BIM-BASED COMMUNICATION MANAGEMENT SYSTEM: A CENTRALIZED INFORMATION REPOSITORY FOR REQUESTS FOR INFORMATION

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ABSTRACT

Owning to the fragmented, uncertain, and dynamic nature of construction projects, the construction industry is being criticized across the globe mainly due to its inefficiency and disintegrated approach. The construction industry is dependent on effective communication among project stakeholders. Request for Information (RFI) is a communication tool to facilitate the resolution of or clarify, construction issues. Building Information Modeling (BIM) has emerged as a favorable and significant development in the architecture, engineering, and construction industry (AEC) as a shared information resource, but there are still challenges that need to be resolved, such as proper communication and coordination among project stakeholders. To observe the BIM-driven communication and information management transformation, this study formulated a theoretical framework, at first, to digitalize the RFI process. Then, a plugin (BIM-CIM) for the management of the RFI process was developed. Feedback from industry practitioners highlighted the benefits of using the BIM-CIM plugin. It is concluded that the project stakeholders can benefit greatly from a BIM-based RFI communication and information management system, this will also ensure effective penetration of BIM in the construction sector.

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering & Construction
API	Application Programming Interface
BIM	Building Information Modeling
ICT	Information and Communication Technologies
RFI	Request for Information
RII	Relative Importance Index

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CHAPTER 1
INTRODUCTION

1.1 Brief Description

The construction industry is dependent on effective communication among project stakeholders. With the increasing complexity and size of projects, the success of projects is increasingly dependent on good communication between teams [1, 2]. Construction data is generated in diverse formats and sizes throughout a project and communicated via a range of mediums [3]. Thus, leading to potential discontinuities and delays in communication [4, 5] disputes, and litigations between project team members [6]. The trend of the construction industry has been changing and moving towards better execution of projects in which communications among the stakeholders is also considered a major part [7].

To deal with the increased complexity of projects, a number of information and communication technologies (ICT) are emerging [8]. It is recommended that construction projects are more dynamic and manageable with ICT applications [9]. To address these problems, Building Information Modeling (BIM) is a favorable and significant development in the architecture, engineering, and construction industry (AEC) and has emerged as one of the promising ICT applications [10]. BIM serves as a shared information resource [11] as it delivers a new working method [12], enhancing communication and collaboration [13], through its ability to visualize and information traceability [14].

The multifaceted responsibilities of the key stakeholders (clients, consultants, contractors, or subcontractors) depend on the transparency, accuracy, and timeliness of the information provided. This information is conveyed to the consultants from the contractors as ‘requests for information’ (RFIs) [15], which is a standard communication form between the consultant and contractor whenever there is a need for clarity about the contract documents or design in a project [1].

To efficiently manage such communications, BIM enables and facilitates a smooth flow of project delivery by using semantically rich 3D models [16]. It increases the efficiency in the life-cycle of a building as it operates on the element-oriented concept

[17]. BIM enhances stakeholders' communication, ensuring collaboration by forming centralized information access and data coordination [18].

Presently, current practices only include the implementation of conventional methods such as using a paper-based form rather than digitized systems. Such practices have affected the efficiency of projects [19]. Such as poor delivery, backlogs, and delays have increased due to the conventional method applications [20].

The aim of the study is the development of a framework for automated communication of key construction stakeholders for requests for information using BIM. A digital BIM-based interactive platform will be developed for the application of a framework to automate the communication of requests for information.

Hence, an ICT BIM-based communication platform will be developed which will create a centralized project's information resource by linking model elements of the building and associated queries. This will allow the more consistent delivery of requests for information throughout, thus minimizing the chances of adverse impacts on the project's success.

1.2 Level of Research already carried out on the proposed topic

Woo et al. [21] applied progressive communication in a multi-user workspace among the project team who were working remotely. To review the design, an interactive shared virtual space was built. Mao et al. [22] used an IFC model to connect the RFI information to a 3D model. It helped the users in visualizing the data, however, lacked the feature of interactive correspondence among the parties.

Recently, some studies have tried to integrate construction project information with 3D models. For example, Kuo et al. [23] proposed a "Construction Dashboard" tool with which construction stakeholders can analyze the information related to the project. The literature on the project's communication is mainly focused on communication at the early management level and design stage [24-26]

Although the procedure for requests for information is somehow established [27]. However, the communicational link between the people issuing or authoring such information and the intended users appears missing. None of the research has focused to develop a digital platform that enables project parties to communicate by accessing it as a centralized resource.

Moreover, BIM has also not been efficiently exploited to deal with communications in the construction industry. It can be attributed to the fact that BIM tools and platforms do have not built-in features to deal with construction communication. This, therefore, calls for these processes to be formalized to allow project players to deliver results more consistently by minimizing any adverse impacts on project delivery.

1.3 Reasons / Justification for Selection of The Topic

The construction industry is facing challenges such as time, cost overrun, poor-quality deliverables, and decreased productivity [28]. Such issues are evolving on the account of unsuitable traditional practices and also because of the increased complexity of the construction projects [29]. BIM can be utilized as a potential solution to the issues encountered in the construction industry as its modern technology can establish a visual link in the communication process [30].

Current communications in the large text databases such as RFI documents exist in spreadsheets or paper-based mediums, which makes it hard to cross-reference the information or manual checking of data for the project stakeholders. RFI documents contain factual information in large amounts but in an opaque and complex manner, thus hard to analyze and understand. Song et al. [31] suggested that there is a need for adequate visualization as construction stakeholders are struggling with the large databases hindering the project's success.

Therefore, developing a BIM-based approach to visualize and link this information with the model elements gives the project stakeholders the ability to explore and analyze data differently as per the requirement of the industry. From this, it can be envisioned that analyzing and understanding the data in a BIM-based interactive environment can help in accessing the potential communication issues that arise in the project database, ultimately, impacting the cost, and schedule parameters of a project.

1.4 Research Objectives

i. To analyze the inefficiencies in the existing RFI communication practices and identify the RFI causes of generation through an extensive literature review;
ii. To develop a framework for digitalized RFI communication of key construction stakeholders using BIM;
iii. To realize the developed framework by developing a BIM-based Communication and Information Management (BIM-CIM) platform.

1.5 Relevance to National Needs

Several motivators are coming together demanding to develop a digital platform for collaborative ways of working, and also to bring a digital built environment within the domestic construction sector. This study will help Pakistani construction players increase the performance of construction projects throughout the life cycle. As a tool, it can be used in resolving most of the identified issues encountered in the industry. It will also help in the adoption of a technology-based solution in the construction industry and thus, improve the general perception of the construction industry by increasing the success rate of the projects.

