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Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis

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24 Despite its immense technical advantages and value potential, the facts remain that the use of
25 BIM worldwide still falls considerably short of its capabilities; many construction projects
26 even disregard BIM (Cao et al., 2014). Barlish and Sullivan (2012) determined that returns on
27 investment (ROI) generated by BIM may vary considerably from project to project. Oakley
28 (2012) revealed minimal effects of several construction projects with the use of BIM on
29 project performance. Although the technology side of BIM is considerably maturing in the
30 construction industry, the managerial areas of BIM (MA-BIM) still have limitations.

31 For a construction project, BIM is not merely a software suite. However, obtaining the
32 promised project benefits of BIM seems to hinge on management changes instead of
33 technology issues. A recent example is the Shanghai Tower, in which the critical challenge of
34 BIM implementation was not the technical aspects but the coordination among 8 BIM teams
35 with members having diverse occupational backgrounds and different interest orientations.
36 Among the involved parties, the Shanghai Construction Group was the general contractor and
37 one of the owners with a 4% of the share on the project (Shanghai Tower, 2015). The IPD-ish
38 partnership (El Asmar et al., 2013) significantly facilitated the involvement of Shanghai
39 Tower contractor in the preplanning and design stages. In this regard, the non-technical
40 challenge necessitates an industry-wide demand for the studies on the MA-BIM. Volk et al.
41 (2014) presented a comprehensive review on BIM from a “broad” sense, which comprises
42 functional, informational, technical and organizational/legal issues throughout the entire
43 lifecycle of a project. According to Volk et al. (2014), the organizational/legal issues are what
44 MA-BIM needs to improve for project performance.

45 For these reasons, MA-BIM could be proposed as:

46 *Organizational and legal strategies for coordinating and managing overall project*
47 *information, processes and aligning project policies to improve the level of BIM adoption and*
48 *implementation.*

49 Literature review is regarded as an expedient approach to gain in-depth understanding of a
50 research area. Through a systematic examination of existing studies, state-of-the-art
51 advancements and emergent trends can be identified with the purpose of spurring
52 encouragement for future studies. Despite the importance of critical review, almost no such
53 work has yet been conducted regarding MA–BIM. Therefore, the current study undertakes a
54 scientometric analysis of MA–BIM articles published from 2007 to 2015. Different from
55 previous studies, this study does not distinguish between sources specific to MA–BIM, which
56 enables data to provide a highly accurate general perspective in the field.

57 The objectives of this study are as follows: (1) to summarize MA–BIM studies from 2007
58 to 2015; (2) to acquire a holistic research status for MA–BIM from the perspective of
59 keyword co-occurrence network, as well as to identify research theme-divisions through
60 abstract term cluster analysis; (3) to identify emergent trends from studies in this field through
61 keyword burst detection; and (4) to develop an MA–BIM framework that illustrates a future
62 research roadmap. The rest of this paper is structured as follows. Section 2 elaborates on the
63 research method used in this study. Section 3 presents the results of the keyword
64 co-occurrence analysis and burst detection, followed by Section 4 that describes the results
65 and findings from the abstract term cluster analysis. Then Section 5 develops and presents the
66 MA–BIM conceptual framework based on the scientometric analysis. Finally, Section 6
67 concludes the findings of this study.

68 **2. Research method**

69 **2.1 Paper retrieval**

70 To achieve the research objectives of this study, academic journals with the BIM
71 publications were identified. The list of publications was obtained using two databases,
72 namely, Scopus and Web of Science (WoS), for a comprehensive search on the subject area.
73 WoS database covers over 12,000 of high impact journals worldwide, including open access
74 journals and over 150,000 conference proceedings (Thompson-Reuters, 2014). And Scopus
75 includes over 21,500 peer-reviewed journals, 7.2 million conference papers, and over 60
76 million records (Elsevier, 2016). The integration of sources from these two databases was
77 considered sufficient to justify broad conclusions regarding the overall development of BIM.

78 Given the difficulty of searching each related article, a delimitation of the research
79 boundary is frequently necessary (Chen et al., 2015). The main point of each paper should be
80 determined by its research objectives, methodologies, and major contributions. In the current
81 study, three criteria were proposed during the delimitation process of the BIM literature in the
82 managerial areas. Fig. 1 shows the research framework of this study.

83  Insert Fig. 1

84 *Firstly*, only papers in peer-reviewed English journals were included for the review with
85 considering their impact positions in the BIM research in terms of SCImago Journal Rank and
86 H-index. Book reviews, editorials, and conference papers were excluded so that all retrieved
87 papers could be screened using an identical analytical construct in terms of research aims and
88 methods (Mok et al., 2015).

89 *Secondly*, the topics of these papers were limited to the managerial issues in BIM adoption
90 and implementation rather than the technical development of BIM. The topic of each paper

91 was determined by its research aims and methods from abstract. Those papers, which aim at
92 providing technical solutions of BIM without referring to project strategies for improved BIM
93 adoption level or implementation process, were preliminarily excluded. Meanwhile, the topic
94 of each paper could also be identified from the research methods. It is noteworthy that
95 interviews and questionnaires are typically used as the principal means of investigating the
96 managerial issues of BIM. In contrast, technologies integration and systems development are
97 essentially employed to address the technical issues of BIM.

98 *Thirdly*, papers aimed at addressing functional issues that describe BIM functionalities and
99 applications, informational issues that describe industry foundation classes (IFC) and model
100 view definition (MVD), and technical issues that describe data capture, data processing,
101 object recognition, and modeling, were excluded. After identifying the research aims and
102 methods from abstracts, there was still a need for in-depth understanding of the primary
103 contents of each paper. For example, if the main body of a paper discussed the whole process
104 of BIM plug-in development, but nearly had no relationship with organizational/legal issues,
105 it was screened out. To decrease potential bias during the selection of target papers, the
106 contents of each paper were screened by different authors to identify the ones suitable for this
107 study.

108 The search rule in this study was (“BIM” OR “building information modeling” OR
109 “building information modelling” OR “building information model” OR “virtual design and
110 construction” OR “VDC” OR “as-built model” OR “virtual model”) AND (“management”
111 OR “managerial” OR “managing” OR “manage”). To avoid omissions of target papers, the
112 timespan of the publication search was set for “all years” (ended in August 18, 2015).

113 According to the first criterion, a total of 308 journal papers were retrieved. As shown in
114 Table 1, 16 journals are selected in this process. These journals have published at least one
115 paper that fit the first criterion, and are highly ranked by construction management
116 researchers. Despite the rigorous search rule, some retrieved publications appear to be less
117 relevant. Based on the second and third criteria, 126 papers were identified for further analysis
118 after the filtering process. The first study on the ‘selection of papers’ list is Fox and Hietanen
119 (2007), which conducted an investigation on the potential of BIM for interorganizational use
120 in Finland, including its automational, informational, and transformational effects. The
121 subsequent analyzing process is thus set from 2007 to 2015 in CiteSpace.

122 Insert Table 1 about here

123 **2.2 Scientometric analysis**

124 Due to a wide spectrum of research topics in relation to MA–BIM, there is little prospect of
125 characterizing the overall field through manual literature analysis. And the manual review,
126 while insightful, is prone to be biased and limited in terms of subjective interpretation.
127 Therefore, the current study provides a holistic analysis of MA–BIM using the scientometric
128 technique, a research method that refers to knowledge domain visualization or mapping
129 (Pollack and Adler, 2015). This technique is a quantitative method that applies bibliometrics to
130 published literature; it is used to map the structure and evolution of numerous subjects based on
131 large-scale scholarly data sets (Börner et al., 2003). Through network modeling and
132 visualization, scientometric research aims to analyze the intellectual landscape of a knowledge
133 domain and perceive questions that researchers have been attempting to answer, as well as
134 methods that they have developed to achieve their goals (Chen, 2006). Visualizing the entire

135 MA–BIM provides an approach to acquire a global perspective of research patterns and trends
136 in the field.

137 The MA–BIM literature provides tangible evidence of the developments in this field, which
138 can lead to conclusions on influential studies that drive BIM adoption, implementation, and
139 post-evaluation, as well as the managerial areas where these works are embodied. The size and
140 scope of the MA–BIM field have expanded, which makes it considerably beyond the reach of
141 manual and intellectual analysis. The techniques required to undertake rapid and effective
142 analysis belong to the domain visualization toolkit, such as CiteSpace, Science of Science (Sci2
143 Tool), and BibExcel (Chen et al., 2011). In this quantitative interpretivist research, CiteSpace
144 software is used for network analysis and visualization based on the terms that the authors have
145 used to describe their publications.

