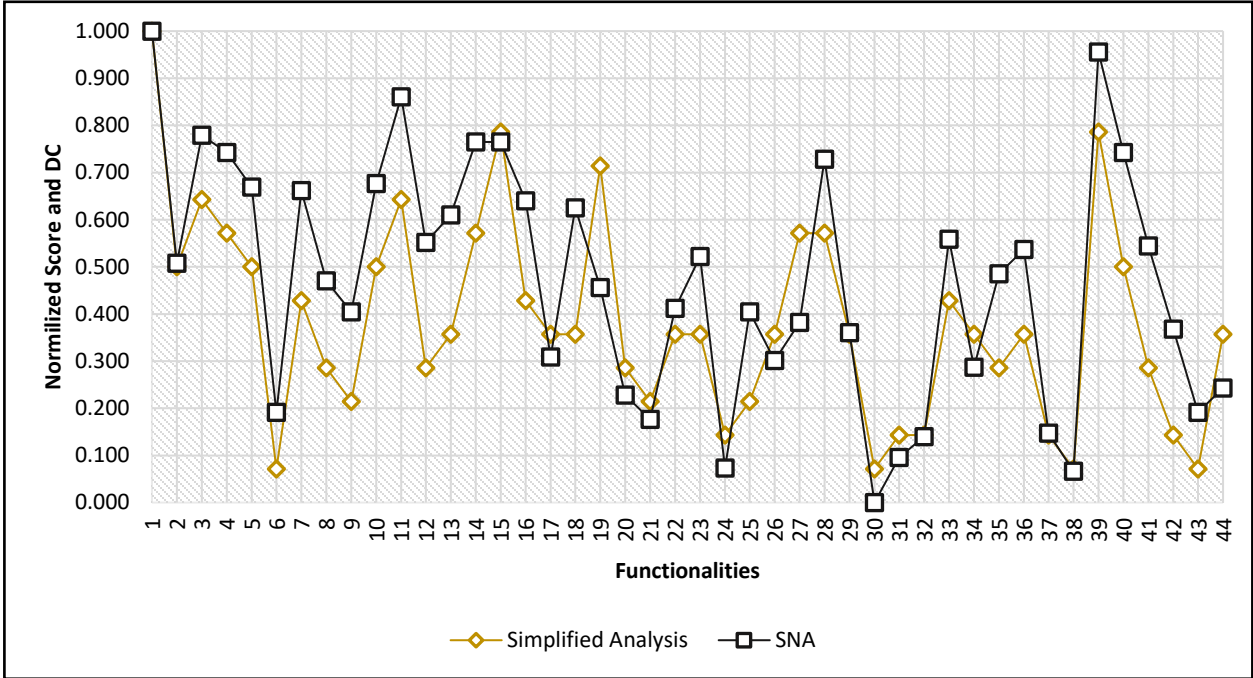


Table1. List of journals and conferences

Journal name	
Journal of Construction Engineering and Management	International Journal of Production Research
Automation in Construction	Journal of Information Technology in Construction (ITcon)
Journal of Management in Engineering	Production Planning & Control
Engineering, Construction and Architectural Management	Construction Management and Economics
Journal of Computing in Civil Engineering	Journal of Engineering, Design and Technology
International Journal of Project Management	Lean Construction Journal (LCJ)
International Journal of Construction Management	Construction Innovation
Journal of Building Engineering	Applied Sciences
Canadian Journal of Civil Engineering	Buildings
Advanced Engineering Informatics	Frontiers of Engineering Management
Conference name	
International Symposium on Automation and Robotics in Construction (ISARC)	
European Conference of Computing in Construction (EC3)	
International Group for Lean Construction (IGLC)	
Construction Research Congress (CRC)	

Table2. Search query

String
<p>("CPM" OR "Critical Path Method" OR "CCPM" OR "Critical Chain Management system" OR "Critical chain method" OR "LPS" OR "Last Planner System" OR "Takt Planning" OR "Takt time planning" OR "LBMS" OR "Location Based Management System" OR "LBS" OR "Location-based system" OR "LOB" OR "Line of Balance" OR "BIM" OR "Building Information Modeling" OR "4D" OR "4DBIM" OR "Linear Scheduling Method" OR "LSM" OR "Simulation" OR " Monte-Carlo" OR "PERT") AND ("Project Planning" OR "Project Scheduling" OR "Project Control" OR "Construction Planning" OR "Construction Scheduling")</p>