1.6 Advantages

This study will allow the correspondence among the key stakeholder to be efficiently captured and integrated into a model. Increased efficiency will be gained as overhead costs will be reduced as the postal service in handling those documents is no longer needed, thus expediting the whole process. It will enhance the information flow, alleviating the confusion between project stakeholders. Moreover, the visual support of the document search and retrieval will be enhanced by a 3D linking of the building model. In conclusion, the study aims to improve management practices.

CHAPTER 2
LITERATURE REVIEW

2.1 Construction Industry

Owning to the fragmented, uncertain, and complicated nature of construction projects, the construction industry is being criticized across the globe mainly due to its inefficiency and disintegrated approach [12]. The industry has, therefore, transformed the paradigm to enhance quality, productivity, efficiency, and sustainability, and decrease lifecycle cost and delivery time via efficient collaboration and communication between all the project players [32, 33]. Construction projects are highly collaborative complex events that involve various entities e.g. designers, clients, contractors, and consultants from private and public sectors [34, 35]. The industry is different from other sectors due to its distinctive characteristics [36]. Effective communication among the project players is a key aspect of the construction project's success [2, 37].

2.2 Communication in Construction Industry

Communication is a process whereby the information relevant to the project is acquired, interpreted, and disseminated among the people who may need it [38]. In construction, information may vary in all the operations related to construction. Communication, in its generic meaning, is, 'the transmission of information', a phrase that encompasses the processing of data, knowledge, technology, or skills [39].

For any project management function, communication plays a major part [40, 41]. The importance of communication can be assessed from the fact that it has been attributed to as the life-blood of a project by many experts [42]. During project operations, communication exists in different forms and with varying ranges. Project team players communicate regularly with various stakeholders and team members at different levels of the organization [43]. It is a challenging process as they regulate all the information. The more complex the project, the more significant communication is to achieve project objectives. Communication practices create associations among people and information that is critical for project success [44]. This ultimately impacts the financial and schedule parameters of a project [38] and is a main contributing factor to its success [45].

Communications have been extensively investigated by PMI [40]; during construction projects, adopting effective communication can massively aid in achieving the stipulated objectives and goals of the project. Effective communication plays a significant role in improving the relationship among the project team members [46]. In short, communication is about "correct information available at the right time to the right stakeholders and in an efficient way" [47, 48].

Communication is of significant importance for every entity involved, directly or directly in the project [49]. Poor communication can have an adverse effect on project performance. As studied by Maslej [50], poor communication affects the project quality, cost, and schedule. Communication complexity in projects is often misunderstood even though most of the time is spent communicating [51]. The establishment of clear lines of responsibility can clarify the roles played by project team members thus clearing obstructions and hindrances in the communication process [52]. Similarly, improved communication has many benefits including increased success rate, significantly influencing the quality, thus, helps in better decision making, fewer conflicts, and high expectations [53].

Any construction project that has a communication system to link its participants enjoys a better flow of information and improved project functionality. Effective communication of information between project participants will ensure quick and accurate communication of technical information leading to easier decision-making. It will improve teamwork, enhance quality, reduce conflicts and reworks, and then contribute to the project's success [54].

The importance of communication among the team players is concisely summarized by Armstrong [55]:

- Achievement of integrated outcomes/results
- Reforms management
- The motivation of employees and understanding their needs

2.2.1 Research conducted in the domain of communication

The literature on the project's communication is focused on communication at the early management level and design stage [24-26]. Sysdox is an IT-based application developed by Craig et al. [56] for construction projects. The system manages the information securing, creation, dissemination, distribution, and management. This information is for all project data; a vast database of information is created and managed by the project members. In the research by Olanrewaju et al. [57] various sources of communication problems were identified after surveying the construction industry as well as through literature and experience. Similar research work was conducted by Liu et al. [54] to analyze the factors that lead to the complexity of the flow of information on construction projects. Therefore, it is important to recognize the challenges to data transfer and communication that restrict the project information and its effective communication among project participants which resultantly give rise to complexity.

2.3 Building Information Modeling (BIM)

BIM has been adopted extensively and promises to yield the desired change for improvement in the construction industry [58, 59]. The capabilities of BIM are listed in three stages [60]:

i. Modeling based on an Object
ii. Modeling based on a Model
iii. Modeling based on a Network

BIM provides the advantage of handling digital data with ease [61]. It is important to consider that BIM is a process with software, not just software. It facilitates the creation of information related to the design, execution, and operational phase [62]. BIM facilitates effective collaboration and communication among key stakeholders [63], ensures better management throughout the project lifecycle [62, 64], conflicts/clash detection, and identification [63, 65], cost estimation and tendering [66, 67]and better site planning [63, 68, 69]. Several researchers have explored the capabilities of BIM in other regimes such as:

a) 3D models contain information, as a minimum, on length, width, and height. Benefits are improved coordination, general information gathering [32, 70, 71] enabled visualization [29],

b) Design and Constructability Reviews for early errors identifications [70],

c) 4D Scheduling i.e., linking objects with tasks, sequences, and schedules [72, 73],

d) 5D Cost Estimation; 4D model in addition to cost information [32, 74, 75],

e) 6D Model-based analysis for early accurate decisions early in the building life-cycle [70], Structural Analysis, Lightning Analysis, Mechanical (HVAC) Analysis [70] Energy Analysis [76] sustainable building designs [77, 78],

f) Prefabrication due to accurate designed models [74, 79],

g) 7D Operation and Maintenance [32, 80, 81],

h) 8D Modeling; Risk assessment for prevention through design [82] Safety management [83]

2.3.1 BIM as a Potential Solution

The AEC industry has always demanded technologies and processes to improve project time and cost, quality, and increase productivity for disciplines. BIM is one of the most assertive technologies that have the potential to fulfill these demands for many tasks [32]. Different organizations and professionals use BIM for performing specific tasks as per their requirements [84-89]. BIM platforms can be programmed for features that are available out-of-the-box. Application Programming Interface (API) is a function of BIM platforms to develop plugins or add-ins through data accumulation, visualizing, and modeling to achieve the specialized tasks [90].

Many BIM-based design tools offer ways to enhance their functionality using either visual scripting or plugin development application programming interface (API). Each one of these has its pros and cons. A visual scripting solution is usually fast to develop than a full-scale plugin but it is limited in terms of available options like user interface, performance, and external libraries. The plugin development using API is a very powerful method to add sophisticated tools to BIM software but requires much more development skills and effort as compared to visual scripting. It also requires professional software development tools aside from the BIM software. A common approach is to develop a solution using visual scripting as a prototype and then move on to full-scale plugin development to provide a professional graphical user interface and optimize performance-critical operations.