146 Keywords and abstracts are considered as clear and concise descriptions of research
147 contents, which necessitates using such terms as units of analysis to identify prominent
148 groupings that affect the structure of the MA–BIM field. In this study, the MA–BIM literature
149 was analyzed in terms of keywords and abstract terms to retain the opinion of the authors as
150 much as possible. And the keyword co-occurrence analysis, keyword burst detection, and
151 abstracts cluster analysis were employed to reveal the research patterns and trends in the
152 MA–BIM field.

153 *Firstly*, the keyword co-occurrence analysis makes an aggregate representation of the
154 MA–BIM field, and the indicators of keyword co-occurrence network provide evidence for
155 the subsequent cluster analysis. *Secondly*, the keyword burst detection shed further insight on
156 the relative change of significance between keywords over time to identify the research trends

157 of MA–BIM, in contrast to the keyword co-occurrence analysis that merely presents a static
158 description of the field as a whole, *Thirdly*, the abstracts cluster analysis indicates the research
159 patterns of the MA–BIM field in detail, and various specific research themes associated with
160 each principal area are identified, which lays the foundation for the establishment of
161 MA–BIM conceptual framework.

162 **3. The keyword co-occurrence analysis and burst detection**

163 **3.1 The keyword co-occurrence network**

164 The selected 126 MA–BIM papers were analyzed in terms of keywords. Four common
165 keywords were noted, namely, “building information modeling,” “building information
166 modelling,” “building information model,” and “BIM.” These keywords were defined as the
167 domain stop-words because they form a high percentage in the analysis domain (Hu and
168 Zhang, 2015). These four stop-words were excluded because they did not add value to the
169 current study, as well as influenced cluster accuracy of keyword co-occurrence network.
170 Moreover, not all the keywords provided by the authors were determined to be normalized;
171 thus, the extracted keywords were normalized to ensure consistent treatment of unifying
172 synonyms. As shown in Table 2, “information technologies” was replaced with “information
173 technology” and “construction projects” was replaced with “construction project”, and so on.
174 Börner (2010) described that “...80% effort in scientometric research is spent on data
175 acquisition and preprocessing.” After data acquisition and preprocessing, analyses of keyword
176 co-occurrence, keyword burst detection, and abstracts cluster were conducted.

177 Insert Table 2 about here

178 Keyword co-occurrence network analysis was performed using CiteSpace. The overall

179 network characterizes the development of MA–BIM over time and showed the most
180 important footprints of this field. Nodes in the network represented individual keywords used
181 to generalize the essence of each article. Edges that connect nodes were co-occurrence links,
182 wherein two different keywords were used together in the same article.

183 Table 3 indicates the overall characteristics of the keyword co-occurrence network. In
184 particular, modularity Q and mean silhouette scores are two significant metrics that determine
185 the overall structural properties of the network. It is notable that a modularity Q of 0.8115 is
186 relatively high ($Q > 0.3$), which indicates that the network is reasonably divided into loosely
187 coupled clusters (Newman, 2006). A mean silhouette score of 0.9372 (> 0.7) suggests that the
188 homogeneity of these clusters is also relatively high, which indicates that network cluster is
189 efficient and reliable (Kaufman and Rousseeuw, 2009). The results provide the basis for
190 ensuring usefulness and credibility of datasets in the succeeding work.

191 Insert Table 3 about here

192 The overall keyword co-occurrence network is shown in Fig. 2. Node size represents the
193 frequency at which a keyword occurs, whereas edge weight represents the frequency at which
194 two keywords are used jointly. The colors of these lines are designed to show when a
195 connection is made among different keywords for the first time. The color encoding clarifies
196 which part of the network is old and which one is new. Fig. 2 indicates that blue represents
197 the keywords connected for the first time in 2007, whereas orange represents the connections
198 of keywords in 2015. Color transition from a cool tone to a warm tone represents the timespan
199 from past to present.

200 Insert Fig. 2 about here

201 The timespan set for the present study in CiteSpace is from 2007 to 2015, which is related
202 to the size of dataset (Chen, 2014). After searching from WoS and Scopus within “all years”
203 as well as delimitation process as introduced in Section 2.1, the dataset of this study that
204 included 126 papers published from 2007 to 2015 were identified and considered as recent
205 work. The concept of BIM can be traced back to the “building description systems” proposed
206 by Eastman in the mid-1970s (Eastman, 1976). It is acknowledged that the 126 identified
207 papers do not include all publications that contribute to MA-BIM research to date. However,
208 16 selected journals include the most prominent publications relevant to MA-BIM. The 126
209 identified papers were considered sufficient to represent the latest developments in the last
210 decade as a whole.

211 Fig. 3 highlights the most frequently occurring keywords. The frequency of “information
212 technology” is the highest, which represents the physical attribute of BIM. As a major shift in
213 information technology during the last decade, BIM, which refers to both the activity of
214 modeling and the digital and virtual models of a building, triggers the transformation of the
215 project management paradigm (Succar, 2009). Other keywords that relate to “information
216 technology” also include “information system” and “information management.” The
217 proximity of the keywords “education,” “engineering education,” and “adoption” aligns with
218 the expectation of an association between these topics. Hartmann and Fischer (2008)
219 concluded that “far-reaching education and training programs” are required to achieve
220 extensive BIM adoption. Similarly, arriving at conclusions regarding the association of other
221 keywords based on their placement is possible. For example, “integration,” “coordination,”
222 and “lean construction” are distributed on the bottom left side of Fig. 3. Lean construction and

223 BIM are relatively different initiatives, but are inextricable part of each other. The integration
224 and coordination between these two initiatives can be maximized to improve project
225 processes beyond the degree to which such processes may be improved by the independent
226 application of either of these paradigms (Sacks et al., 2010). On the one hand, construction
227 projects on a lean journey are contingent on BIM to enhance the lean outcomes. On the other
228 hand, changes in business processes as a consequence of BIM implementation significantly
229 contribute to make a project considerably lean. Based on the placement, issues associated
230 with design and construction appear to be highly associated with information technology,
231 whereas issues associated with operation and maintenance are lacking. Although the review
232 of BIM literature indicates an increasing interest in facility management, a considerable
233 divide remains between the studies that focus on new construction and existing buildings.

234 Insert Fig. 3 about here

235 Keyword co-occurrence network is a static representation of a specific field that has not
236 considered changes over time in the manner in which the terms are used. However, CiteSpace
237 provides a time zone perspective that each term is arranged in chronological order to show
238 development trends and interactions among keywords. As shown in Fig. 4, the evolution of
239 MA–BIM-related keywords continued from 2007 to 2015. The lines that connect nodes are
240 co-occurrence links between different keywords. The colors of these lines are designed to
241 show when a connection has been made for the first time. Given the transformation of BIM
242 from 3D to nD, keywords unsurprisingly veer away from “collaborative design” to
243 “construction safety,” “cost,” and “energy.” Increasing interests are emerging on “change
244 management,” “information technology strategy,” and “team working” in 2015. By contrast,
245 earlier keywords tend to focus on specific implementation process in relation to MA–BIM,

246 such as “implementation”, “design process” and “process improvement”, which potentially
247 indicate a change from a tactic focus to an emphasis on strategy. This change may also be
248 partly caused by the increasing complexity of construction projects, particularly emerging
249 mega construction projects (MCPs), which leads to high project uncertainty, complex
250 stakeholder interrelationships, and conflicting interests. It should be noted that keywords
251 co-occurrence taken in isolation can lead to misinterpretation if taken out of context (Pollack
252 and Adler, 2015). In this study, it is essential to refer to specific articles using these keywords
253 to avoid ambiguity.

254 Insert Fig. 4 about here

255 **3.2 The keyword burst detection**

256 Keyword co-occurrence analysis through network mapping provides several insights into
257 the MA–BIM field. However, the process of keyword frequency change with time remains
258 unclear. A keyword burst provides evidence that a particular keyword is associated with a
259 surge of occurrence frequency. Accordingly, a keyword burst is considered an indicator of a
260 highly active research area that represents changes in significance among keywords from a
261 historical perspective. As a function in CiteSpace based on Kleinberg’s bursty and
262 hierarchical structure in streams (Kleinberg, 2003), keyword burst detection can be used in
263 the present study to explore emergent trends and passing fads within the MA–BIM field
264 (Pollack and Adler, 2015). Evidently, the bursting keyword has attracted an unusual degree of
265 attention from the research community during a specific period. Fig. 5 shows a visualization
266 of the keyword burst analysis in the MA–BIM field from 2007 to 2015; the top 25 bursting
267 keywords are also shown, as sorted based on their beginning year of burst.

268

Insert Fig. 5 about here

269 The burst detection algorithm indicates unusually large changes in the frequency of a
270 datum over time (Pollack and Adler, 2015). For example, with the proliferation of 4D, 5D, or
271 nD BIM, the keyword “three-dimensional models” was barely part of the common terms at
272 present. Since 2007, a robust growth was observed in the “three-dimensional models” use for
273 construction project management. After 2010, the term “three-dimensional models” became
274 common, although of a relatively high frequency compared with that in the 2000s, and would
275 no longer be considered to be bursting because it already reached a steady state.