Table3. Inclusion and exclusion criteria for screening

Inclusion	Exclusion
<ul style="list-style-type: none"> • Written in English • Peer-reviewed articles that have been published in reputable scholarly construction and manufacturing journals and conferences • Act towards at least one combination of scheduling methods (LPS-4D) 	<ul style="list-style-type: none"> • Written in a different language than English • Not peer-reviewed; book, book chapter, technical reports • Deals only one scheduling method (LOB OR LPS) • Outside the scope of the construction industry

Table4. Full-text reviewed articles

Year	Full-text analyzed papers	Number of papers
1994-2003	(Suhail and Neale 1994), (Lu and AbouRizk 2000), (Simmons 2002), (Sriprasert and Dawood 2002), (Huber and Reiser 2003), and (Sriprasert and Dawood 2003)	6
2004-2013	(Jongeling and Olofsson 2007), (Shen and Chua 2008), (Staub-French et al. 2008), (Russell et al. 2009), (Kim and Ballard 2010), (Mota et al. 2010), (Sacks et al. 2010), (Seppänen et al. 2010), (Bhatla and Leite 2012), (König et al. 2012), and (Ammar 2013)	11
2014-2023	(Ajweh 2014), (Büchmann-Slorup 2014), (Lu and Olofsson 2014), (Al Hussein 2016), (Al Nasser et al. 2016), (Dave et al. 2016), (Jeong et al. 2016), (Olivieri et al. 2016), (Salama et al. 2016), (Toledo et al. 2016), (Burguete 2018), (Novinsky et al. 2018), (Olivieri et al. 2018), (Salama et al. 2018), (Abdelmegid et al. 2019), (Frandsen 2019), (Heigermoser et al. 2019), (Igwe et al. 2019), (McHugh et al. 2019), (Melzner 2019), (Ratajczak et al. 2019), (Tokdemir et al. 2019), (Abbasi et al. 2020), (Andújar-Montoya et al. 2020), (Aslam et al. 2020), (Etges et al. 2020), (POLIANI 2020), (Schimanski et al. 2020), (Wickramasekara et al. 2020), (Abdelmegid et al. 2021), (Barkokebas et al. 2021), (Boton et al. 2021), (Igwe 2021), (Lin and Golparvar-Fard 2021), (Ortenburger and Hartmann 2021), (Salama et al. 2021), (Sbiti et al. 2021), (Schimanski et al. 2021), (Schimanski et al. 2021), (Silveira and Costa 2023)	40

