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Potential features of building information modeling (BIM) for application of project management knowledge areas in the construction industry

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ABSTRACT

The construction industry (CI) plays a vital role in infrastructure development and improves the socio-economic status with employment opportunities and contribution to gross domestic progress (GDP) of countries. However, its productivity has diminished in recent years due to increasing complexities in construction projects (CPs) and lack of adoption of novel technologies such as Building Information Modeling (BIM). Also, there is a significant need of polishing the capabilities of construction practitioners to meet the project requirements in agreement with project management knowledge areas (PMKAs). This study, therefore, focused on identification and evaluation of factors necessary for measurement of extent of application of PMKAs. Subsequently, noteworthy features of BIM helpful for enhancing the capabilities of project managers (PMs) in application of PMKAs were identified from literature. A total of thirty-three factors for measurement of extent of application of PMKAs and sixty-six features of BIM helpful in enhancing the capabilities of PMs in application of PMKAs were found. The detailed study and analysis of these ninety-nine factors with the help of previous studies suggested that extent of application of PMKAs is measured with three sub-tasks i.e., plan, manage/develop, and monitor/control. In addition, by virtue of remarkable features and services of BIM, it helps in enhancing the capabilities of PMs in applying PMKAs: project integration, scope, cost, time, quality, resource, communications, procurement, risk, safety, and stakeholder management.

1. Introduction

Due to the growing uncertainties, expanding approaches, and unique technologies that are being used in many construction phases and processes, the construction industry (hereafter CI) has become extremely dynamic [1]. It has been witnessed that, CI exhibits significantly variable working environment due to involvement of various construction players, and occurrence of various certain and uncertain events [2]. CI not only plays a pivotal role in development of infrastructures, but also uplifts the socio-economic status and

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lifestyle standards in developing and developed countries [3]. Subsequently, CI also creates employment opportunities for skilled and unskilled workers and provides its contribution in gross domestic progress (GDP) of countries [4]. The projects undertaken by CI are considered successful, only if completed within the stipulated set of physical (materials, money, manpower etc.) and non-physical (time, skills etc.) resources [5].

However, in recent decades, CI has experienced detrimental effects of various challenges because of fragmented [6] yet dynamic nature of CI and lack of proper communication between various CI stakeholders [7]. Likewise, global CI has shown very low productivity due to time and budget overruns, and generation of enormous waste and anthropogenic emissions harmful to living environment [8–13]. This certifies that the adoption of emerging technologies in construction activities can play a crucial role in overall revamping and progress of the industry [6,9]. To lead construction projects (CPs) towards success, project managers (PMs) must (i) enhance; efficacy, productivity, excellence, infrastructure value, and its capacity to endure (ii) decrease; lifecycle costs, times devoured through expanding collaboration and connection of stakeholders of a project [14] which can be achieved by means of novel technologies [15].

Building Information Modeling (BIM) is one such technological approach [15] which as a tool helps in object-based parametric modeling of structures [14,16,17] and helps PMs in collaborative process of CPs [18–20]. Although, the history of BIM is not so long but recent decades have witnessed its utility in various construction and manufacturing processes [21,22]. BIM enhances collaboration between all parties and framework divisions and effectively coordinates with integrated project delivery systems. In addition, BIM provides integration of various distinct disciplines by viable communication, analyses the project systems for constructability, assesses the expense and time of projects whenever using cost and materials amount take-offs, attracts a giant image of projects using visualization and builds cooperative groups of these are what a PM will do in an alternate scale throughout a project life cycle [21]. Thus, BIM has changed the shape of CI market from traditional to digital marketplace [23]. The recent developments in body of knowledge related to BIM imply that there is an enormous potential in BIM to enhance the management attributes of PMs and polish their knowledge areas in AEC industry [24,25]. This review study, therefore, aimed to evaluate the contribution of BIM in enhancing the capabilities of PMs in applying various knowledge areas in the CI.

2. Review methodology

In this study, a methodology focusing identification of potentials of BIM in enhancing the capabilities of project managers in applying knowledge areas in the CI was undertaken by conducting an extensive review of published literature. Initially, the publications were retrieved using titles, keywords, and abstracts in research databases and search engines such as Google, Science Direct, SAGE, Frontiers, Bing, the Web of Science database, Google Scholar, and Scopus database etc. For the sake of acquiring most relevant literature, Boolean operators i.e., AND, OR etc. were used separately and in combination with search keywords as "BIM", "Construction Industry", "Project Management Knowledge Area" etc. The literature search and retrieval methodology has been illustrated in Fig. 1. In order to retrieve relevant and close publications, a few of the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process [26] were employed. The criterion followed for choice of literature publications was based on i) those focused on relationship of project management knowledge areas and BIM (checking titles and abstracts) ii) the publication period was 2000–2022, iii) the language of publication was English as it is widely spoken and understood being a global lingua franca [27]. In all the reviewed studies, the inclusion/exclusion criterion were critically analyzed, and all the gathered information was passed through double-checking. The possible risk of bias was handled by checking all the reviewed research studies under a similar set of rules. Nevertheless, it is still possible that some of the relevant publications may not be obtained because of the restricted retrieval process

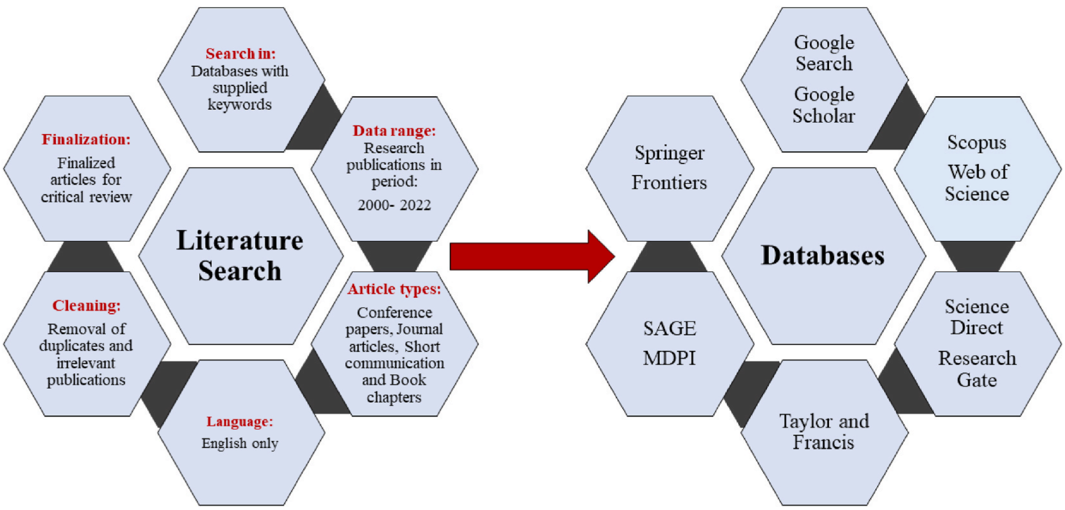

Fig. 1. Literature search methodology.

and selection (inclusion/exclusion) criteria that is based on aforementioned keywords. However, the risk of bias of intrinsic nature in all the individual studies reviewed in this study did not influence the review process because the risk stress levels have not been determined in this research. Thus, the approach employed in this study for mapping various factors, based on the count, is unbiased. A similar approach has been utilized by Ullah et al. in their recent studies [28,29] and the same has been established in PRISMA guidelines [26]. The process of literature retrieval and inclusion or exclusion of sources is illustrated in Fig. 2. All the relevant publications retrieved from various databases were reviewed to identify the potential features of BIM helpful for enhancing the capabilities of PMs in applying various knowledge areas in CI.