276 Fig. 5 shows that the keywords “change management,” “information technology strategy,”
277 “maintenance,” “design errors” and “team working” have continued bursting from 2007 to
278 2015, which is consistent with the findings of the timeline view in Fig. 4. This case is
279 unsurprising based on the results of keyword burst detection. For example, as MCPs emerged
280 in multitude, their extreme uncertainty and complexity resulted in cost overruns and time
281 delay, which led to the demand for efficient change management and the minimization of
282 design errors. Similarly, research focus shifts from design to maintenance (Becerik-Gerber et
283 al., 2011), particularly of complex construction projects, which is also in line with the
284 analysis results in Fig. 5. It is noteworthy that keyword burst detection may indicate an
285 emphasis away from individual-centered issues to a broad organizational perspective in
286 general. This case highlights the importance of “team working”, “collaborative design” and
287 “organizations.” In addition, MA–BIM hotspots and frontiers are also identified based on
288 keyword burst detection, particularly on frequency changes occurring within the last five
289 years, such as “lean construction,” “impact,” “diffusion,” “constructability,” “sustainable

290 development,” “information system,” “adoption,” “modelling,” and “education.”

291 **4. The abstract term cluster analysis**

292 **4.1 Summary of abstract term cluster analysis**

293 A keyword co-occurrence network provides several general insights into the MA–BIM
294 field. However, frequency and timeline analyses fail to clarify major areas and structures of
295 MA–BIM studies. As a mathematical and statistical method, cluster analysis is used to
296 identify the latent semantic themes within the textual data (Hossain et al., 2011). Cluster
297 analysis employs a set of algorithms to convert unstructured text into structured data objects
298 to detect research patterns for the discovery of knowledge (Delen and Crossland, 2008). The
299 main idea behind cluster analysis is to collect all the contexts belonging to the words in the
300 literature dataset, and derive associated clusters that represent related research themes
301 (Yalcinkaya and Singh, 2015). Therefore, cluster analysis can be used to identify several
302 prominent groupings, and has been adopted in this study to show research patterns in the
303 MA–BIM field.

304 As a tool for progressive knowledge domain visualization, CiteSpace provides various
305 functions to facilitate the understanding and interpretation of network patterns, including
306 decomposing a network into clusters and automatic labeling clusters with terms from the titles,
307 keywords, or abstracts (Chen, 2006). Apart from keywords, titles and abstracts are also
308 typically used by authors to describe a publication. Ultimately, abstracts are taken as a unit of
309 cluster analysis because they provide the complete expression of research contents, and
310 consequently, reliable indicators of theme-divisions in the MA–BIM field. To characterize the
311 nature of an identified cluster, CiteSpace can automatically extract noun phrases from the

312 abstracts based on a set of algorithms, including frequency–inverse document frequency
313 (tf*idf), log-likelihood rate (LLR) and mutual information (MI) (Chen, 2014). Each cluster
314 reserves and represents a certain amount of the overall observed terms, and the clusters are
315 organized in the order of how many terms they explain. Fig. 6 shows that the clusters are
316 numbered in descending order of cluster size, starting from the largest cluster #0, the second
317 largest #1, and so on. And this is the default naming patterns of clusters in CiteSpace.

318 Insert Fig. 6 about here

319 Overall, MA–BIM has 8 prominent research clusters; each cluster can be regarded as a
320 research theme. These themes are relatively independent of one another, as well as partially
321 overlapping. In any text, multiple words may share the same meaning and one word may have
322 many synonyms in different contexts. Cluster analysis “loads” the words that share the same
323 meaning to their associated theme and also “loads” one word to various latent semantics other
324 than its main associated theme (Yalcinkaya and Singh, 2015). Thus, there is the case that
325 some of the clusters are overlapping. In other words, some of the abstract terms belong to
326 several clusters at the same time.

327 It is notable that the automatic labeling clusters can lead to misinterpretation if their labels
328 are taken out of context. As mentioned earlier, one word may bring out various meanings in
329 different contexts. It is thus necessary to refer to the specific abstract terms of each cluster to
330 resolve this. Three to five abstract terms with top frequencies were, therefore, selected to
331 represent the theme-clusters because they were most likely to be selected and used by the
332 researchers in each cluster. And the names of each cluster were further refined by referring to
333 the individual articles using these high-frequency abstract terms, with a view to avoiding and

334 eliminating the ambiguity of the automatic labels generated by CiteSpace. Table 4 shows the
335 cluster size and representative terms of each theme-cluster. Cluster size refers to the number
336 of abstract terms involved for each cluster, and the silhouette shows the homogeneity of a
337 cluster as mentioned in Section 3.1. The higher the silhouette score, the more consistent the
338 cluster members. Unlike most previous studies based on the subjective understanding of a
339 specific field from authors, abstract term cluster analysis provides a more objective approach
340 to perceive the overall structure of a certain knowledge domain.

341 Insert Table 4 about here

342 **4.2 Detailed MA–BIM research themes**

343 **4.2.1 Collaborative working environment**

344 Cluster #0 is related to the research of collaborative working embedded into various
345 environments. In the current digital economy, the construction industry is on the verge of a
346 technological revolution. The main trajectories that characterize the development and
347 application of digital technologies include visualization, collaboration, automation,
348 integration, and transformation (Hassan, 2013). BIM appears to be the emerging leading
349 paradigm, which should be considered a dynamic process rather than a model per se, thereby
350 supporting collaborative working environments for involved parties during the overall project
351 life cycle. As a backbone for collaboration, interoperability in relation to BIM is not only a
352 technical issue, but also concerns business processes, culture, values, and management of
353 contracts between interacting parties. To achieve significantly high value levels in the
354 construction industry, changes in interoperability are required to depart from “efficiency and
355 differentiation” to “value innovation;” these changes are emerging with the design of new

356 3D-based collaborative environments that sustain creativity and also through a complete
357 dematerialization and reconfiguration of traditional processes within cross-organizational
358 construction projects (Grilo and Jardim-Goncalves, 2010).

359 Apart from interoperability, collaborative working using BIM also demands new expert
360 roles of model managers who possess information and communications technology (ICT) and
361 construction process expertise (Sebastian, 2011). It is hard for a BIM manager to be involved
362 neither in decision making on design and engineering solutions nor in project management
363 processes but mainly focuses on model specification and information management. In many
364 cases, managerial hierarchy also exists among BIM managers, which leads to some
365 differences in their organizational roles. Furthermore, changing roles in collaborative work
366 that applies BIM affect the traditional contractual relationship, particularly payment schemes.
367 Given that engineering work is done concurrently with the design through BIM, for example,
368 a new payment percentage in the early design phase is also necessary (Chao-Duivis, 2009).

369 **4.2.2 Innovation**

370 Cluster #1 refers to the studies on innovation during the BIM diffusion process. Within the
371 construction industry, innovation is infamously known to be difficult to define and
372 conceptualize (Green et al., 2004). However, the concept of innovation is certain to be further
373 related with the espoused change in the construction industry, which is renowned for its
374 adversarial relationship and lack of trust among involved parties. Elmualim and Gilder (2014)
375 investigated the relationship among design management, innovation, and the role of BIM in
376 advancing collaboration in response to the required change. The innovation and the
377 application of emerging technologies are considered as enablers for transforming the project

378 delivery process and adding value across the entire project life cycle. Two main innovation
379 processes are involved with regard to the use of BIM as an innovative technology, namely,
380 innovation adoption and implementation.

381 Innovations take time to become extensively adopted because of insufficient referential
382 experiences (Gu and London, 2010). BIM is a relatively complex and influential innovation
383 (Eastman et al., 2011), and the general rate of BIM adoption is still much lower than expected
384 (Cao et al., 2015). To explore the internal mechanism of varying levels of BIM adoption,
385 Linderoth (2010) considered the diffusion of BIM as the transfer and spread of innovations
386 that are occurring in networks of actors linked to one another. The roles and relationships of
387 actors in a network relate to their potential motives for accepting or rejecting BIM.
388 Furthermore, Singh and Holmström (2015) investigated innovation-related decisions from the
389 viewpoint of Maslow's motivational theory on the hierarchy of needs, which developed
390 insights into the psychological processes that underlie the motivation to adopt BIM.