Table 5. Identified integrated scheduling methods

ID	Integrated Scheduling Methods	Abbreviations	References
1	4D BIM-Last Planner System	4D-LPS	(Igwe et al. 2019; Igwe 2021; Lin and Golparvar-Fard 2021; Ortenburger and Hartmann 2021)
2	4D BIM-Linear Scheduling Method	4D-LSM	(Russell et al. 2009; Staub-French et al. 2008)
3	BIM-Just In Time	BIM-JIT	(Abbasi et al. 2020; Jeong et al. 2016)
4	BIM-Location-Based Management System	BIM-LBMS	(Jongeling and Olofsson 2007; Ratajczak et al. 2019)
5	BIM-Last Planner System	BIM-LPS	(Al Hussein 2016; Barkokebas et al. 2021; Bhatla and Leite 2012; Etges et al. 2020; Heigermoser et al. 2019; McHugh et al. 2019; Sacks et al. 2010; Sbiti et al. 2021; Schimanski et al. 2020; Schimanski et al. 2021; Schimanski et al. 2021; Sriprasert and Dawood 2002; Sriprasert and Dawood 2003; Toledo et al. 2016)
6	BIM-Last Planner System-Kanban	BIM-LPS-Kanban	(Sacks et al. 2010; Schimanski et al. 2021)
7	BIM-Simulation Modeling	BIM-SM	(Abbasi et al. 2020; Jeong et al. 2016; König et al. 2012; Lu and Olofsson 2014)
8	BIM-Takt Time Planning	BIM-TTP	(Abbasi et al. 2020; Frandson 2019; Melzner 2019)
9	BIM-Takt Time Planning- Simulation Modeling	BIM-TTP-SM	(Abbasi et al. 2020; Aslam et al. 2020; Frandson 2019)
10	Critical Chain Project Management- Last Planner System	CCPM-LPS	(Shen and Chua 2008)
11	Critical Chain Project Management- Last Planner System- Linear Scheduling Method	CCPM-LPS-LSM	(Salama et al. 2021)
12	Critical Path Method- Location-Based Management System	CPM-LBMS	(Olivieri et al. 2018; POLIANI 2020)
13	Critical Path Method- Last Planner System	CPM-LPS	(Huber and Reiser 2003; POLIANI 2020)
14	Earn Value Management- Last Planner System	EVM-LPS	(Kim and Ballard 2010; Novinsky et al. 2018)
15	Location-Based Management System- Critical Chain Project Management	LBMS-CCPM	(Büchmann-Slorup 2014)
16	Location-Based Management System- Last Planner System- Critical Path Method	LBMS-LPS-CPM	(Olivieri et al. 2016; POLIANI 2020)
17	Line of Balance - Critical Path Method	LOB-CPM	(Ammar 2013; Suhail and Neale 1994)
18	Line of Balance- Monte Carlo Simulation	LOB-Monte Carlo	(Tokdemir et al. 2019)
19	Last Planner System-BIM-Simulation Modeling	LPS-BIM-SM	(Wickramasekara et al. 2020)
20	Last Planner System- Location-Based Management System	LPS-LBMS	(Dave et al. 2016; Salama et al. 2021; Seppänen et al. 2010)
21	Last Planner System- Line of Balance- Simulation Modeling	LPS-LOB-SM	(Ajweh 2014; Salama et al. 2021)
22	Last Planner System- Six Sigma	LPS-SS	(Aslam et al. 2020)
23	Linear Scheduling Method- Critical Chain Project Management	LSM-CCPM	(Salama et al. 2018; Salama et al. 2021)
24	Last Planner System- Simulation Modeling	LPS-SM	(Abdelmegid et al. 2019; Abdelmegid et al. 2021; Hamzeh et al. 2015; Hamzeh et al. 2015; Mota et al. 2010)
25	Critical Path Method- Simulation Modeling	CPM-SM	(Simmons 2002; Tokdemir et al. 2019)
26	Linear Scheduling Method- Critical Chain Project Management- BIM	LSM-CCPM-BIM	(Salama et al. 2016)

Table6. scheduling methods' functionalities

ID	Functionalities
F1	Improving the reliability of the planning
F2	Increasing productivity
F3	Considering the continuous flow of work
F4	Decreasing workflow variability
F5	Analyzing constraints more effectively
F6	Visualizing the status of work-in-progress
F7	Visualizing the schedules to understand and communicate content to a variety of stakeholders
F8	Avoiding omissions and sequencing mistakes
F9	Analyzing schedule constructability
F10	Increasing teamwork, and communication between all stakeholders
F11	Identifying and elimination wastes
F12	Decreasing meeting durations
F13	Enhancing the performance of construction project management
F14	Detecting and solving spatiotemporal conflicts
F15	Improving managerial practices
F16	Considering Supply chain instability
F17	Improving predictability
F18	understanding of the subprocesses more accurately
F19	Managing uncertainties
F20	Considering contractual requirement
F21	Managing work density
F22	Maintaining continuity of resources
F23	Automatically determines the resources quantities
F24	Scheduling of modular and offsite construction
F25	Improving the understanding of the project's progress
F26	Filling gaps related to delay analysis
F27	Applying analytical method
F28	Supporting human decision making
F29	Improving production tracking, forecasting and control
F30	Eliminating the root causes of variability
F31	Integrating offsite and onsite planning for modular and offsite construction
F32	Understanding the behaviour of the performance indicators
F33	Linking the supply chain and construction process
F34	Testing research hypotheses and improving understanding of the schedule
F35	Automating the generation of schedule
F36	Reducing of production cycle time
F37	Improving the usability of the 4D BIM for workflow analyses
F38	Increasing safety on construction sites
F39	Increasing transparency
F40	Enabling the coordination of the look-ahead plans
F41	Promoting the reliability of the Commitment Plan
F42	Providing more valuable handouts to the planning meetings' participants
F43	Implementing of pull flow control
F44	Applying creativity techniques to planning and scheduling

Table 7. Statistical test results on the simplified analysis and SNA

	Simplified Analysis	SNA
Mean	0.381	0.469
Variance	0.046	0.0640
Standard Deviation	0.214	0.253
Pearson Correlation		0.845