As many researchers have used BIM for automating different tasks [86, 91-93]. To quantify the change in time through time ripple effect in the BIM platform, a plugin is developed by Moayeri et al. [94], In the safety domain, a BIM-based plugin for near-miss events is developed [95], Storage system for information related to construction for quality defects is developed [96]. Likewise, Goedert et al. [61] and Schlueter et al. [97] explored BIM API to analyze, visualize, and simulate features.

The mainstream BIM applications currently do not have the tools and options natively to address communication and information management during the traditional practice of requests for information. In other words, building information modeling has also not been efficiently exploited for managing communications in the construction industry [98]. This is attributed to the fact that managing construction communication is not a built-in function of BIM tools and platforms. If proper tools are developed on the platform for communication and Information management, the construction industry will benefit from using BIM, and provide means for automation of the process. A similar approach can be adopted to develop a solution for automation of the processes involved in communication and information management. The problems and issues faced in communication and information management can be addressed as it is very flexible and allows for automation using many development tools.

2.4 Construction Communication and Information Management

The word “Management” is described as a way of controlling or dealing with things or people. When combined with the words “communication and information”, the term “Construction Communication and Information Management” can be interpreted as the means of controlling or dealing with the seeking of consideration or change by one of the involved parties.

Communication management comprises the processes that guarantee appropriate and timely planning, distribution, management, and discarding of project information [99]. A communication management plan helps the project team to identify various stakeholders and to enhance communication between parties involved [51]. Communication management is all about any project information’s content, amount, quality, sequence, and what needs to be communicated for optimal completion of a task [100].

The term 'Information' can be defined as "all the messages and data which are communicated among the people within a network". [101] whereas, Information management is "the information control of an organization, which identifies and shares, manages, and ensures standardization, security, control, and reliability of stored data" [102].

Management of communication and information in construction is a major activity. The whole construction process is dependent on the information being interpreted, transmitted, and generated. Construction team players are more concerned with the exchange of information and deal with specifications, drawings, programs, cost data, and other information needed for the smooth implementation of a project. Organizations that are successful in the field can vouch for the importance of the efficient way of information transfer [103].

Information related to construction can be explained in three categories: information of general nature, information organization-specific, and project-related information [104]. Similarly, Information can be grouped into two types that construction stakeholders face during the expectation of projects; Structured and Unstructured [105]. Structured information can be processed adeptly on computers as it can be conveniently and effectively shared recognized and stored as a database. However, Unstructured or semi-structured information in construction projects includes a massive amount of text-based information about the project and is heavily document-oriented such as change orders, field reports, and RFIs [106, 107].

Improper communication channels, slow information flow, reworks, poor interpretation and design, etc. can delay the project [2, 108, 109] and can become the cause of conflicts and disputes. Chan et al. [110]. Issues in communication in the construction industry have been studied by many researchers. Due to its utmost importance, it has attracted the interest of researchers in the construction industry [2] as it is one of the key causes of project failure [111] subsequently it results in time and cost overruns [112] and mismanagement among construction stakeholders [113].

A system that manages information combines web technologies and databases, in turn, proves to be significantly important for the communication and information processes. Information management systems conceptual frameworks have been discussed and presented in the studies by García et al. [114], Abudayyeh [115], and He [116]. Tam

[117] and Deng et al. [118] developed an internet-based system, comprising information and data exchange functions. Atkin [119] discussed some problems related to managing construction information and presented their suggestions. Chassiakos et al. [120] argued the key aspects of the process and also suggested the use of computers for such a purpose.

Shahid et al. [121] studied the flow of information and process of the project's information, mapped information with the documents that access it, and provide the construction information. An IFC-based application has been proposed by Faraj et al. [122] in construction management. It facilitates information flow and communication. Abudayyeh [115] implemented and designed the cost control intranet-based system allowing an automated report development. Dawood et al. [104] built an online information management system for buildings of industrial use, concentrating on the management of drawings. Chan et al. [123] presented a meta-data system for managing information for the exchange of documents on the web. Cheung et al. [124] developed a monitoring system of performance that is web-based including indicators of Time, Cost, Communication, Safety and Health, and Quality. Similarly, using a web-based XML approach for managing information exchange, a system was developed by Zhiliang et al. [125]. Abdel-Monem et al. [126]'s study article utilizes IVR technology to collect on time and precise information related to RFI and as-built.

Typically, information about the building is in the form of drawings, documents, and plans and is typically transmitted across many organizational and professional boundaries [127]. Construction information can further be identified or filtered into categories as illustrated in Table 2-1.

Table 2-1 Categorization of Construction Information

BT [128]	**Murray et al. [129]**	**Jesus et al. [130]**	**Scott et al. [131]**
Control Commercial Technical Management	Verbal Instructions Queries of technical nature Instructions on site Site Instructions to Subcontractor Day works Programs Drawings Sketches Administration of drawings Payment Application Photographs Correspondence Video	RFIs Management of materials Management equipment Management budget Time Techniques Keeping of record Safety Records Submittals Future Trends QA/QC	Contractual docs Drawings working Progress plans and records Measurement and financial Records Record of quality Safety records Contract Amendments Contractual Claims P&M Records Miscellaneous

Darwish [132] stated that information generated through RFIs on site is 58% more in occurrence than through any other mode of communication. Thus, this study has especially addressed Requests for Information in its domain. BIM has simplified standards of practice and accelerated the flow of work by a direct linkage of project players in sharing of digital information [127].

2.5 Requests for Information

An RFI is defined as "a written process originated by a contractor, which seeks further information or issues clarification related to the construction, design, and other contractual documents."[15].

Typically, an RFI is generated by the contractors seeking clarity or extra detail about defects, contradictions, or subtle ambiguities in building drawings, measurements, or contracts. Many different factors can necessitate the initiation of the RFI to resolve problems, such as ambiguous project documentation (drawings and specifications), a discrepancy between design documents, or unexpected site conditions[22].

Hanna et al. [15], RFI’s purpose is to issue identification experience in the field that requires solutions thus avoiding contractual claims and disputes. RFIs can be analyzed by various variables which include [133, 134]:

- No. of RFIs,
- RFIs average time,
- RFIs respond to the selected time,
- No. of RFIs due to inadequate responses,
- RFIs to many respondents,
- RFIs necessitating contract modification,
- Transmission method.

A typical RFI process is explained by Chin et al. [135]. RFI process, in most cases, starts when a subcontractor or a contractor has a question regarding the plans, drawings, or specifications. In the case of a question from a subcontractor or a supplier, the RFI is sent to the contractor first, who then reviews the question for content and clarity. If the contractor can answer the question himself, then he gives a response directly to the subcontractor or supplier but if the contractor is unable to answer the question, the RFI is forwarded to the architect. After receiving the RFI, the architect starts reviewing the RFI to determine if it needs to be forwarded to the appropriate consultant (such as the structural engineer for questions regarding structural issues), in cases where the architect cannot answer the question. If the architect can respond, then the RFI is sent back directly to the contractor. However, if the consultant responds, then the RFI goes back to the architect before it returns to the contractor. Provided that the response is adequate, the contractor then forwards the RFI to subcontractors who are affected by the response. If the response is inadequate, the contractor drafts a follow-up RFI, clarifying the question further, and sends it back to the architect. Figure 2-1 represents the flow of RFIs.