391 Along with BIM implementation, innovations are constantly emerging in this process to
392 improve management efficiency. Numerous variations of BIM technology arises at different
393 implementation stages to enhance information management efficiency performance and
394 facilitate the accomplishment of established project goals, including "site BIM," "green
395 BIM," and "cloud BIM." Davies and Harty (2013) applied an innovative "site BIM" system
396 in a major hospital construction project based on BIM-enabled tools that allow site workers to
397 use mobile tablets to access design information and acquire work quality and progress data
398 synchronously. "Green BIM" has become a tremendously popular term and concept in recent
399 years; it is applied to both building sustainability analysis and design management, as well as

400 construction stages; the goal of this process also extends to the entire life cycle of a building,
401 including the operation (commissioning and occupation), repair and maintenance, and
402 demolition stages (Wong and Zhou, 2015). Cloud computing refers to both the applications
403 delivered as a service over the Internet and the hardware and system software in data centers
404 that openly interoperate and exchange information (Armbrust et al., 2010). Cloud-based BIM
405 serves as an innovative platform that will enhance BIM usability experience for various
406 disciplines in making key design decisions at a relatively early project stage (Redmond et al.,
407 2012).

408 **4.2.3 Stakeholder/actor network**

409 Cluster #2 is related to the analytical perspective of the stakeholder or actor in BIM
410 adoption and implementation studies. As a “system” of multiple innovations, BIM generates
411 derived benefits to those involved in its implementation, but is also associated with the
412 potential for failures (i.e., cost overruns, and legal disputes). Gilligan and Kunz (2007)
413 conducted a survey to determine the value of BIM to project stakeholders, which mainly
414 referred to reducing risks for stakeholders distributed across the project and to engage
415 stakeholders further. By contrast, BIM has been challenged with the issues regarding
416 stakeholder collaboration and the manner of managing and controlling information (Sebastian,
417 2011). Murphy (2014) explained that the mechanism problem exposed in BIM
418 implementation was based on BIM currently being delivered as a project rather than an
419 innovation, as well as the failure to address stakeholder competency as the key delivery agent
420 of BIM.

421 Apart from the research that focuses on the individual level, the organizational-level

422 research related to the overall structure and characteristics of the actor network in which BIM
423 is applied provides a holistic approach to determine how BIM defines roles and relationships
424 among actors in a network (Linderoth, 2010), as well as how and why project networks
425 respond to new systemic innovations (i.e., BIM) that are misaligned to the existing network
426 structure (Alin et al., 2013). Moreover, the overall network approach suggests a need to
427 rethink actor interlinkages and interorganizational effects (i.e., task sequence alignment,
428 knowledge base alignment, and work allocation alignment), as well as to create new roles
429 associated with the implementation of BIM in construction projects.

430 **4.2.4 Spatial visualized management**

431 Cluster #3 refers to the studies related to spatial visualized management using BIM in
432 construction projects. ICT changes architectural visualization by extending architectural
433 design to visualization in information systems and by applying highly extensive computer
434 visualization given the availability of digital media (Koutamanis, 2000). Architectural
435 visualization plays a significant role in managing complicated interactions among involved
436 parties to balance all types of constraints and requirements (Wang et al., 2014). As a digital
437 representation of the physical and functional characteristics of a building, BIM fosters
438 multi-dimensional visualization capabilities to communicate ideas and share information
439 among various stakeholders in construction projects (Johansson et al., 2015). The application
440 and development of BIM in the spatial visualized management of a project are embodied in
441 two significant methods.

442 The first method is the integration of BIM with augmented reality (Wang et al., 2013), a
443 geographic information system (GIS) (Irizarry et al., 2013), and a wireless sensor (Riaz et al.,

444 2014), which extends the limits of visualized management, with the attempt to fill in the
445 technical gap. The second method concerns the synergy between BIM and lean philosophy to
446 provide process transparency to all participants and to pull the flow of teams and materials
447 (Sacks et al., 2009). Given the dynamic and dispersed physical environments and the
448 complicated contracting interfaces of construction projects, efficient and reliable visualized
449 management is based on addressing technical solutions and on improving
450 management-centered processes. This process highlights the importance of bridging both
451 technical and non-technical issues to create the enabling environment of real-time
452 autonomous decision making within highly variable project information flows.

453 **4.2.5 BIM adoption**

454 Cluster #4 covers the issues that focus on adoption activities in BIM implementation
455 process. Although the potential benefits of technologies may appear evident in BIM, the
456 industry adoption level of this process varies extensively, and the actual diffusion rate of
457 technology among involved parties worldwide remains considerably lower than expected (Gu
458 and London, 2010). Such a discrepancy between expected adoption and the realized adoption
459 of BIM may be explained by the uncertainty of its value and effectiveness. By considering the
460 possible gap among technical feasibility, potential value, and practical adoption, increasing
461 research interests and efforts are presented to examine the degree by which BIM is currently
462 adopted through the life cycles of construction projects in different countries or regions (Cao
463 et al., 2015; Samuelson and Björk, 2014; Mahalingam et al., 2015; Imoudu Enegbuma et al.,
464 2014), as well as the factors that drive BIM adoption in various types of organizations
465 (Aibinu and Venkatesh, 2013; Son et al., 2015). The studies on investigating BIM adoption

466 can be placed at three levels: the individual/actor, the project/organization, and the entire
467 market/industry.

468 The initial decision for BIM adoption has mostly been considered at the individual level, or
469 occasionally, at the organization level, and for single actors in the industry (Samuelson and
470 Björk, 2013). It is noteworthy that individual-level studies mainly revolve around technology
471 acceptance behavior-related theories, including theory of planned behavior (TPB), technology
472 acceptance model (TAM), and task-technology fit model (TTF). These theories put
473 considerable emphasis on the behavioral intentions of individuals. For the
474 project/organization level, the most prominent studies of BIM adoption include those on the
475 practices and effectiveness of BIM in construction projects in China (Cao et al., 2015) and
476 where to focus on the successful adoption of BIM within an organization (Won et al., 2013).
477 In summary, these findings identify numerous factors that drive or impede BIM adoption at
478 both the individual and project levels. These factors can be further grouped into three
479 dimensions, namely, technical and non-technical, institutional and non-institutional, and
480 internal behavioral intentions and external environment.

481 Regarding the market level, Succar and Kassem (2015) introduced a number of
482 macro-adoption models, matrices, and charts to assess BIM adoption across markets
483 systematically, as well as to inform the structured development of country-specific BIM
484 diffusion policies. Based on the industry level, Gu and London (2010) analyzed the readiness
485 of the industry with respect to the products, processes, and people to position BIM adoption in
486 terms of the current status and expectations across disciplines. The aforementioned studies
487 also established the collaborative BIM decision framework to facilitate BIM adoption in the

488 construction industry. Both market- and industry-level studies provide the holistic conceptual
489 framework to facilitate decision making, particularly for policymakers, within the BIM
490 diffusion process.

491 **4.2.6 Transmission**

492 Cluster #5 refers to the studies that focus on culture or policy transmission related to BIM
493 through the project life cycle, which is closely associated with cluster 4; however, the two
494 clusters have different priorities. BIM adoption is suggested to pay increased attention to
495 individual-level decision making in light of behavioral intentions. By contrast, culture or
496 policy transmission actually focuses on the BIM diffusion process, which highlights the
497 importance of creating the enabling environment to drive large-scale applications of BIM.

498 From the cultural transmission perspective, Brewer and Gajendran (2012) determined the
499 link among culture formation, culture development, and their effects on using BIM in
500 temporary project organization (TPO), which illuminated the positive cultural traits
501 demonstrated by the specialist subcontractor.

502 Policies are “written principles or rules to guide decision making,” which results in
503 environmental pressures (i.e., preparatory, regulatory, and contractual requirements) to
504 project decision makers in terms of acquiring institutional legitimacy. Succar (2009)
505 introduced an integrated framework that treated policy as one of the three major fields of BIM
506 to provide a research and delivery foundation for BIM diffusion policy development.
507 Furthermore, Succar and Kassem (2015) provided a “policy action model” by which the
508 actions that policymakers take to facilitate market-wide diffusion are identified, assessed, and
509 compared, thereby informing the macro-environment of country-specific BIM adoption

510 policies. These findings suggest that BIM diffusion is a highly socialized and complicated
511 activity that may be motivated by individual behavioral intentions to improve the efficiency
512 and effectiveness of the design, construction, and operation processes. This activity may also
513 be driven by cultural and policy transmission to be in line with its specific external
514 environment.

515 **4.2.7 Conceptual framework**

516 Cluster #6 is related to the development of a conceptual framework in MA-BIM studies. To
517 analyze MA-BIM, a few conceptual frameworks are proposed to represent domain concepts
518 and their relations, which can be divided into two types, namely, strategic- and tactical-level
519 frameworks. A strategic-level framework mainly focuses on the conceptual system, diffusion,
520 and adoption of BIM from a macroscopic perspective regardless of detailed implementation
521 steps. A tactical-level framework is concerned with the BIM application process, which aims
522 to provide a specific approach to overcome technical, procedural, and organizational
523 challenges.