3. Literature review

Usually, projects possess impermanent nature as they may last minutes, hours, days, weeks, months, or years. In addition, projects are always unique in the sense that the same has not been previously accomplished in a similar way to reach at a new deliverable with similar precision [30]. Thus, Project Management Institute (PMI) [31] defines project as "a temporary endeavour undertaken to create a unique product, service, or result". Project management is associated with the effective delivery of projects. According to the PMI, "Project Management is the utilization of knowledge skills tools, and techniques to project activities to meet or surpass stakeholder requirements and desires from a project. Meeting or surpassing stakeholder needs, and desires constantly includes balancing contending demands between: (1) scope, time, cost, and quality, (2) stakeholders with contrasting requirements and expectations, and (3) distinguished requirements (needs) and unidentified needs (desires)." [31].

PMs in industry would decide to rely upon project management information and common management attributes such as setting up the project, suitable execution, clear control, effective conveyance, and efficient utilization of project team to accomplish project targets and exploit project constraints. Thus, project management is never viewed as only the completion of project, rather it encompasses broad and overall management skills that permit and aid the PMs to complete the project with some adequate level of potency and control. In bound regards, managing a project is identical to maintaining a business: there are rewards and hazards, accounting activities and finance, human resource problems, stress management, and a reason for the project to exist. Common management abilities are required in each project [30,32].

3.1. *Project management knowledge areas (PMKAs)*

According to the distribution of Project Management Body of Knowledge (PMBoK), ten distinct project management knowledge areas: project integration, scope, cost, time, quality, resource, communications, procurement, risk, and stakeholder management are reported [33] as shown in Fig. 3 adopted from Shaqour (2022) [25]. Each of PMKA can be easily broken into three main tasks say as plan, manage/develop, and monitor/control [25,33]. However, literature has also reported safety management as required knowledge area for PMs [25,30] as the clients and PMs have axial role in ensuring occupational health and safety on their projects [34,35].

3.1.1. *Project integration management*

CPs include numerous distinct categories of activities going on and thus, there occurs a need to keep the entire project overall

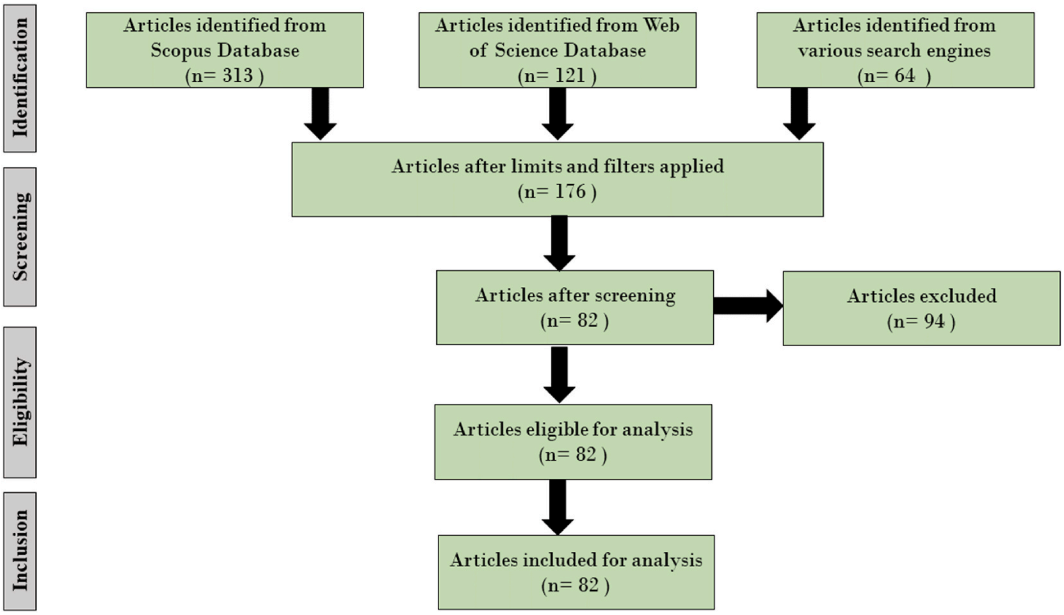

Fig. 2. PRISMA-based Review Flow Diagram (modified in accordance with [26]).

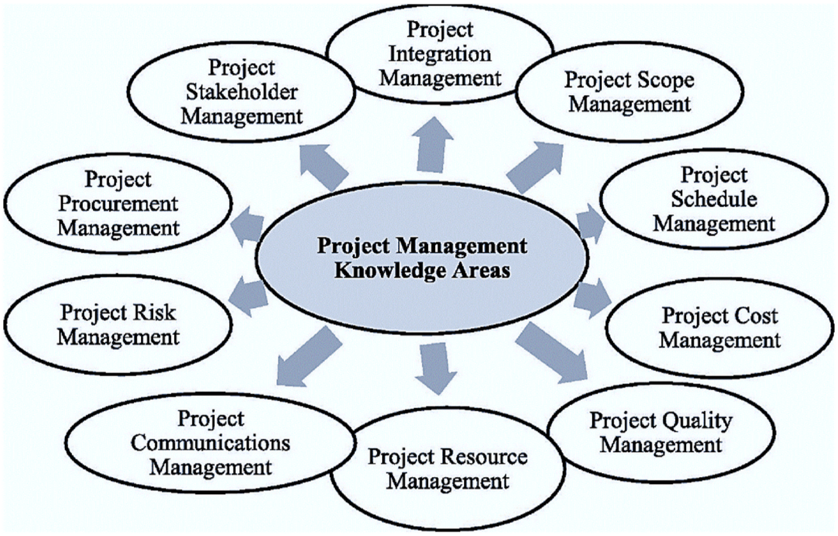

Fig. 3. Project management knowledge areas (PMKAs) [25,31].

mobile, with strong integration of all the ongoing dynamics. Project Integration Management is tied in with building up the scope statement, project charter, and plan to coordinate, oversee, monitor, and control project change [25,30,31].

3.1.2. *Project scope management*

The scope of CPs is the first of accomplishment measurements, due to its globalizing nature, and predictive significance, just as for its strategic significance against various change orders. In addition, it is affirmed that the scope management of CPs is displayed as one of the key drivers and critical success factors of construction organizations, this last being the abstract of the accomplishment of projects, business, and associations themselves [30,36].

3.1.3. *Project time management*

Time management is the way forward towards organization and implementation of a process identified with the time frame required for distinct work activities on CPs. Nevertheless, effective time management is always considered as a pre-requisite of effectively, proactively, and proficiently adhering to program and budget targets, as similar to accomplishing profitability. CPs can end up acquiring pointless time and costs overruns due to ineffective management of time, either by neglecting to consider the overall complexity of a project, or by neglecting to effectively manage scheduled work or sudden events [30,37].