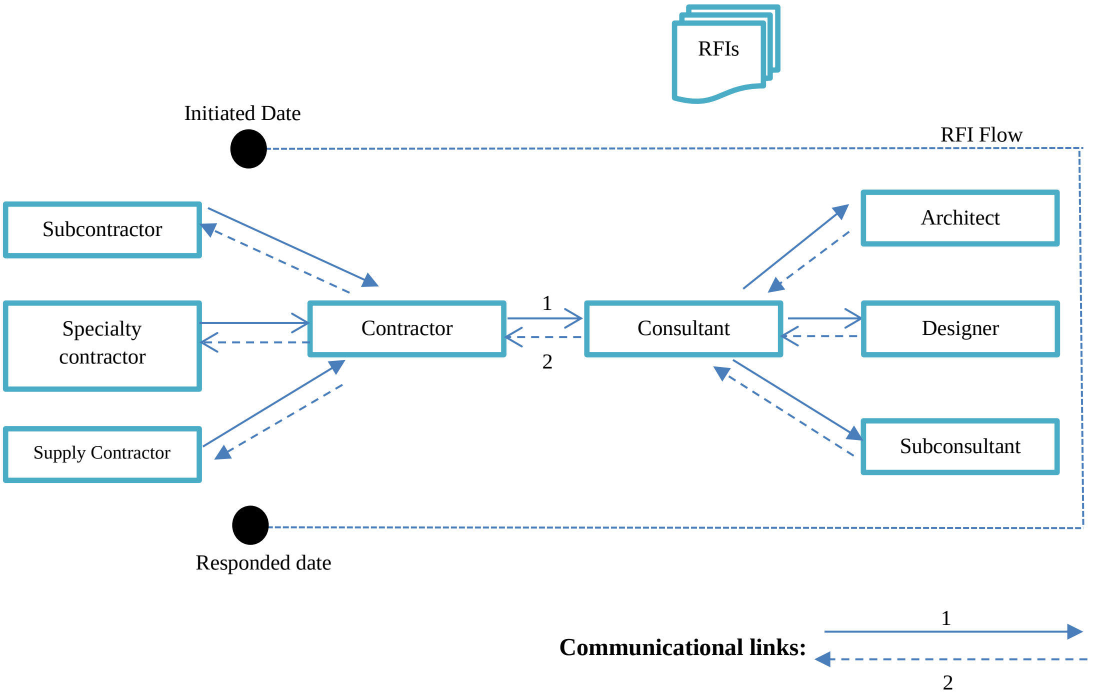


Figure 2-1 RFI process Flow Diagram [135].

The importance RFIs can be determined by the fact that any delay in the reviewer's (A/E/ firm) response to an RFI can trigger a delay in the contractor, resulting in a delay in the project as a whole. Many members of a project team (i.e., subcontractor, designer, engineer, and consultant) must exchange and process details during the RFI process [135]. Thus, RFIs should be managed efficiently and in time for the success of a project as they have an impact on the project parameters i.e., performance, schedule, and cost and they indicate design and document deficiency [134, 136].

2.5.1 RFI management literature

RFIs have been classified by various based on RFI queries, their initiation causes, structure components, and so on. Some researcher's classified RFIs as types [137]. Few researchers analyzed the reasons or causes of the RFIs. Tilley et al. [134] grouped RFIs in two after analyzing several projects. Chin et al. [135] and Hanna et al. [15] deeply studied RFIs and developed the codes for their reasons. The further classification was done by Hanna et al. [15]. Chin et al. [135] categorized and classified Uni-format RFIs based on structural components. Mao et al. [22] built a structure model of IFC to manage RFI data.

Several researches have been undertaken for better and efficient management of RFIs [15, 137-139], mentioned as follows:

- RFI process and hierarchy establishment, informing the process of RFI to the contractor.
- RFI Standard format:
  - Unique no., Reason category for RFI, A priority level of RFI, Respond date
  - The proposed solution, Impact on time and cost of the project
  - Relevant drawings and details
- Monitoring of RFIs via RFI log

This study has developed a metadata model 'Architectural Desktop Tool', a programming language for project stakeholders to manage documents related to construction projects [22].

2.6 Identification of RFI generation causes

An extensive investigation of existing literature was carried out to extract the factors related to the RFIs generation causes during the execution of projects. More than 54 numbers of articles that are related to the subjects' domain were analyzed, scrutinized, and evaluated to identify the generation causes of the communication practices in the construction industry. These studies included published and academically published papers. Then causative factors were extracted based on these papers. Analysis of these factors was done using frequency and similarity analysis. Similarity analysis was done to remove any repetitive factors having different synonyms or phrases but the same meaning. Frequency analysis: how many times each factor has appeared in different sources of literature.

Table 2-2 depicts the similarity analysis of one factor of RFI. The factor appeared in different papers with different words but has the same meaning; thus, a common term was assigned representing all the factors satisfying the meaning.

Table 2-2 Similarity analysis of one factor of RFIs

Diversion of Information	Document Discrepancies, Conflicting information, Inconsistent data/information, Divergence of information, or Design Ambiguities.

When the construction issues are identified in the field, it generates a Request for Information (RFIs). Based on the previous research, RFIs generation causes have been recognized. For searching the literature, sources like "ASCE", "Science Direct", "Google Scholar", "ICE Virtual library", "Web of Science", and "Emerald Insight" etc. were used. Keywords used in the searching process include RFIs, Requests for Information, Communication practices, Information management, and Construction communication. 54 total articles published in the range years 1997-2020 were selected for further analysis.