524 At the strategic level, Succar (2009) introduced a series of conceptual frameworks to
525 structure the term “BIM” in a stepwise manner, including BIM fields, BIM maturity stages,
526 and BIM lenses. With the proliferation of BIM concepts through project organizations, a few
527 strategic assessment frameworks are introduced to recognize BIM “value proposition,” inform
528 the status of BIM implementation, and evaluate BIM diffusion policies based on the need for
529 guidance on the place to start, the tools available, and working through both technical and
530 non-technical issues.

531 At the tactical level, numerous conceptual frameworks were proposed to integrate BIM

532 with other technologies or business processes to provide implementation approaches. Varying
533 levels of understanding, adoption, and implementation of BIM within and among countries
534 exist—from discipline to discipline and from project to project. The challenges to achieve a
535 completely integrated collaborative multi-disciplinary platform of implementation is based on
536 determining technical solutions or addressing MA–BIM issues, as well as on setting up the
537 enabling conceptual framework, which integrates both strategic- and tactical-level
538 approaches.

539 **4.2.8 Operation and Maintenance**

540 The research themes of cluster #7 concentrate on the operations and maintenance (O&M)
541 stage in BIM implementation process. It is noteworthy that the use of BIM focuses on the
542 preplanning, design, and construction of buildings and infrastructure; however, the focus of
543 recent research has shifted from early life cycle stages to maintenance, refurbishment, and
544 deconstruction (Volk et al., 2014). The long building life cycles has resulted in O&M
545 management that becomes a major to exploit the functionalities and benefits of BIM fully,
546 particularly in relation to environmental performance monitoring and management using
547 virtual prototyping/visualization tools. Therefore, an increasing number of studies are
548 emerging, which aims to explore how BIM can be a beneficial platform to supplement O&M
549 practices. The two major dimensions that are centered on the research themes of cluster #7 are
550 building types (e.g., new buildings and existing buildings) and application areas (e.g.,
551 energy/thermal analysis and control, space management, refurbishment/renovation planning
552 and execution, quality assurance and control).

553 Within the dimension of building types, Volk et al. (2014) explained that with a decrease in

554 new construction rates worldwide, particularly in industrialized countries, existing buildings
555 would become the main application field of BIM. Unlike new buildings (e.g., buildings under
556 construction, and recently completed buildings), existing buildings without preexisting BIM
557 face the considerable challenges of automatic data capture and BIM creation, along with the
558 handling and modeling of uncertain data, objects, and relations. The limitations of BIM use in
559 the O&M stage of existing buildings call for future research efforts.

560 For the dimension of application areas, Becerik-Gerber et al. (2011) conducted an online
561 survey and face-to-face interviews to assess the current status of BIM implementations in the
562 O&M stage, potential applications, and the interest level in the utilization of BIM, which
563 highlighted the synergy between BIM and O&M in terms of data requirements. Moreover,
564 resource scarcity and highly strict decrees for recycling and resource efficiency in
565 construction projects have awakened the construction industry to the importance of enhancing
566 environmental sustainability through emerging new technologies (i.e., ‘green BIM’).
567 Therefore, BIM-based environmental performance management is among the highly
568 important application areas in O&M stages. Wong and Zhou (2015) stated that a
569 “one-stop-shop” BIM for environmental sustainability monitoring and management over the
570 entire life cycle of a building should be considered in future studies, particularly during
571 building maintenance, retrofitting, and demolition stages. Based on the aforementioned
572 problems and challenges, “green BIM” and BIM-enabled existing building management seem
573 to be the most important directions for future O&M studies.

574 **5. The conceptual framework for MA–BIM**

575 **5.1 Introduction to MA–BIM conceptual framework**

576 The scientometric analysis of MA–BIM provides supporting elements to this study in its
577 objective to develop an integrated framework. Although the framework is currently
578 conceptual, the scientometric analysis of the overall structure, theme-divisions, and emergent
579 trends, along with the practical experiential knowledge, of MA–BIM makes this framework
580 both practical and enlightening.

581 Fig. 7 shows that the conceptual framework has three major parties, namely, current status,
582 research areas, and future directions. Instead of applying an a priori classification approach,
583 this paper conduct a quantitative analysis based on the abstract terms to distinguish different
584 research themes. And 8 theme-clusters are further integrated into 5 research areas according
585 to the framework developed by Gu and London (2010). It is noteworthy that this framework
586 summarizes the perceptions of BIM from the perspective of *product*, *process*, and *people*, and
587 also emphasizes the importance of creating the enabling *environment* of BIM management
588 and choosing suitable *application approaches* to fulfill BIM potential.

589 

590 BIM adoption leads to substantial changes in the existing project management processes,
591 involving innovation diffusions, culture and policy transmissions. In parallel with the rapid
592 popularization of BIM technologies, a series of “soft” products (i.e., conceptual frameworks)
593 have emerged to provide support and guidance for BIM implementation. And stakeholders
594 and actors are people whose roles associate with BIM practices. It is noteworthy that
595 collaborative working environment refers to the external context in relation to BIM, and

596 spatial visualized management and O&M are particularly concerning issues when choosing
597 suitable application approaches of BIM. Fig.8 summarizes the 5 principal research areas of
598 MA–BIM at a broad level, and shed further light on their inter-relationships. The implications
599 and inter-relationships of 8 theme-clusters are further described on the basis of 5 research
600 areas of MA–BIM as follows.

601 *Firstly*, conceptual framework (#6) can be regarded as a managerial product to structure
602 strategies and implementation approaches against MA-BIM issues. *Secondly*, innovation (#1),
603 BIM adoption (#4), and transmission (#5) are interrelated and interact on each other in the
604 BIM diffusion process. *Thirdly*, new roles and relationships within the project teams are
605 emerging through the BIM adoption and implementation process. And stakeholder or actor
606 (#2) is the implement subject of BIM throughout the project life cycle. *Fourthly*, spatial
607 visualized management (#3) is the application way of BIM in relation to managerial aspects
608 (i.e., lean philosophy). O&M (#7) becomes the most potential stage for future MA–BIM
609 research as mentioned in Section 4.2. Both of application way and stage for this study is
610 summed up in one aspect—‘application approach’, with a view to focusing on the way of
611 realization for MA–BIM benefits. *Finally*, collaborative working environment (#0) is
612 regarded as the ideal external condition to be achieved for MA–BIM. Through the lens of the
613 aforementioned 5 principal research areas, the current status and future directions of
614 MA–BIM are further discussed as follows.

615  Insert Fig. 8 about here

616 **5.2 Detailed elements of MA–BIM conceptual framework**

617 **5.2.1 Conceptual framework**

618 The conceptual framework corresponds to cluster #6 (conceptual framework), which can be
619 divided into two levels (i.e., strategic and tactical). Apart from the adoption and diffusion of
620 BIM, developing strategic-level frameworks for the post-evaluation process in view of
621 tracking BIM application performance throughout the project life cycle is useful. It is notable
622 that the applicability of tactical-level frameworks should be regarded within different
623 organizational and regional contexts. Contextual factors (i.e., organizational model,
624 institutional pressures, and cultural environment) exert substantial implications on the manner
625 by which stakeholders engage in BIM adoption and implementation processes. Despite the
626 close association between MA–BIM framework and contextual factors, there is still a lack of
627 studies exploring this issue and its impact. A substantial proportion of existing literature has
628 ignored contextual differences and endeavored to establish MA–BIM frameworks which are
629 universal across organizational and regional boundaries. Therefore, future research in this
630 field could bring insightful and beneficial results.

631 **5.2.2 Adoption process**

632 The adoption process relates to clusters #1, #4, and #5 (i.e., innovation, BIM adoption, and
633 transmission, respectively), which involve the spread of innovation, cultural and policy
634 transmission, technology acceptance behavior-related theories, and influential factors of BIM
635 adoption. In future studies, leadership theory and psychological factors can be considered for
636 empirical studies in terms of individual BIM adoption process. For instance, empirical studies
637 can be undertaken to explore the influences of different styles of leadership (e.g.,

638 transformational leadership and transactional leadership) and psychological capital on the
639 individual BIM adoption process. Moreover, exploring the influences of organizational inertia
640 on BIM adoption process is also necessary. For the market-level BIM adoption, the influences
641 of regional differences (e.g. culture variances and institutional environment) cannot be
642 ignored.