3.1.4. *Project cost management*

By virtue of extensive life cycle of CPs and presence of numerous engineering stakeholders/participants, there are several issues in project cost management. Various challenges may include, non-exact prior cost estimation, low information handling speed, bottlenecks in sharing data between project participants, and obsolete methods for engineering cost information preservation [30,38].

3.1.5. *Project quality management*

The quality of any item is mirrored in its capacity to fulfil declared or silent design requirements and internal attributes of a completed item moreover to its outer design [30,39]. Hence, construction item quality is outlined as: “the degree to that the declared or silent wants and also the internal attributes are warranted all through the process of construction” [40]. The importance of construction quality management is in line with the principles of the measures and in the discipline responsible for the relationship analysis between results, activities, and customers. When the interconnection between relationships is analyzed and understood, it guarantees achievement of organizational goals through enhanced focus [41,42].

3.1.6. *Project resources management*

CPs comprise of teams which should be managed by PMs during the project lifecycle. However, finding the ideal resources, managing their results, and maintaining their assignments with respect to schedules is key to resource management. Resources management is associated with resource planning, procuring, hiring, developing, and managing a project team [30]. In continuation, resource management is viewed mandatory in accelerating the mobility of construction organizations. Various intrinsic and/or fundamental principles of resource management may include planning, acquiring, and managing the resources, complainant dealing, recruitment and selection, human resource planning and performance management, on-site safety, organizational development, and industrial relations [25,30].

3.1.7. Project communication management

In CPs, communication is considered as core, where PMs devour 90% of their time communicating with project members. Effective and efficient communication insures complete functionality of communication process, robust understanding of receiver, and achievement of desired results. The application of effective and active communication skills by PMs overcome tough junctures encountered by CPs [43]. In short, effective communication management serves the purpose of efficient planning, managing, and monitoring various resources available in CPs [25].

3.1.8. Project procurement management

CPs involve procurement of services, equipment, and tools from externally located vendors and contractors. There is a need to oversee how merchants are chosen and oversaw inside the project lifecycle. Procurement management is related to acquisition and contracting plans, vendors' responses and choices, contract administration, and contract closure [30].

3.1.9. Project risk management

CPs being unique in nature involve complex processes from start to end, with numerous ambiguities and uncertain events [44,45]. Because, the risk and uncertainty are never unavoidable in CPs, both should be properly handled with various risk management approaches and attitudes but should never be ignored [45,46]. Risk management holds a central and critical place in overall construction management processes. It is accomplished by means of various tools such as brainstorming, spreadsheets, SWOT analysis, and risk registers etc. [45].

Table 1
Factors Measuring Extent of Application of PMKAs, as identified from literature.

S. No.	Factors Identified from Literature	References
	Project Integration Management	
1.	Project Plan Development	[30,31,52]
2.	Project Plan Execution	[30,31,52]
3.	Integrated Change Control	[30,31,52]
	Project Scope Management	
4.	Initiation and Planning	[30,31,52]
5.	Scope Verification	[30,31,52]
6.	Change Control in Project Scope	[30,31,52]
	Project Time Management	
7.	Activity Definition, Sequencing & Duration Estimation	[30,31,52]
8.	Schedule Development Control	[30,31,52]
9.	Progress Monitoring	[30,31,52]
	Project Cost Management	
10.	Resource Planning	[30,31,52]
11.	Cost Estimating	[30,31,52]
12.	Cost Budgeting & Control	[30,31,52]
	Project Quality Management	
13.	Quality Planning	[30,31,52]
14.	Quality Assurance	[30,31,52]
15.	Quality Control	[30,31,52]
	Project Resources Management	
16.	Organizational Planning	[30,31,52]
17.	Staff Acquisition & Team Development	[30,31,52]
18.	Project Team Closeout	[30,31,52]
	Project Communication Management	
19.	Communication Planning	[30,31,52]
20.	Information Distribution	[30,31,52]
21.	Performance Reporting and Administrative Closure	[30,31,52]
	Project Procurement Management	
22.	Procurement Planning	[30,31,52]
23.	Solicitation Planning	[30,31,52]
24.	Contract Administration and Contract Closeout	[30,31,52]
	Project Risk Management	
25.	Risk Identification	[30,31,52]
26.	Risk Analysis	[30,31,52]
27.	Risk Monitoring and Control	[30,31,52]
	Project Stakeholders Management	
28.	Identification and Planning the Management of Parties in Project	[30,31]
29.	Management of Participation of Project Parties	[30,31]
30.	Management of Project Parties	[30,31]
	Project Safety Management	
31.	Safety Planning	[30,52]
32.	Safety Plan Execution	[30,52]
33.	Safety Administration and Records	[30,52]

3.1.10. *Project stakeholders management*

Project stakeholders management is one in all the foremost remarkable project important success factors, as the success of any CP mainly depends upon stakeholder's satisfaction [47]. Reference [48,49] characterized the stakeholders as internal and external. Internal stakeholders have a consistent and official association with the project while external stakeholders only affect the projects. Further division of internal stakeholders can be made as from perspective of demand side and supply side, while for external stakeholders, private and public categories can be formed [48,49].

3.1.11. *Project safety management*

CPs around the globe are under tremendous pressure for maintaining the safety protocols to avoid increasing accidents, injuries, and fatalities at construction worksites. Because of increasing complexity and uncertainties in CPs, higher levels of risks are being witnessed. The domain of project safety management knowledge area includes proper performance management and monitoring of all the stakeholders involved in CPs to avoid uncertain accidents leading towards injuries and deaths [50]. Initially, for the assessment of safety performance, hazards are identified, and prioritized in terms of effects to reach at viable options available for avoiding them [51].

3.2. *Factors measuring extent of application of PMKAs*

Application of PMKAs in any CP is verified by ensuring proper check on every phase of project. All the distinct project management knowledge areas: project integration, scope, cost, time, quality, resource, communications, procurement, risk, stakeholders, and safety management [33] can easily be broken into three main tasks viz. plan, manage/develop, and monitor/control [25,33]. Thus, the application of PMKAs in CPs starts from initiation or planning, with verification, sequencing, estimation, and analysis, to monitoring, control, and closure. All such identified factors measuring extent of application of PMKAs in CPs are listed in Table 1 as under.

3.3. *Building Information Modeling*

The concept of BIM evolved in 1970s while the term 'building model' (in the sense of BIM as utilized today) was first used in scientific papers in mid 1980s. In continuation, the term "building data model' was first used in the paper [53], published in 1992 [14].

BIM is a methodology or approach employed for production and handling of digital representations of various structural elements. BIM Models contain data which can be extracted, altered, and shared via collaborative networking to assist construction practitioners in decision making processes. At present, BIM is in use by various organizations to set up, arrange, design, construct, operate, and maintain various types of infrastructures; for instance, water, energy/electricity, gas, communication utilities, roads, bridges, ports, tunnels etc. BIM also aids in making choices between various viable options available from construction to demolition of buildings. Also, BIM makes it possible for construction players to visualize the built-up deliverables even before commencement of construction works [54,55]. BIM also reduces waste generation and reworking that enables the project to be completed within the available time, cost, and material [56]. Overall, BIM is viewed as an information handling tool used to make on-time decisions for sustainable execution and delivery of CPs.