Table 2-3 RFI causes of generation

Sr. No.	Factor	Description	Reference Frequency
1	Design Clarifications	Scope, intent, or the content of plans/drawings of the design clarification. Further information, such as sketches, drawings, or narrative types, is requested to better understand and explain components of the design and its related constituents. It will not alter any of the drawings or plans' requirements.	44
2	Diversion of Information	When different drawings present conflicting details, design mistakes are correlated with a lack of attention; Document Discrepancies, Conflicting information, Inconsistent data/information, Divergence of information, or Design Ambiguities.	31
3	Incomplete plans/specifications	Absence of design. Error or omission in the plans/specifications. Lack of dimensions, missing or omitted details; lack of detailed drawing, etc. When an element is overlooked in the design. Inadequate/ ill-defined project objectives.	30
4	Design Change	Errors in the schedule or sequencing. Modification of a design or an error correction in construction. Design revision	30

Sr. No.	Factor	Description	Reference Frequency
5	Design Correction	Problems with the current solution in execution or incompatible version; to fix an error and make it right. The problem is associated with the technical feasibility of the solution presented in the design.	27
6	Confirmation only	No action is required. Confirmation of verbal understanding among the stakeholders. Verbal understandings. Confirmation of client instructed changes/variations and an assumption about the solution.	21
7	Design Verification	Low complexity issues where design is not necessarily wrong, but it offers an opportunity for improvement and design enhancement. Design conformation	11
8	Design Modification	An adopted solution is not wrong, but there is a better opportunity leading to a more desirable outcome. For value engineering: Reducing cost and better techniques. Substitution request. Resource constraints/alternates, Alternative design solutions.	34
9	Resource Substitution/Modification	An adopted solution is not wrong, but there is a better opportunity leading to a more desirable outcome. Material availability: request for substitution which has improved performance. Alternate products or materials used. Due to resource constraints, alternative design solutions are presented. Removal of any materials and goods from the site and the substitution of any other materials; Replacement of materials or procedures.	34
10	Issues in Constructability	Design Inadequacies. Suggestions for an Installation process or technique change.	23
11	Design Review	Review of documents from other disciplines or for an updated design revision, Design coordination.	7
12	Guidance	Consultation about an error or an issue that occurred on site. In other words, seeking advice on mistakes/problems.	7
13	Differing Site Conditions	Hidden/Differing/ Unexpected/ Unforeseen-Site conditions different from the information in the contract documents.	19

Sr. No.	Factor	Description	Reference Frequency
14	Addition/Deletion in Scope	Addition or removal of items to the original scope of the project.	18
15	Schedule Coordination	Timing or sequence change of the Works. A request to reorganize the resources, sequence of the works, or reschedule the works according to the other crucial activities for increased performance.	10
16	Others	**Information Request:** Request more details **Approvals:** Due to inadequate information supply, the contractor seeking an approved method to resolve conflict issues. **Information Validation:** When a concept is partly neglectful in low-complexity situations, the team proposes a solution, to accept it officially. **Different Method:** Different installation process or technique. Conflict in utilities. Information about Subcontractor Communication about design **Others**: A request that does not fit into one of the previously described types. Payment processes, qualification standards, fines, guarantees, and non-design-related documents. Information submission, Non-conformances responses.	10
17	Inadequate RFI responses	Clarification about previously asked RFIs. Incomplete or too direct/specific RFI responses. Nonresponse or inadequate response.	3
18	Additional time	RFI issued to acquire additional time to perform works.	1

This led to the identification of 25 factors identified from the literature which were then shortlisted to 18 factors by renaming or merging factors that seem to have the same concept to avoid duplication. A list of 18 identified causes has been shown in Table 2-3 along with their description and their reference frequency; each factor repetition in different papers.

It can be seen that RFI generated for “design clarification” among construction players occurred 44 times in different literature following that, “diversion of information” cause which has occurred 31 times. This shows the significance of the factors in the communication process of the industry.

2.7 Identification of inefficiencies in communication and information management

During the project's execution phase, many factors influence the efficiency of the construction communication including, Requests for Information (RFIs).

Based on the previous research, the issues were identified as being detrimental to these three communication parameters. For searching the literature, sources like "ASCE", "Science Direct", "Google Scholar", "ICE Virtual library", "Web of Science", and "Emerald Insight" etc. were used. Keywords used in the searching process include Communication practices issues, Information management, Construction communication inefficiencies, etc. Forty-five (45) papers were analyzed and scrutinized to obtain twenty-nine issues in the communication and information management process. Content analysis was performed to evaluate the factors having overlapping meanings. Hence, those overlapping factors having similar meanings, but different names were deleted or merged. Thus, it led to shortlisting of twenty (20) issues/inefficiencies in the communication and information management process.

Table 2-4 enlists 20 identified issues/inefficiencies in communication and information management from previous research with their frequencies. It can be seen that 'slow information flow' among construction players occurred 20 times in the literature. 'Slow responses' occurred 11 times, 'poor record keeping' 10 times in occurrence. From this, it can be ascertained that these factors play a significant role in the poor communication phenomenon in the construction industry.

Table 2-4 Issues/inefficiencies in communication and information management

Inefficiencies	Description	Frequency
Slow information flow	Late information transfer, High information latency; Limited data transfer capacity data flow experiences a delay in its generation and dissemination. Queuing time and waiting time. Time lag in processing	20
Slow responses	Responses are not provided on a timely basis	11
Poor record-keeping	Transfer and storage of project information are not in the way that they should be. Improper storage system. Lack of appropriate data channels.	10

Inefficiencies	Description	Frequency
Unavailability of uniform standards	No Standard Form, and no orderly, reliable, and documented mechanism	10
Inaccessibility of information	At the time of need, information is unavailable. Unavailable for immediate use. No instantaneous access	9
Manual search and cross-referencing of relevant documents and/or drawings	Manual Search carries in the office to find the relevant documents and/or drawings. Much time is wasted on manual gathering and when cross-referencing the files.	6
Ineffective reporting system	Lack of an efficient reporting system.	5
Delayed delivery of relevant amounts of information	The process of contacting the individuals is time-wasting, Circulation time; Timely delivery of relevant amounts of information	5
Poor document preparation	Unstructured documents	4
No proper mechanism for document tracking	inability to track the document	4
Manual entry and/or re-entry of data	Traditional management of documents or information management involves entry of data or re-entry by hand.	4
Lack of integration and co-ordination	Unavailability of integrated process	4
Poorly captured information	The information in the documents is not recorded properly.	3
Unable to analyze the cause	Communication and information management systems exist traditionally as Excel files, and web portal logs, thus, insufficient to analyze the issue or its root cause.	2
Lack of feedback system	An inadequate mechanism that provides the feedback system	2
Lack of adequate representation for project stakeholders	Stakeholders are not aware of the issues, or late information is given to them	2
Multiple similar queries	RFIs need to clearly state their purpose of generation and should be in a single concise question, It is also critical to not generate excessive RFIs on similar queries.	2
Too many face-to-face meetings	Sometimes to visualize a problem, f2f meetings are needed, which can be reduced by a BIM-based visualization environment.	2

Inefficiencies	Description	Frequency
Batch/Bulk handling without proper management	Most of the time, RFIs are sent to the respondents in a bulk in one day, yet, expecting different response times of the queries.	2
Irrelevant overloaded information	All the users in the system are getting every detail of information in a dissemination process, thus, this overloaded information should be reduced.	1