643 **5.2.3 Stakeholder and actor**

644 The stakeholder and actor refers to cluster #2 (stakeholder/actor network), which concerns
645 stakeholder competency, stakeholder collaboration, and actor networks. Successful BIM
646 adoption and implementation process requires fully considering and effectively balancing
647 stakeholder interests relations and priorities of concerns. Notwithstanding the significance of
648 analyzing stakeholder interrelationships in project organizations, existing MA–BIM research
649 in relation to stakeholder or actor has paid inadequate attention to quantitative measurement
650 of stakeholder network characteristics. In future research, social network analysis (SNA) can
651 be undertaken to reveal the overall structure (e.g., density and cohesive subgroup) and
652 relational ties (e.g., expressive ties and instrumental tie) of stakeholder network. By
653 identifying the key stakeholder (e.g. opinion leader) through SNA assessment, the leadership
654 influences could be better exercised to facilitate BIM adoption and implementation. In
655 addition, external environment factors (e.g., institutional pressure) also need to be given
656 attention in project networks analysis.

657 **5.2.4 Application approach**

658 The application approach corresponds to cluster #3 (i.e., spatial visualized management,
659 and O&M, respectively), which focuses on the way (stage) to achieve BIM's capabilities in

660 managerial areas. Currently, real-time information visibility and traceability still falls short of
661 expectations partially because of the complex physical conditions of construction sites and
662 fractured contract interfaces. Therefore, future studies in this area will synchronize visualized
663 management with ongoing project processes in a real-time manner. Combining visualized
664 management with risk scenario planning is also necessary to remove lurking perils beforehand.
665 In addition, increasingly serious worldwide environmental problems and numerous buildings
666 without preexisting BIM in the design and construction stages stimulate research interests
667 related to “green BIM” and existing BIM-enabled building management.

668 **5.2.5 Working environment**

669 The working environment relates to cluster #0 (collaborative working environment), which
670 involves interoperability, as well as changing roles in collaborative working. The efforts for
671 interoperability of the construction industry have been highly focused on technical issues of
672 connecting systems and applications among the involved parties. It is noteworthy that
673 widening the technically focused view of interoperability is required to cover business
674 processes and contractual management in creating a collaborative working environment. The
675 concept of organizational climate is a particularly useful indicator to characterize MA–BIM
676 working environment. In future research, empirical studies can be undertaken to analyze the
677 practical implications of different types of organizational climate (e.g., empowerment climate,
678 ethical climate) for the success of BIM adoption and implementation.

679 **6. Conclusions**

680 BIM technology and its increasing use are prompting several profound changes in business
681 processes and project management practices. As the technical side of BIM evolves, new roles

682 and relationships within project stakeholders, along with various project delivery systems (i.e.,
683 IPD, IPD-ish, or IPD-lite), are constantly emerging. The managerial areas of BIM have been
684 attracting considerable attention from both the construction industry and academia because of
685 the potential of this area in coordinating and managing overall project information and
686 processes, as well as aligning organizational strategies within a complex project environment.

687 This study has drawn findings from a body of literature comprising 126 papers published in
688 16 academic journals, in response to the search term “MA–BIM.” A variety of scientometric
689 techniques are used to analyze changes in MA–BIM studies published between 2007 and
690 2015, including keyword co-occurrence network, keyword burst detection, and abstract term
691 cluster analysis.

692 The keywords and abstracts have been analyzed in terms of the co-occurrence and rate of
693 frequency change of keywords, and semantic grouping of abstract terms. *Firstly*, the
694 keywords are used to construct co-occurrence network maps of the field as a whole. *Secondly*,
695 future directions are identified in the MA–BIM field using keyword burst detection, which
696 indicate a paradigm shift from tactic focus to an emphasis on broad strategy, as well as from
697 individual-centered issues to a broad organizational perspective. *Thirdly*, the abstract term
698 cluster analysis reveals 8 prominent research themes in the MA–BIM field , namely
699 collaborative working environment, innovation, stakeholder/actor network, spatial visualized
700 management, BIM adoption, transmission, conceptual framework, and O&M.

701 Based on the scientometric analysis, this study has further developed an integrated
702 conceptual framework for MA–BIM to refine the 8 theme-clusters into 5 key aspects, with the
703 objective of providing structured means of describing current status and future directions. The

704 traditional BIM adoption analysis, which emphasizes individual behavior intentions, has been
705 extensively used in MA–BIM regardless of leadership factors and organizational inertia. This
706 scientometric analysis of MA–BIM is significant and invaluable in allowing bibliometric data
707 to provide a highly accurate representation of previous research efforts, as well as in
708 illustrating a future research direction for this field.

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Table 1

Distribution of selected papers.

Journal name	Number of retrieved papers from WoS and Scopus	Number of selected papers for this study
Automation in Construction	152	30
Journal of Construction Engineering and Management	27	18
Construction Innovation	22	15
Journal of Professional Issues in Engineering Education and Practice	13	11
Journal of Information Technology in Journal of Management in Engineering	28	11
Construction Management and Economics	12	9
Engineering, Construction and Architectural Management	10	7
Building and Environment	6	6
Building Research and Information	4	3
International Journal of Project Management	4	3
Proceedings of the Institution of Civil Engineers–Civil Engineering	4	3
Canadian Journal of Civil Engineering	5	2
KSCE Journal of Civil Engineering	8	2
Project Management Journal	2	2
Journal of Civil Engineering and Management	7	1
Total	308	126

Table 2

Normalized keywords list.

No.	Primary keywords	Normalized keywords
1	Application areas	Application area
2	Case studies	Case study
3	Costs	Cost
4	Construction projects	Construction project
5	Construction sites	Construction site
6	Computer-aided design (cad)	Computer aided design
7	Computer-aided design	Computer aided design
8	Curricula	Curriculum
9	Decision-making	Decision making
10	Engineering and construction (aec) industry	Construction industry
11	Facilities management	Facility management
12	Information technologies	Information technology
13	Information technology (it)	Information technology
14	Quantity takeoff	Quantity take-off
15	Surveys	Survey
16	Structural equation modeling (sem)	Structural equation model
17	Technology acceptance model (tam)	Technology acceptance model
18	Tam (technology acceptance model)	Technology acceptance model
19	Three-dimensional (3d) models	Three-dimensional models
20	3d models	Three-dimensional models

Table 3

Whole characteristics of the keyword co-occurrence network.

Network	Nodes	Edges	Density	Modularity Q	Mean Silhouette
keyword co-occurrence	490	1448	0.0121	0.8115	0.9372

Table 4

Eight research clusters in the field of MA–BIM.

Cluster	Size	Silhouette	Top terms
#0	15	0.723	Collaboration, Collaborative design, Interoperability
#1	14	0.845	Innovation, Innovation processes, Innovation diffusion, Innovation-related decisions
#2	11	0.892	Stakeholder management, Stakeholder competence, Actor network
#3	11	0.909	Visualization, Visualized management, Real-time visualization
#4	9	0.948	Adoption, Industry adoption, Behavioral intentions, Point of adoption
#5	9	0.912	Cultural transmission, Policy transmission, BIM diffusion policy
#6	5	1	Framework, Conceptual framework, Theoretical framework
#7	5	0.947	O&M, Existing building, Refurbishment, Deconstruction