3.3.1. *Levels and Dimensions of BIM*

The level of maturity of BIM utilization in any CP is defined based on its four levels i.e., Level 0, Level 1, Level 2, and Level 3. The first maturity level of BIM implies mere usage of CAD in CPs which creates plans and drawings. At Level 0, there is no room for collaboration-based decision making among team members. This level of maturity of BIM is obsolete and construction practitioners in developing and developed countries work above this level. The next level is Level 1 which employs 3D CAD modeling for conceptual works and 2D modeling only for drafting and related documentation of information. In Level 1, CAD standards of BS 1192:2007 are

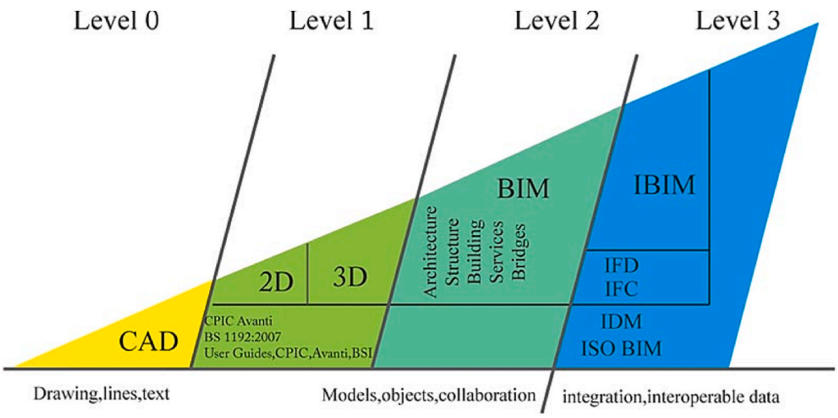

Fig. 4. Maturity levels of BIM [59].

enforced and information is handled and shared via common data environment (CDE). However, the Level 2 BIM facilitates information handling via proper collaborative environment. In this level, all the project stakeholders and team members use 3D CAD but not in the single model. This level of BIM is mandatory in various developed countries as it aids in cost and time savings with minimized reworking by virtue of efficient management of data. However, the Level-3 BIM offers team members to work on a single exchange project model which can be retrieved, accessed, and altered by any of team members. This is also called Open-BIM in which security of data is ensured via clauses related to clashes at every phase of CP [57]. These maturity levels were previously part of the PAS 1192 British Standards series [58]. A virtual representation of maturity levels of BIM has been provided in Figs. 4 and 5.

The level of development (LOD) illustrates the content of building model elements and describes the reliability and excellence of

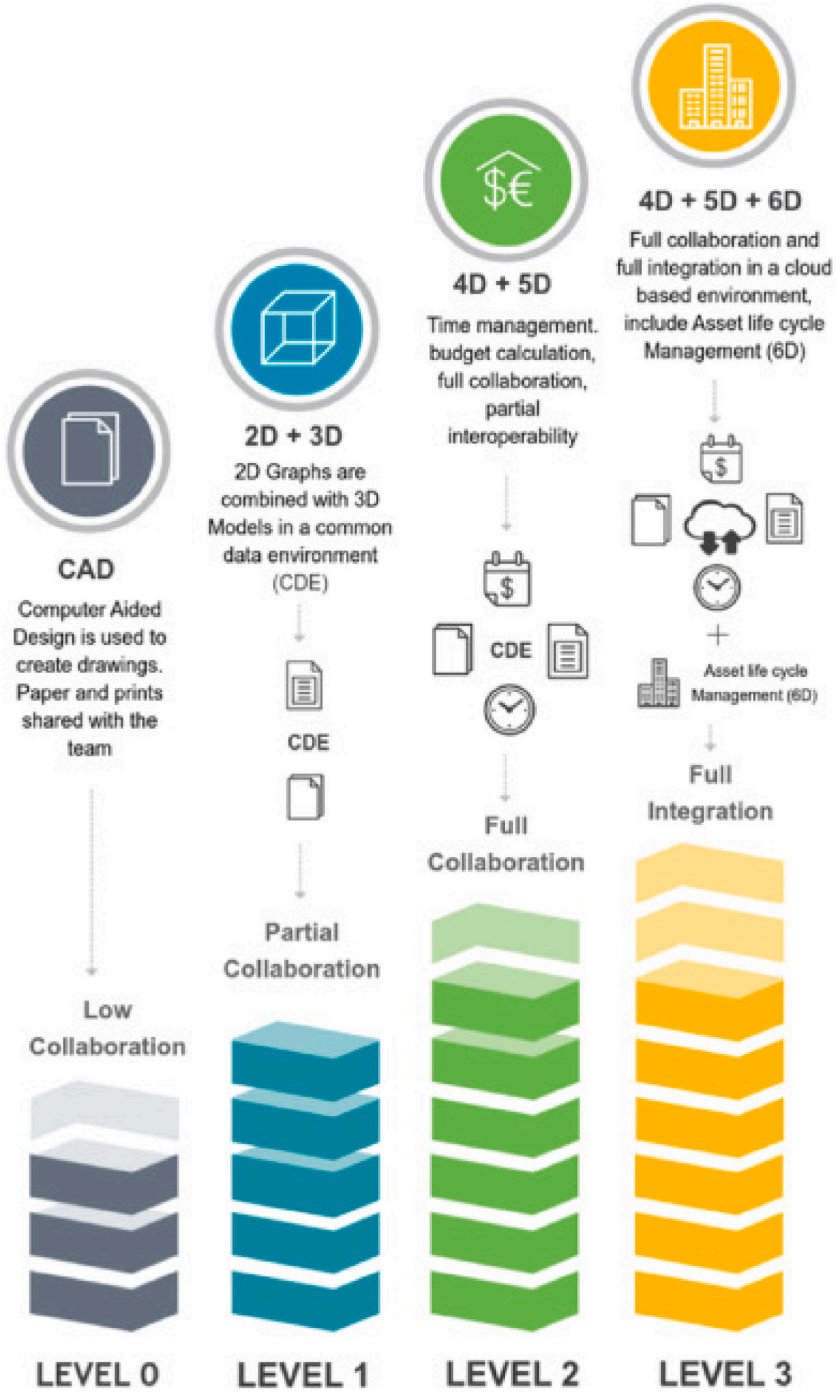

Fig. 5. BIM levels and dimensions [58].

the data obtained from BIM models at various stages [57]. The LOD aids in understanding of utilization and challenges of modelled elements and can be used as supplementary information in contracts and BIM implementation plans. Thus, LOD helps in specifying and informing about the minimum content requirements of every phase of project viz. geometric model requirement, facility management requirement, collaboration-based decision-making requirement etc. [57,60]. In USA BIM Forum, LOD ranges from 100: the conceptual project model, to 500: the as-built model [61]. However, in the UK BIM Protocol, LOD stands for 'Level of Detail' and 'Level of Definition' in BIM model development methodology with seven levels encompassing both 'level of detail' and 'level of information'. Similarly, in Italian Standards, alphabetical representation (LOD-A to LOD-G) has been adopted to illustrate distinct state of development in object's symbolic definition (LOD-A) to actual execution (LOD-F) and upgraded or updated state (LOD-G) [62]. A comparison of these standards with their short description has been illustrated in Fig. 6.