A preliminary survey was then conducted to verify the compiled list of inefficiencies for RFIs. For this purpose, an online questionnaire was administered to construction professionals having experience of more than 03 years in the construction industry. The questionnaire was comprised of two parts i.e., the demographics of the respondents (Figure 2-1) and the impact ranking of inefficiencies pertaining to RFIs (Table 4-1). Based on their knowledge and experience, the participants evaluated the inefficiencies through the Relative Important Index (RII) technique (Equation 2-1) on a 5-point Likert scale, ranging from 1 being 'Very Low' to 5 being 'Very High' [140]. In addition, the participants were also given a choice to add any RFI-based inefficiencies along with the rating of their choice to further strengthen the targeted framework.

$$\mathbf{RII} = \frac{\sum \mathbf{W}}{\mathbf{AxN}} \tag{2-1}$$

($0 \leq \text{RII} \leq 1$) whereas W is the weight assigned to each factor by the participants, the highest weight A=5, and the total number of participants is represented by N.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

A framework proposed by Chileshe et al. [141] for research in construction management is utilized after modifications desired as per the research needs as shown in Fig. 2. This research is conducted in 2 phases including: (1) analyzing the inefficiencies in the existing RFI communication practices and identifying the RFI causes of generation through extensive literature review; and (2) developing a framework for digitalized RFI communication of key construction stakeholders using BIM and its realization by developing a BIM-based Communication and Information Management (BIM-CIM) platform.

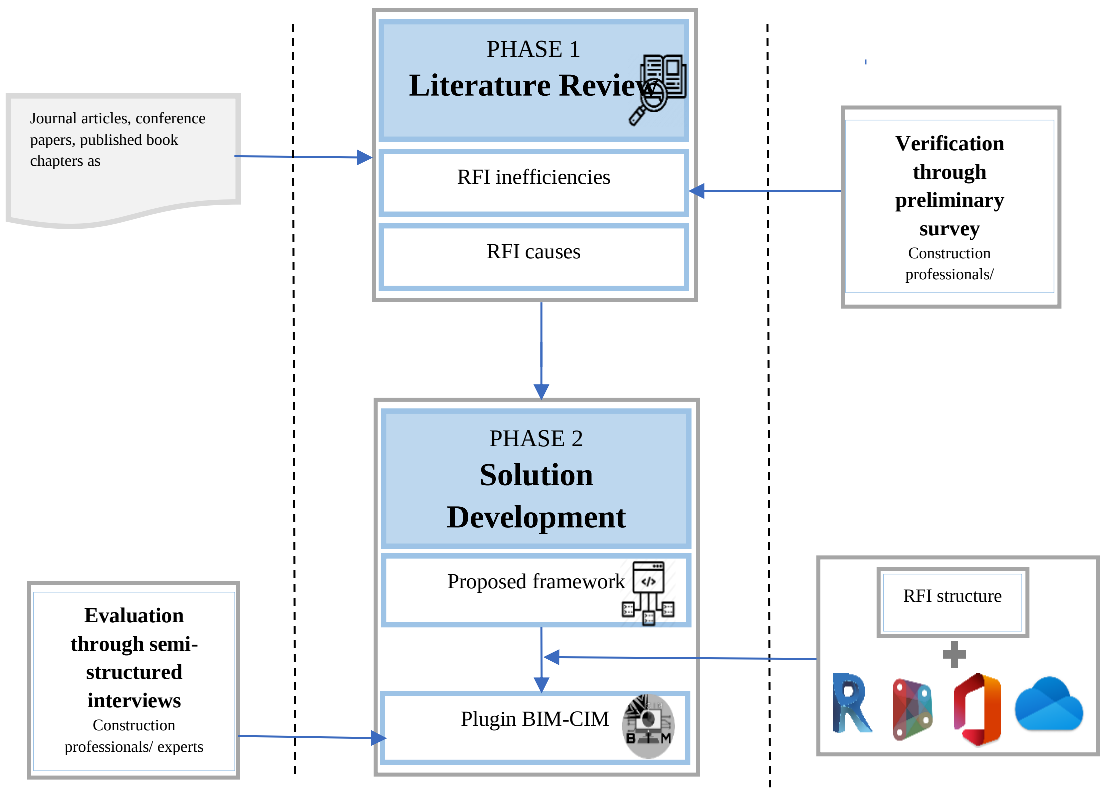


Fig. 2 Research methodology framework [141].

3.2 Identification of inefficiencies in existing RFI communication practices

During the execution phase, many factors influence the efficacy of the construction communication where Requests for Information (RFIs) are also essential [19]. Considering the research needs, the inefficiencies present in the construction communication practices were identified by reviewing the existing literature at first and later rated for RFIs by the industry experts. For the literature review, sources like "ASCE", "Science Direct", "Google Scholar", "ICE Virtual library", "Web of Science", "Emerald Insight" etc. were used. 45 relevant papers were analyzed and scrutinized to obtain 29 issues in the construction communication process. By using the similarity and frequency analysis as utilized by Assaf et al. [142], this exercise resulted in the shortlisting of 20 inefficiencies, presented in the results section. Similarity analysis was done to remove any repetitive factors having different synonyms or phrases but the same meaning. Whereas frequency analysis was used to know the frequency of each inefficiency mentioned in the literature. A preliminary survey was then conducted to verify the compiled list of inefficiencies for RFIs. For this purpose, an online questionnaire was administered to construction professionals having experience of more than 03 years in the construction industry. The questionnaire was comprised of two parts i.e., the demographics of the respondents (Figure 4-1) and the impact ranking of inefficiencies pertaining to RFIs (Table 4-1). Based on their knowledge and experience, the participants evaluated the inefficiencies through the Relative Important Index (RII) technique (Equation 2-1) on a 5-point Likert scale, ranging from 1 being 'Very Low' to 5 being 'Very High' [140]. In addition, the participants were also given a choice to add any RFI-based inefficiencies along with the rating of their choice to further strengthen the targeted framework.

3.3 Identification of RFI generation causes

In the next stage of the literature review, an extensive investigation of existing literature was conducted to extract the possible causes that result in RFIs generation during the execution stage. Similar sources were used for searching the literature as explained in Section 3.1, scrutinized, and evaluated to identify the generation causes in the industry in a similar way. A total of 54 articles were selected for further analysis to obtain 25 causes which were then shortlisted to 18 causes by similarity and frequency analysis as also explained in detail under Section 3.1.