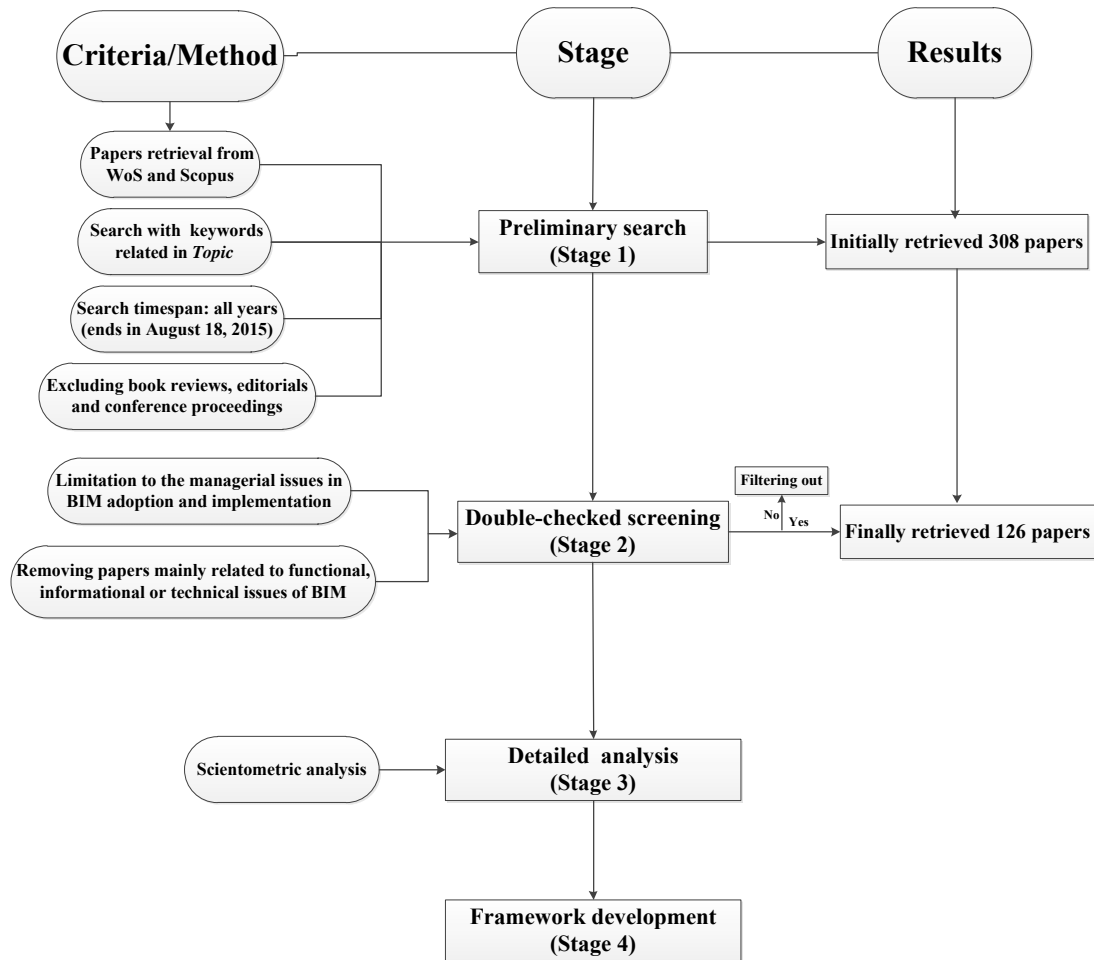


Fig. 1. Research framework of this study.

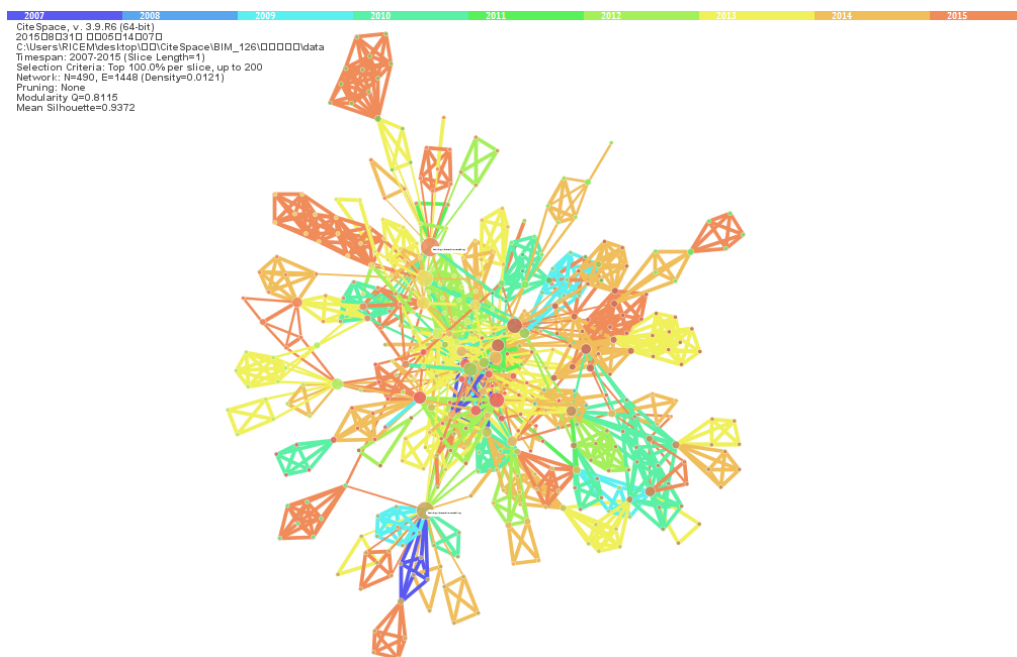


Fig. 2. Keyword co-occurrence network: 2007-2015.

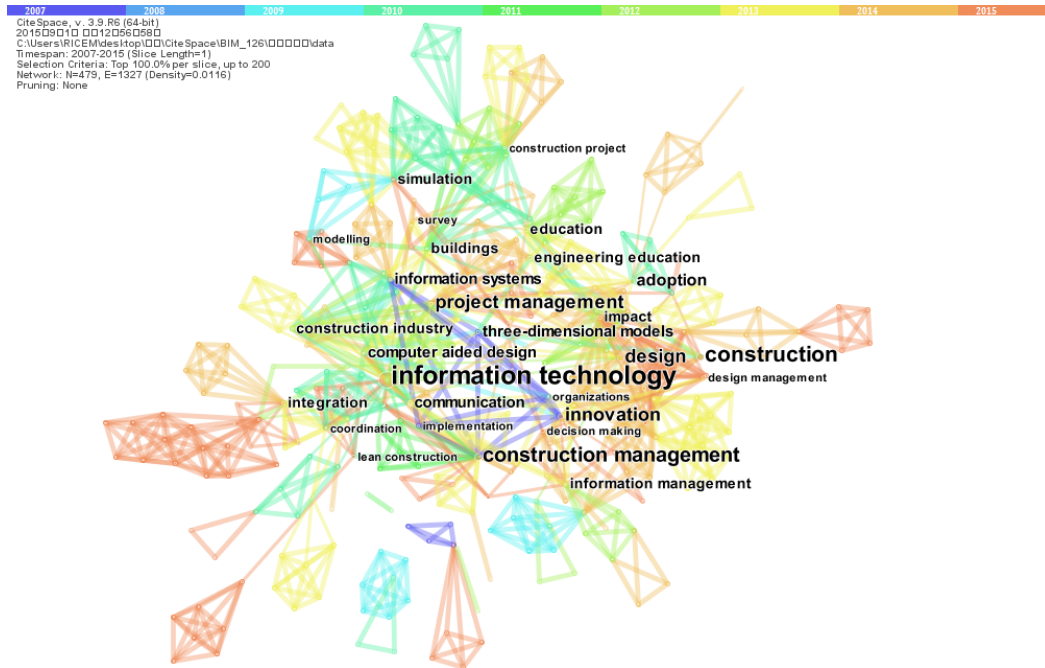


Fig. 3. Top keywords occurring more than twice: 2007-2015.

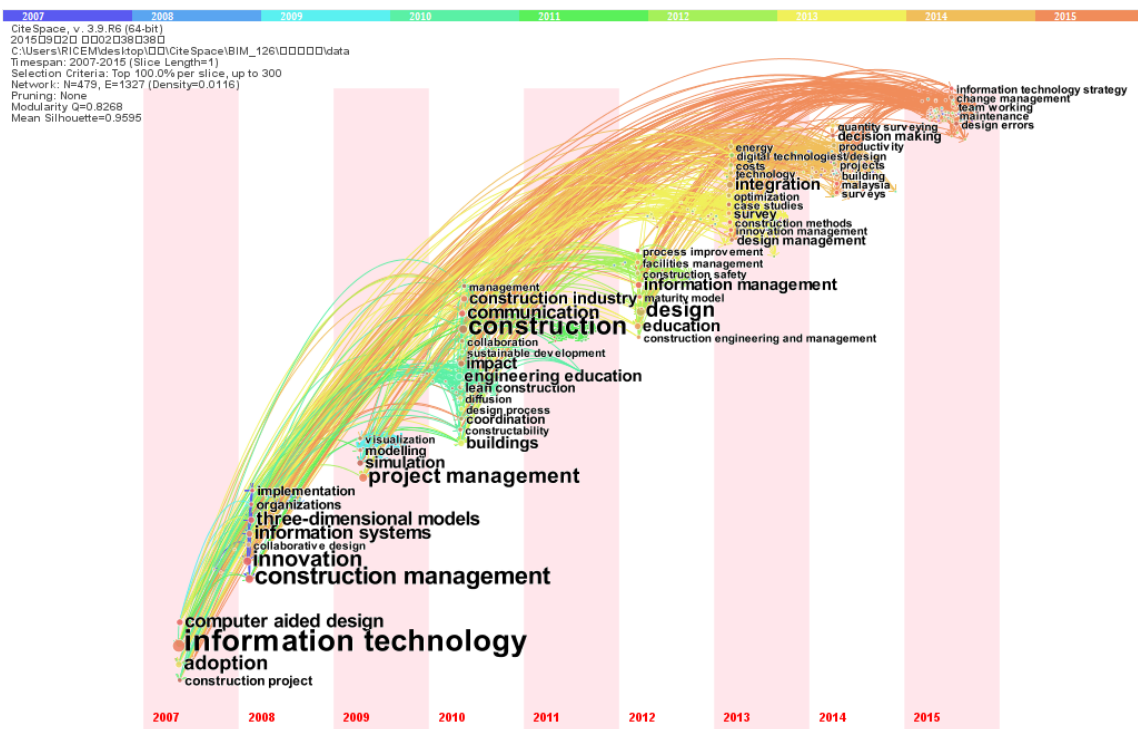


Fig. 4. A timeline view of keyword co-occurrence network: 2007-2015.