3D BIM is a visual illustration of building models in three dimensions [17] which gives a clear and concise idea of design in initial stages of CPs. 3D models also serve the purpose of clash detection for various construction stakeholders. One step further, when time is added to 3D BIM model, time simulation of CPs can be effectively visualized in 4D BIM models. With the help of 4D models, project timeline can be optimized by keeping eye on day-to-day requirements of various resources such as equipment, labor, materials, and time etc. When cost is included in the 4D model, the 5D BIM model shows a clear, accurate, and quick estimate of various costs associated with CPs. In addition, viable options can also be analyzed for saving cost and time. It also provides an option of checking and reviewing of design fluctuations and irregularities with instant updates [57,64–66].

Although, there is less consensus about BIM dimensions beyond 5D BIM [65,67] but, with an enhancement in focus on sustainability in every development, the sustainability analysis or energy analysis is now included in 5D BIM models as the sixth dimension [65]. Thus, 6D BIM models aid construction planners and executors to calculate overall energy and carbon emissions, leading towards less consumption of overall energy [55,57]. In continuation, 7D BIM models incorporate operations and facility management which is beneficial throughout the project lifecycle. The available literature also mentions 8D BIM which adds safety information in geometrical models and 9D BIM which focuses on lean construction for green development [65,67]. Fig. 7 shows numerous dimensions of BIM models with their brief features.

BIM, when categorized into stages starts with a Pre-BIM stage when there is no implementation of BIM on proposed project, then goes through three fixed BIM maturity levels (Stage 1–3) and ends on a variable ending point which delivers the project [70]. Various

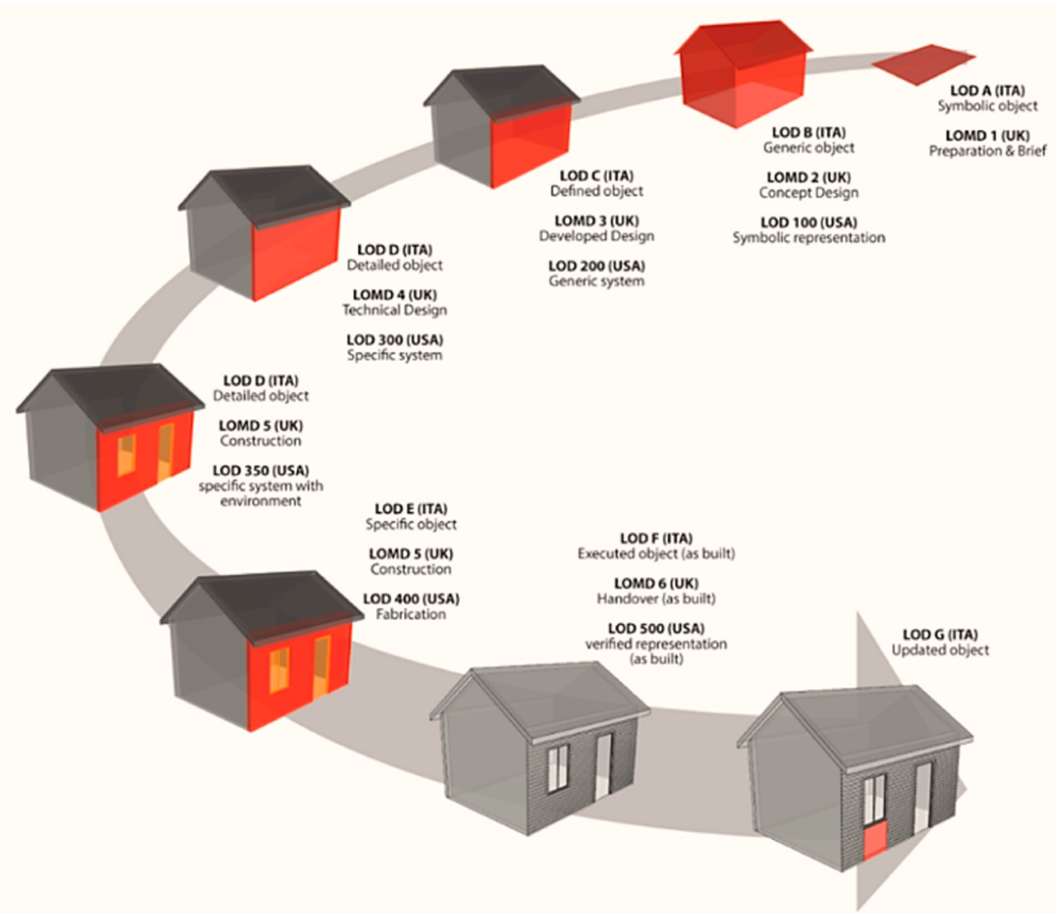

Fig. 6. Comparison of LOD in UK, USA, and the Italian BIM standards [63].

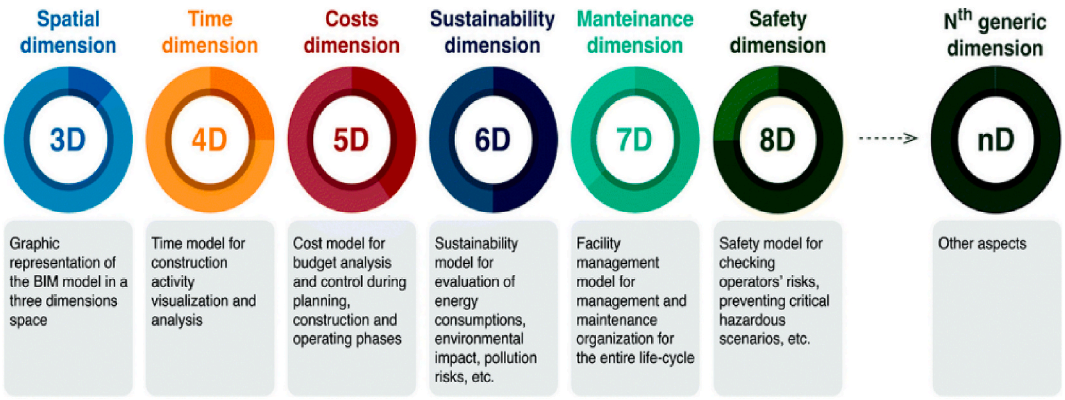

Fig. 7. Functionalities of nD BIM Models [68,69].

policies, technologies, and processes formulate BIM maturity levels and consequently, the stages are further broken as following and shown in Fig. 8.

BIM Stage 1: object-based modeling.

BIM Stage 2: model-based collaboration.

BIM Stage 3: network-based integration [70]In the pre-BIM stage, 2D documentation and modeling describes 3D reality. Moreover, no linkage is established between the specifications, quantity take-offs and cost estimates. Similarly, no coordination and collaboration processes are practiced between various stakeholders in a linear and asynchronous pattern. In first stage, BIM adoption is enabled via an object-based and single-disciplinary 3D model developed by any 3D parametric software tool say as Revit, Tekla, ArchiCAD etc. Thus, a coordination between 2D documentation and 3D visualization is witnessed in this stage. Because of no significant amount of model-based exchange of data between various disciplines, the collaboration pattern remains same as that in Pre-BIM stage i.e., unidirectional, and asynchronous. After the development of single-disciplinary model, construction stakeholders excel towards the next stage which includes active collaboration with interoperable exchange of models or model components via various file formats. In this stage, 4D (time analysis) and 5D (cost estimates) models are generated and model-based collaboration between one or more than one phases can occur. In the third stage of BIM, integrated data rich models are developed and shared between stakeholders with the help of various file formats and unified common data environment. This stage enables all the stakeholders to visualize and analyze multi-dimensional interdisciplinary models leading towards smart and attainable implementation of principles of green and sustainable development, lean construction, business intelligence, lifecycle costing, and green architecture. Such maturity of processes, technologies, and processes up till this stage ultimately aid in achieving integrated project delivery (IPD), the final goal [70,71].