3.4 Framework development and realization

In the second phase, a BIM-based framework was formulated for the digital RFI communications of key stakeholders using BIM. The framework was aimed at mitigating the inefficiencies of the RFI communication process, identified in the first phase. For this purpose, the existing RFI communication practices were meticulously reviewed from multiple sources i.e., [123, 133, 137, 143-145] that helped in identifying the general RFI structure (heads, format, common stakeholders) being used in the practice. A better structure can enhance the effectiveness of RFI management and tracking and lead to improved project performance in time and cost parameters [137]. This also resulted in a clear understanding of the RFI communication process, which further led to the formulation of a digitalized RFI communication framework using BIM. Since BIM has the capability to manage varied information throughout the construction project [146]. The concept offered by the proposed framework was taken forward to realization through the development of a digital platform within the BIM environment. Since most of the BIM platforms provide options for functionality enhancement through their inbuilt API capabilities [90], the same was used for developing a prototype plugin that represented the BIM-based Communication and Information Management (BIM-CIM) platform, presented later in detail in the result section. For this research, Autodesk Revit software was utilized on account of its extensive use in the industry, high-quality visualizations, and open-sourced API support [147]. To add the features in Revit and utilize Revit API, Dynamo was used. Dynamo is a visual scripting tool and has a user-friendly graphical interface that eases the script writing by its pre-defined nodes without having to compose the long lines of codes from scratch [148]. Whereas OneDrive cloud storage service was used as an online information repository for RFI communication purposes.

3.5 Plugin evaluation

Lastly, the BIM-CIM plugin was evaluated to determine how well can it serve the desired purpose along with the identification of areas for further improvement. Though for such newly developed plugins, few studies like [93, 149] have adopted objective measurements, some studies have adopted subjective measurements to grasp a holistic view [150, 151]. For this study, one-to-one semi-structured interviews were conducted with 09 industry practitioners having experience in dealing with RFIs. The panel covered largely the spectrum of the stakeholders associated with the construction projects. In each evaluation session, experts were first briefed about the study aims followed by the demonstration of the BIM-CIM plugin. The respondents evaluated the BIM-CIM plugin in accordance the parameters provided as envisaged by [151, 152] and also rated the effectiveness of BIM-CIM in resolving the identified inefficiencies. Based on their knowledge and experience, the experts evaluated the above-mentioned parameters on a 5-point Likert scale, ranging from 1 representing ‘Strongly Disagree’ to 5 representing ‘Strongly Agree’ [153]. RII technique (Equation 2-1) was applied to rank the issues resolving capability of BIM-CIM, and the overall ranking [154] of the inefficiencies which can be effectively addressed using BIM-CIM. Later, practitioners’ views were also recorded by discussion based on the stated criteria set for evaluation.

CHAPTER 4
RESULTS AND ANALYSIS

The results are presented in the sequence of research, as discussed in the research methodology section of this paper.

4.1 Inefficiencies in the existing RFI communication practices

Finalized 20 inefficiencies pertaining to RFI communication practices are tabularized in Table 4-1. Out of the 88 distributed questionnaires, a total of 58 complete questionnaires were received. After the screening of the experience limit, 38 responses to the questionnaire were utilized for further analysis using the Relative Importance Index (RII). As a result, many factors had an RII value of more than 0.5 as can be seen in Table 4-1 thus, depicting their significance in the RFI process of the construction projects.

Table 4-1 Finalized inefficiencies in Requests for Information (RFIs) communication practices.

Sr. #	Inefficiencies	Reference Frequency	RII
1	Poor record-keeping	10	0.63
2	Poor document preparation	4	0.62
3	Manual search and cross-referencing of relevant documents and/or drawings	6	0.60
4	Poorly captured information	3	0.58
5	Slow responses	11	0.58
6	No proper mechanism for document tracking	4	0.57
7	Batch/Bulk Information handling without proper management	2	0.57
8	Lack of uniform standards for construction information	10	0.57
9	Too many face-to-face meetings	4	0.57
10	Lack of integration and co-ordination	4	0.57

Sr. #	Inefficiencies	Reference Frequency	RII
11	Irrelevant overloaded information	1	0.57
12	Unable to analyze the cause	2	0.56
13	Manual re-entry of data	4	0.56
14	Slow information flow	20	0.55
15	Delayed delivery of relevant amounts of information	5	0.55
16	Lack of feedback system	2	0.55
17	Inaccessibility of information	9	0.55
18	Ineffective reporting system	5	0.54
19	Lack of adequate representation for project stakeholders	2	0.54
20	Multiple similar queries	2	0.53

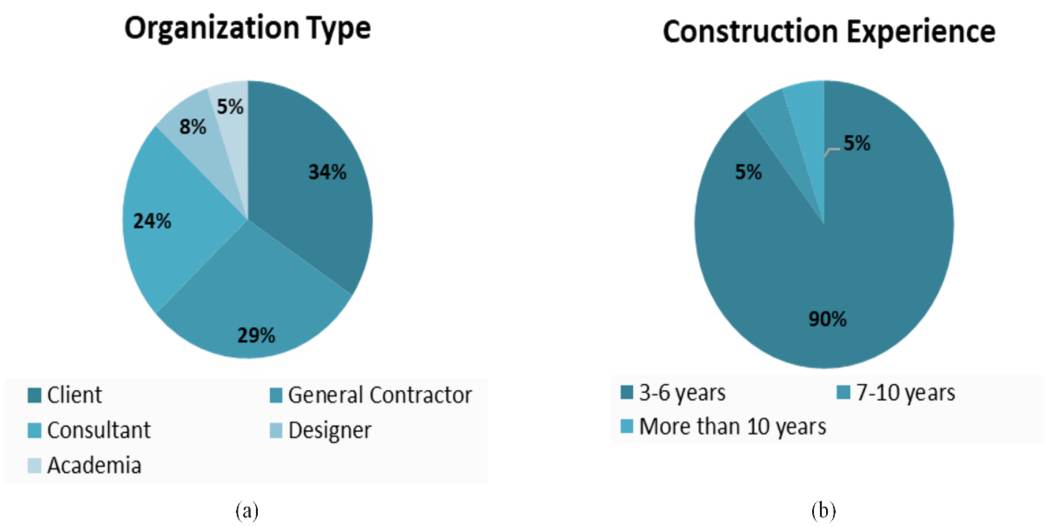


Figure 4-1 Demographics of Respondents

4.2 Identification of generation causes

A list of 18 finalized causes has been shown in Table 4-2 along with their reference frequency. It can be seen that RFI generated for "design clarification" among construction stakeholders occurred 44 times in different literature following that, "diversion of information" which has occurred 31 times. This shows the significance of the factors in the communication process of the construction industry.

Table 4-2 Finalized generation causes of Requests for Information (RFIs).