Keywords	Year	Strength	Begin	End	2007 - 2015
three-dimensional models	2007	1.1287	2007	2010	
change management	2007	0.9851	2007	2015	
information technology strategy	2007	0.9851	2007	2015	
maintenance	2007	0.9851	2007	2015	
design errors	2007	0.9851	2007	2015	
team working	2007	0.9851	2007	2015	
decision making	2007	0.9686	2007	2013	
design	2007	0.9065	2007	2011	
construction	2007	0.7398	2007	2012	
collaborative design	2007	0.9645	2008	2015	
project management	2007	0.2976	2009	2013	
innovation	2007	1.1533	2010	2012	
organizations	2007	0.6091	2010	2015	
collaboration	2007	0.4853	2010	2013	
management	2007	0.4853	2010	2013	
construction industry	2007	0.4746	2010	2012	
lean construction	2007	1.1636	2011	2015	
impact	2007	0.8715	2011	2013	
diffusion	2007	0.7749	2011	2015	
constructability	2007	0.7749	2011	2015	
sustainable development	2007	0.7749	2011	2015	
information systems	2007	0.6545	2011	2015	
adoption	2007	0.3972	2011	2013	
modelling	2007	1.0924	2012	2015	
education	2007	0.5654	2012	2015	

Fig. 5. Top 25 bursting keywords: 2007-2015 (sort by the beginning year of burst).

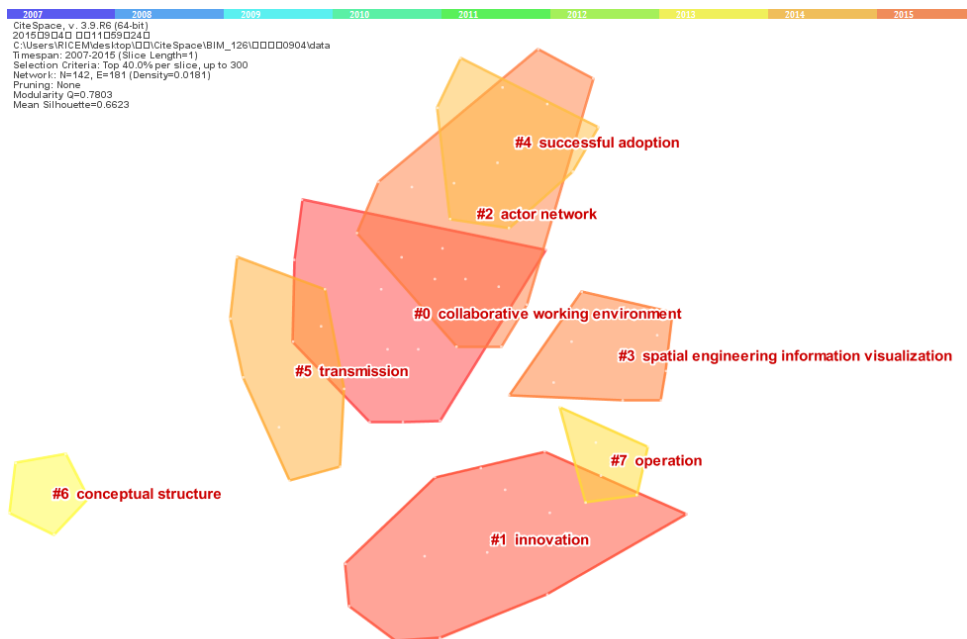


Fig. 6. Cluster analysis in MA-BIM field: 2007-2015.

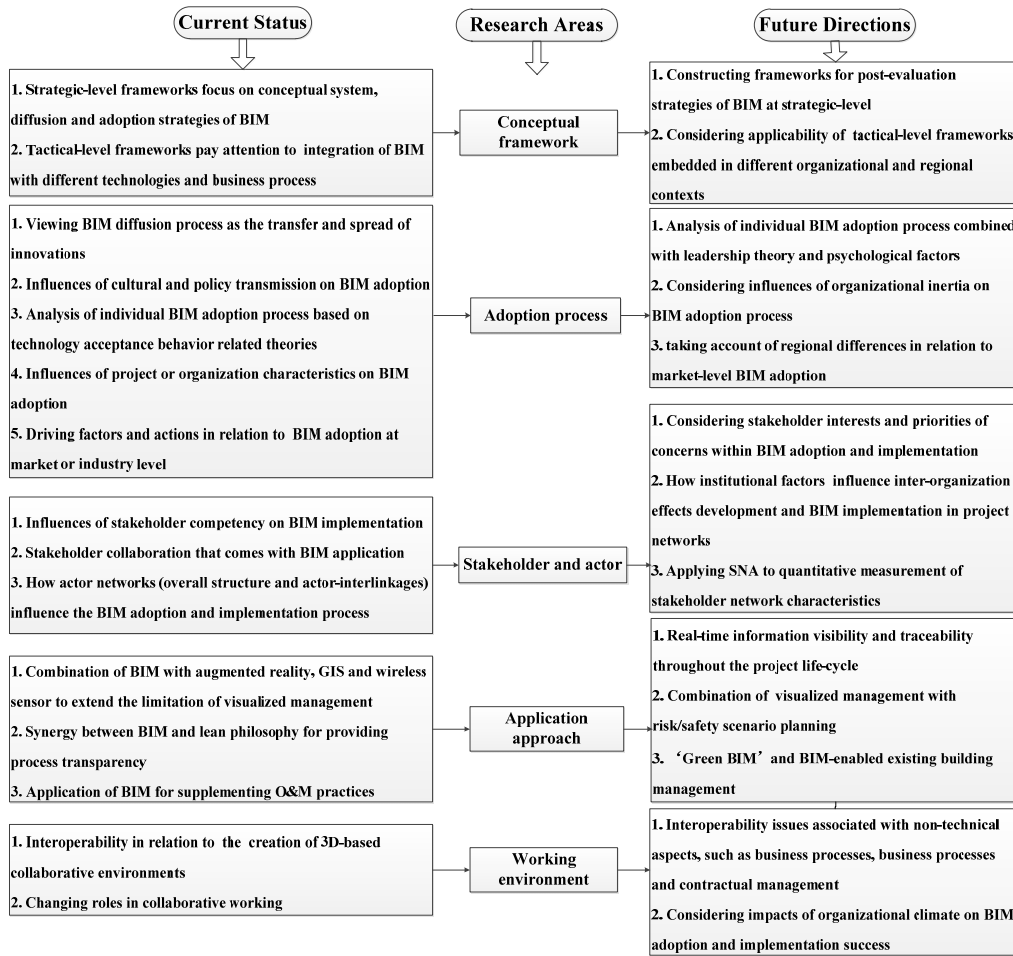


Fig. 7. The conceptual framework for MA-BIM.

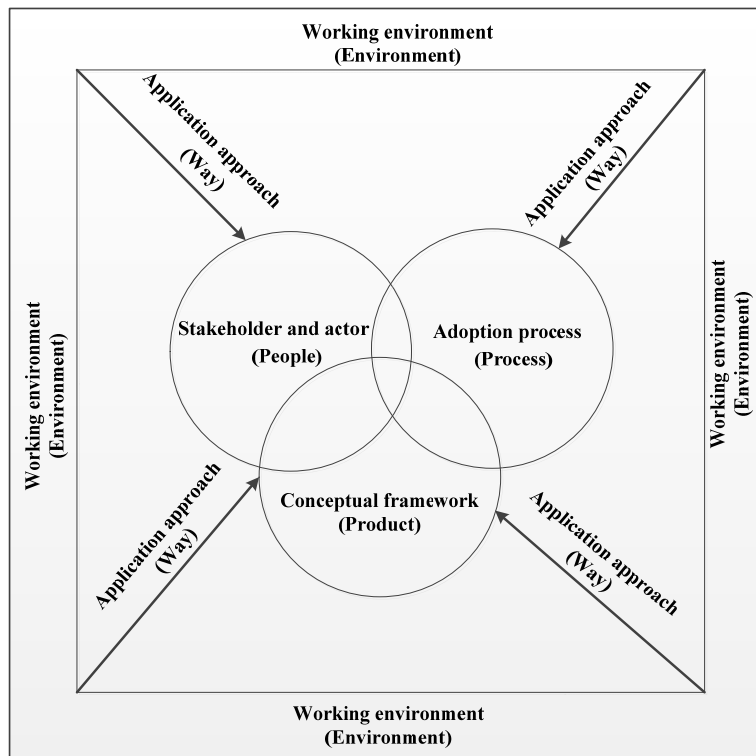


Fig. 8. The five principal research areas of MA-BIM