Integrated Project Delivery (IPD), which is an ultimate goal, represents the long-term vision of BIM as a point of conjunction of processes, policies, and technologies. The term IPD offers more meaningful outputs than "Fully Integrated and Automated Technology" or "nD Modeling" like terms. The IPD approach gathers information and human resource for effective collaboration for improving the performance of project managers and projects in all lifecycle phases [70]. IPD gives integrated design solutions which are "improved collaboration, coordination, communication, decision support, and other work processes enabled by increased horizontal, vertical, and temporal integration of data and information management to enhance the value added in whole network of shareholders throughout the building lifecycle." [73].

3.3.2. *Perceptions and expectations of BIM*

With the increase in quest for facilities management and multi-disciplinary collaborative decision making for sustainable design and construction of infrastructures, the adoption of BIM is witnessed to be increasing day by day [55]. Various perceptions for and expectations of BIM in comparison of current practices of CI can be viewed from three main perspectives: product, process, and people [74].

3.3.2.1. In terms of product. Because BIM is a technological approach useful for various disciplines, the expectations from BIM also vary across disciplines. The design disciplines consider BIM as an advancement in 2D CAD modeling while PMs and contractors view BIM as an information management and handling tool which can extract the required data for decision making. Although there is an

Fig. 8. BIM stages [70–72].

evident overlapping but the integration of both is not yet viable and mature. Interestingly, many studies with a few exceptions, have assigned more weightage to the feature that BIM is an enhancement of 2D CAD modeling as compared to data management applications of BIM [74].

3.3.2.2. In terms of process. If viewed as a process, the adoption of BIM will require a significant amount of change in existing work practices of CI. The preparation of integrated building models requires increased communication and collaboration across disciplines. When multiple disciplines contribute to one shared model, there will be a need for a different approach to model development. In addition, there will be a need of agreed protocols and standard procedures for assigning roles and responsibilities to conduct design reviews and approvals. Although, prior experience of data management will be useful but there will be a need of developing new database suitable for unique project requirements and team structure [74].

Moreover, the success of projects will be doubtful if ownership and proprietorship associated issues of BIM models and business models are not addressed with comparison to needs of CI. BIM models offer in-house management and can also be outsourced to service providers. However, if outsourced to third party, the user satisfaction and data security will need to be protected with legal contracts and agreements [74].

3.3.2.3. In terms of people. Due to increasing complexities and emerging technologies, newer roles in CI and their relationship are under consideration. The need for dedicated roles such as BIM manager is expected to be very soon inevitable in mega projects. Team members and stakeholders will need adequate training and knowledge required to be capable for their contributions and active participation in varying work environment [74].

3.3.3. Technical features of BIM

BIM offers various technical features that can be utilized for enhanced project management in CPs, as illustrated below [75].

Clash Detection: When various disciplines of engineering work together in CPs, there occurs a significant chance of geometrical irregularities and clashes in various structural elements. BIM enables the PMs to visualize the plans for clash detection and adjustment of aesthetics associated issues [21,75].

Analysis: BIM enables construction stakeholders to conduct investigations for efficient decision making. In addition, it aids in connecting the BIM models with appropriate tools. For instance, BIM can analyze the energy consumption of project and can propose solutions like orientation of structural elements and materials being utilized for construction. Nevertheless, BIM can also perform acoustics, light, and mechanical analyses [14,21,55,75].

Time and Cost Estimations/Quantity Take-offs: BIM offers time and cost estimation features for PMs to obtain straightforward and robust comprehension of various phases of projects. The estimation of time is referred to as 4D while the cost estimation is termed as 5D, and both features are used in initial phases of CPs for effective decision making. With this, PMs can modify their schedules, procure resources, and avoid time and budget overrun issues [14,21,30,75].

Integration: With integrated and unified BIM models, various project team members of distinct disciplines work on one composite model. Thus, various construction players can see through details for efficient planning and analysis leading to integration in CPs [21].

Collaboration and Communication: BIM enables effective collaboration and teamwork as accomplishments on CPs by virtue of access to unified model. Thus, all disciplines work on one model to form decent collaboration throughout phases of project [30]. With ability to input, change, and critically analyze the information obtained from BIM models enhances correspondence between all CP stakeholders. Thus, effective communication is ensured, and conflicts are reduced due to BIM adoption in CPs [21].

3.3.4. BIM in connection with project management knowledge areas

3.3.4.1. BIM and project integration management. Various potential features of BIM for PMKA project integration management as identified from literature have been listed in Table 2. Overall, BIM offers construction practitioners a unified system for work via one composite model formulated by keeping together models prepared by various disciplines. With such ability, the project team can conduct effective planning, analysis, and execution of CPs with enhanced integration. BIM provides project information to all parties, which increases collaboration and improves communication. In addition, schedules and projects overall can be visualized with comprehensive documentation which ensures swift and integrated project delivery. Thus, BIM in project integration management brings all the disciplines at one table and ensures integrated project delivery (IPD) [19,21,25,59,76,77].

Table 2
Potential features of BIM for project integration management.

S. No.	Potential Features of BIM for Project Integration Management	References
1.	Increased collaboration and integration for promotion of integrated project delivery	[19,21,25,59,76]
2.	Unified system	[21,25,59,78]
3.	Cost and schedule integration	[8,25,59,79]
4.	Visualization and immersion experience	[25,59,78,80,81]
5.	Information availability	[25,59,77]
6.	Better coordination between documents	[25,59,82]
7.	Logic analysis	[25,59,83]

3.3.4.2. BIM and project scope management. Since the composition of BIM models consists of objects rather than geometrical surfaces, and thus, the composite model can be broken in distinct small objects. With such an ability of visualizing BIM models after breakdown, construction stakeholders can get a clear view of scope of CPs. When components can be visualized as distinct objects, project operations such as design, estimation, and execution can be improved with efficient management [21,30].

Subsequently, using BIM in CPs can also improve scope achievement criterion inside the projects. With 3D modeling, scope clarification becomes easy, and with integrated 5D BIM models, any change in project can be visualized and incorporated with a clear idea of any possible effect of such change. This also increases communication between architects, contractors, and clients ensuring strong realization of scope to all project team members [84]. Table 3 shows features of BIM for project scope management.

3.3.4.3. BIM and project time management. In conventional mode of schedule management in CPs, schedules are greatly influenced by work environments. Also, construction processes are disturbed because of subjective environments. However, with 5D BIM models, start to end construction operations can be optimized and made easy. BIM 5D records start, end, planned, and actual time of execution of projects to audit planned schedules, and provide on-time information. In addition, defects can be found and rectified if encountered during construction process [78].

BIM offers synchronization between design and execution schedules by integration of building models to the project schedule to mitigate delays. Also, it allows clients to visualize complete simulation of construction processes to monitor the progress of projects. Similarly, BIM provides clear, concise, and reliable cost estimates via automated quantity take-offs attained from BIM models. This consequently improves pace of cost feedback on any change orders in design of buildings [79]. BIM technology in CI can aid in design and visualization of building models with accurate view of design changes for systematic management of CPs [78,86]. Table 4 shows potential features of BIM for project time management.

3.3.4.4. BIM and project cost management. An integrated schedule and cost control system has always been a key issue for practitioners of CI. With 5D BIM models, users can quickly estimate the costs in projects with accuracy via automated quantity take-offs from BIM models. This also allows them to receive swift feedback about cost when any change occurs in design [79,87,91]. With early cost decisions and increased collaboration and communication, construction practitioners can monitor overall budget of project and can achieve higher productivity by virtue of enhanced control over costs [25,30,92–94].

Vitasek & Žák (2018) [91] opined that the use of BIM for cost management is increasing with every passing day in developing countries. Although it brings many benefits, but it also requires modifications in traditional workflows in accordance with prevailing information modeling requirements. Nevertheless, BIM can act as a modern tool for solution of costs and technicalities related concerns of construction practitioners. Table 5 mentions potential features of BIM for cost management in CPs.

3.3.4.5. BIM and project quality management. Table 6 describes the identified features of BIM for project quality management. Using BIM and associated technological approaches for quality management in CPs brings significant quality information with real status of project as monitored via visualization feature of BIM [86]. When distinct models developed by various disciplines are joined, important details of structural elements and quality of materials can be audited. In addition, obligations of various stakeholders become clear and transparent in nD BIM models, and thus, collaboration is improved between parties to ensure smooth workflow for accomplishments of quality in CPs. All such exchange of information improves quality in CPs with enhanced documentation of defects and conflict management [30,96]. With clash detection feature of BIM, errors are reduced which avoid reworking and waste generation [8,45,55,97]. In addition, timely supervision of construction progress and quality identifies root causes of failures which are documented and managed to improve quality management in CPs [25,30,80,89,98–100]. When defects and their mitigation measures are documented in quality information repository, construction practitioners can extensively utilize such comprehensive information to improve quality via quality status feedback and necessary maintenance or remedial measures [25,59,76,83,87,93,96,101].

3.3.4.6. BIM and project resources management. As mentioned by Rokooei (2015) [21], BIM improves interdisciplinary collaboration, teamwork, and coordination between stakeholders to eradicate conflicts. Thus, human resource in CPs work on unified model composed of endeavors created by professionals of varying specialties. Similarly, Reference [30] opined that, in case of resources other than manpower, BIM is very necessary for resource management. Especially in construction and demolition projects, BIM offers efficient, effective, and economically viable solutions to counter the generation of wastes. This paves way towards enhanced utilization of resources and circular economy in CPs. Various researchers have affirmed the utility of BIM in project resource management by virtue of its potentials in enabling collective decision making for effective use and management of resources in CPs [14,25,59,77,78,89,97,101,105]. Table 7 listed the identified features of BIM for resource management in CPs.

3.3.4.7. BIM and project communication management. CPs require collaboration and communication between various stakeholders

Table 3
Potential features of BIM for project scope management.

S. No.	Potential Features of BIM for Project Scope Management	References
8.	Element based model	[21,30,59]
9.	Visual scoping of work	[25,59,81,85]

Table 4
Potential features of BIM for project time management.

S. No.	Potential Features of BIM for Project Time Management	References
10.	Reduced time and mitigated delays	[19,59,85,87–89]
11.	Maintenance of construction schedules	[8,59,87,90]
12.	Timely monitoring of progress	[8,59,78,81]

Table 5
Potential features of BIM for project cost management.

S. No.	Potential Features of BIM for Project Cost Management	References
13.	Model based quantity take-off	[21,79,92,95]
14.	Cost estimation	[8,30,79,83,88,91,92,94]
15.	Accuracy, reliability, and reality of cost	[25,59,79,91]
16.	Flexibility and quickness of cost	[8,25,59,88,94]
17.	Collaboration and consistencies	[25,30,59,92]
18.	Early cost decisions	[25,30,59,92]
19.	Higher productivity	[25,59,93,94]
20.	Real monitoring for cost	[8,25,59,78]
21.	Improved cost control	[25,30,59,94]

Table 6
Potential features of BIM for project quality management.

S. No.	Potential Features of BIM for Project Quality Management	References
22.	Defect management system and recording	[25,59,78,83,93,102]
23.	Decreased repeating errors and avoiding reworking	[14,19,25,45,59,97,103]
24.	Enhanced quality via quality status feedback	[25,59,76,83,87,93,101]
25.	Physical clash detection	[8,25,59,78,81,83,89,90,98–101]
26.	Detecting failure root-cause	[25,30,59,80,98,99]
27.	Lower waste and omissions	[14,19,21,25,59,83,89,93]
28.	Timely supervising quality	[78,89,100]
29.	Maintenance helping	[25,30,59,78]
30.	Comprehensive quality information repository	[25,30,59,96,104]
31.	Efficient information utilization	[25,30,59,83]

involved. Thus, a clear and concise channel for exchange of information becomes a critical success factor in projects. BIM is a data-rich tool for virtualization and visualization of information required for decision making and improving the construction processes. In traditional 2D drawings, there is a stepped approach for exchange of information between clients, consultants, and contractors which possesses various delivery concerns and significant chances of misconceptions and conflicts. However, in BIM models, information is simultaneously available to all parties due to virtualization and visualization feature of BIM [86] which leaves negligible chances of ambiguities and conflicts in CPs [21,88,95]. In addition, BIM ensures centralized and well-structured management of data with descriptive illustration of objects in nD models [87,95,102,107]. With unified model and smooth flow of information, collaboration and understanding is improved and decision making is simplified with reduced conflicts [21,25,88,95,102]. Table 8 listed the identified features of BIM for communication management in CPs.

3.3.4.8. BIM and project procurement management. With BIM 5D models, schedules can be prepared in pre-construction phase for dynamic simulation of progress of CP. In addition, possible collisions between various disciplines can be viewed in early stages to reduce reworking, changes, and omissions. BIM can also predict quantities of required material and other resources for construction with report output function which aids in formulating efficient procurement plan for management of deliverables in CPs [78].

Costa & Grilo (2015) [108] proposed a BIM based e-procurement framework and tested on a case study via simulation on a prototype. The framework required detailed BIM model with all mandatory information for fetching the quantities of required

Table 7
Potential features of BIM for project resources management.

S. No.	Potential Features of BIM for Project Resources Management	References
32.	Conflict reduction via enhanced interdisciplinary collaboration and coordination	[25,59,76,82,87,88,93,99,106]
33.	Reference for conflicts	[25,59,88]
34.	Efficient use of resource and tracking	[14,25,59,77,78,89,97,105]
35.	Collective decision making	[25,45,59,89,101]
36.	Inventory management	[25,30,59,77]

Table 8
Potential features of BIM for project communication management.

S. No.	Potential Features of BIM for Project Communication Management	References
37.	Centralized structured data management and information flow	[25,59,87,88,95,102]
38.	Descriptive information of objects	[25,59,88,95]
39.	Planning of several responsibilities	[25,30,59,95]
40.	Model based approach of working	[25,59,88,95]
41.	Unique language, data interoperability, and consistent information sharing	[21,25,59,76,85,88,95,102]
42.	Clear and concise channel for enhanced communication	[21,25,59,76,85,87–89,93,102]
43.	Decision making	[25,45,59,88,95]
44.	Swift understanding	[25,30,59,88]

resources. The procedure of tendering could be accomplished using BIM element details and interlinked features such as "request for information" and "request for quotes" [108]. With such a coherent information availability and management, the details, and costs of various resources and/or products can be visualized to ensure reliability and integrity of procurement process for management of deliverables in CPs. Such an automated system can also aid in eradicating errors to get rid of errors, reworking, and reworking that may be frequently confronted in traditional procurement models [30,89,108]. Table 9 mentioned the discussed features of BIM for procurement management with mention of corresponding sources.

3.3.4.9. BIM and project risk management. With increasing opportunities in CI, increased ambiguities and complexities have resulted a notable surge in risks of various categories in CPs. However, by virtue of advancements in information technology, various technological approaches have been developed for management of such risks. BIM is one such technological approach for information and communication management, utilized by construction stakeholders for identification, registering, mitigation and management of hazards and/or risks [45].

By spatial visualization and model-based analysis features of BIM, risks in design and construction drawings can be identified and managed accordingly. With increased communication and collaboration, BIM improves stakeholders' management and reduces the risks of change orders and reworking. In addition, it also facilitates safety management by developing site safety plans [14,45] and prepares accurate and on-time estimates to help construction stakeholders in eradicating the risk of cost and time overruns with controlled dependencies and contingencies to pave ways towards constructability [14,21,30,93,100].

The integration of BIM in all phases of CPs from planning to demolition, going through design, construction, and maintenance can formulate a knowledge-based risk management model for risk management, as proposed by Refs. [109,110]. Thus, BIM can facilitate construction stakeholders to identify and manage risks for accomplishments in CPs via efficient decision making [25,30,45]. Table 10 mentioned the valuable features of BIM for risk management as identified from literature.

3.3.4.10. BIM and project stakeholders management. BIM has evolved as a novel paradigm in CI which facilitates the integration of roles of various stakeholders in CPs to enhance collaboration and management of stakeholders from various backgrounds [30,87]. As opined by Ref. [76], such an enhanced collaboration-based networking and joint efforts of stakeholders can enhance productivity and overall quality of CPs. This also aids in achieving satisfaction, trust, and confidence of clients [18,25,59,77,85,90]. In addition, Ref. [22] affirmed that joint efforts improve organizational harmony and capabilities to pave ways towards efficient management throughout project phases.

Also, Travaglini et al. (2014) [47] mentioned that BIM in CPs brings more opportunities and Return-on-Investment (ROI) for architects because of enhanced comprehension and clarity in design processes, reduced errors and reworking, and multi-dimensional visualization of structural elements. Similarly, engineers find the utility of BIM in construction phase with notable features like reduced conflicts and changes with high productivity and profits. In addition to positive impacts on marketing, stakeholders communication is improved [25,59,76,89]. This is why, construction practitioners view BIM as a mandatory requirement in CPs because it not only reduces conflicts [25,59,85], but also brings them a lot of networking and financial benefits by virtue of collaborative environment, synchronized exertion and information sharing [111]. Table 11 mentioned the valuable features of BIM for project stakeholders' management as identified from literature.

3.3.4.11. BIM and project safety management. BIM also offers important features for effective safety management in CPs, but the research concerning delivery of knowledge on safety training using digital technologies like BIM is scarce in literature. BIM features and various safety factors are interrelated; thus, construction practitioners can utilize suitable features of BIM for particular safety related concerns [81]. With integration of BIM features and safety standards and actions, researchers have developed rule-based safety checking systems which can automatically identify potential hazards for necessary mitigation measures. This feature can aid construction stakeholders in designing for safety as potential hazards can be designed out in preconstruction phase. In addition, safety communication can also be improved to save time and efforts of safety staff via such an automated safety code checking and simulation tool [80]. Table 12 listed the identified features of BIM for safety management in CPs.

Table 9
Potential features of BIM for project procurement management.

S. No.	Potential Features of BIM for Project Procurement Management	References
45.	Product description through modeling	[25,30,59,108]
46.	Contractual management for procurement	[25,30,59,108]
47.	Integrity and reliability of procurement	[25,30,59,108]
48.	Good procurement plan limiting requisition list and diminishing of errors	[25,59,78,89]
49.	Management of deliveries	[25,30,59,89]

Table 10
Potential features of BIM for project risk management.

S. No.	Potential Features of BIM for Project Risk Management	References
50.	Risk assessment and mitigation	[14,21,25,59,80,93,95,100]
51.	Model based analysis of possible hazards and particular risk scenario during project phases	[25,30,59,87,95,110]
52.	Spatial visualization	[25,30,59]
53.	Reduced financial and schedule risk	[14,25,30,59,100]
54.	Reduced contingencies	[25,30,59,93]
55.	Increased opportunity	[25,30,59,93]
56.	Decision making	[25,30,45,59,93]

Table 11
Potential features of BIM for project stakeholders management.

S. No.	Potential Features of BIM for Project Stakeholders Management	References
57.	Dealing with stakeholders of different backgrounds	[25,30,59,85,95]
58.	Client satisfaction, trust, and confidence	[18,25,59,77,85,90]
59.	Positive impact on marketing	[25,59,76,89]
60.	Enhanced stakeholders' involvement, communication, and developed relationship	[25,59,76,77,85,89,95,102]
61.	Mitigation of conflicts	[25,59,83,85]
62.	Core managing	[21,25,30,59,85]
63.	Informed decisions from stakeholders	[25,30,59]

Table 12
Potential features of BIM for project safety management.

S. No.	Potential Features of BIM for Project Safety Management	References
64.	Automated safety code checking	[25,30,59,80,93,112,113]
65.	Design for safety	[19,25,30,59,80,81,89,112]
66.	Safety communication	[25,30,59,80,81,113,114]

4. Conclusions

In this review study, potential factors for measurement of extent of application of PMKAs and features of BIM helpful for enhancing the capabilities of PMs in applying those PMKAs were identified from an extensive literature review. The study served the purpose of developing a clear understanding of the significant contribution of BIM in enhancing the capabilities of PMs in applying PMKAs in CPs. It was concluded that process of application of all the PMKAs can be separated into three main tasks viz. plan, manage/develop, and monitor/control. Moreover, BIM is helpful in time and cost estimations which aid in schedule management for reduced threats of budget and time overruns. The pre-execution visualization feature of BIM enables the construction practitioners in clash detection leading to reduced errors, omissions, and reworks. In addition, visualization in multiple dimensions aids in quality and safety management with checks on progress of projects. While working on unified model, integration management and communication management is ensured by stakeholders in CPs. Because BIM aids in enhancing the productivity of deliverables, it brings numerous financial benefits and uplifts the status of construction organizations it is utilized in. Thus, by virtue of its distinct and remarkable features, BIM technology has an enormous potential in enhancing the capabilities of PMs in applying PMKAs in CPs.

Author contribution statement

Muhammad Saleem Raza, Bassam A. Tayeh, Yazan I. Abu Aisheh & Ahmed M. Maglad: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

No data was used for the research described in the article.
No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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