Sr. #	Causes of RFIs generation	Reference Frequency	Selected references
1	Design Clarification	44	[143, 155-160]
2	Design Modification	34	[143, 155-158]
3	Resource Substitution/ Modification	34	[143, 155-158]
4	Design Discrepancies	31	[143, 157, 158]
5	Incomplete plans/specs	30	[143, 155, 156, 158]
6	Design Change	30	[143, 157, 158]
7	Design Correction	27	[143, 157, 158]
8	Confirmation only	25	[143, 155, 156, 158]
9	Constructability Issues	23	[143, 155, 158]
10	Differing Site Conditions	19	[143, 158]
11	Addition/Deletion in Scope	18	[156, 158]
12	Design Verification	11	[143, 155, 156]
13	Guidance	11	[155, 160, 161]
14	Schedule Coordination	10	[158]
15	Design Review	7	[158]
16	Inadequate RFI responses	3	[161, 162]
17	Additional time	1	[162]
18	Others	10	[143, 158]

4.3 BIM-CIM framework

Figure 4-2 illustrates the framework for RFI communication management. The developed BIM-CIM plugin in the BIM platform derives its inputs from the building model and user-defined values and is connected to a cloud database. In the first step, the BIM model was initiated in Autodesk Revit and upon observing an ambiguity, it was decided to initiate the RFI process. For this purpose, the BIM-CIM plugin was invoked. Only the authorized personnel/stakeholders could start the RFI generation process. Project-related information was extracted automatically from the building model. Element(s) associated with the query was selected by the user in the BIM model. Further details were then added to complete the RFI form. All the information inserted for an RFI was stored in the cloud database. The information stored could be viewed in the BIM-CIM plugin and also within the BIM platform in form of a table. Notification intimating the RFI generation was sent to the relevant personnel requiring a response. After receiving a response, the data was also stored in the database.

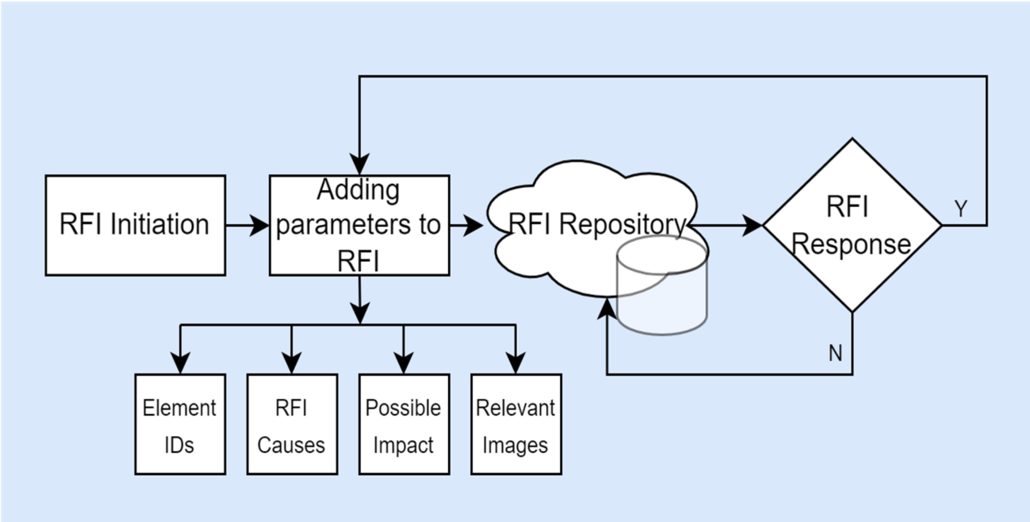


Figure 4-2 BIM-CIM framework.

4.4 BIM-CIM architecture

The system architecture of the BIM-based communication platform for the RFI process is shown in Figure 4-3.

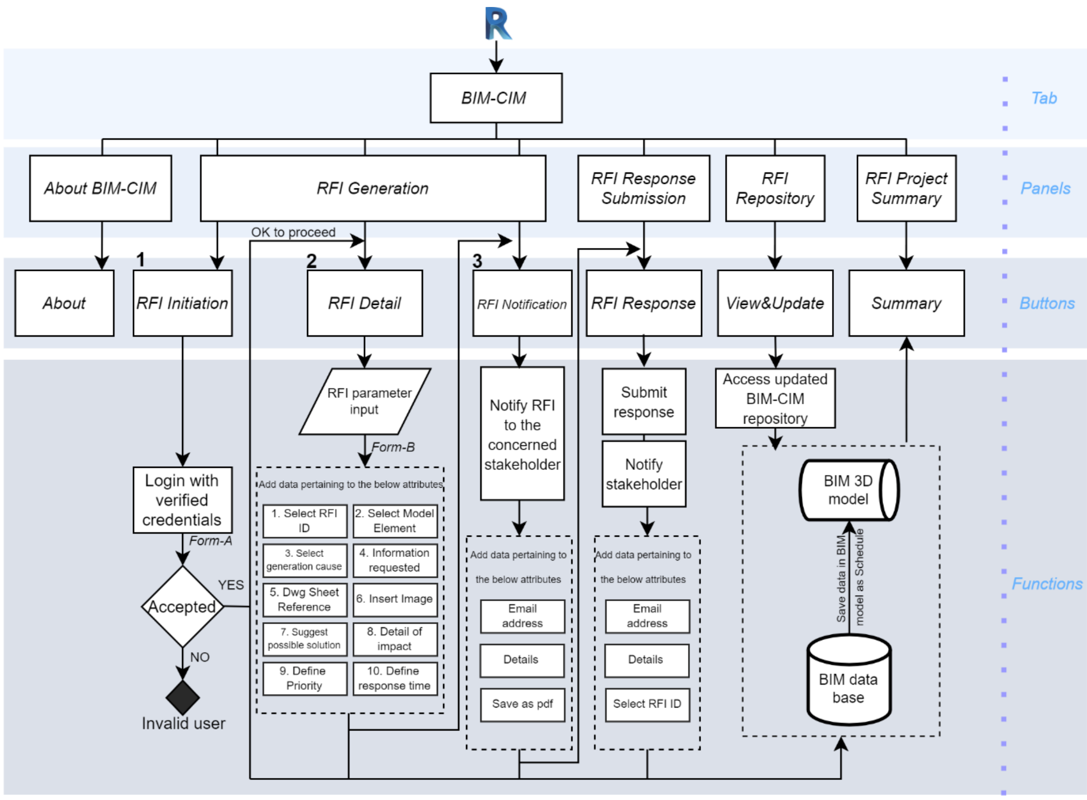


Figure 4-3 System architecture of BIM-CIM.

Figure 4-4 shows an overview of the built BIM-CIM Toolbar and encompassing 05 panels to carry out different commands: About BIM-CIM panel, RFI generation panel (a) in Figure 4-4, RFI response submission panel (b) in Figure 4-4, RFI repository panel (c) in Figure 4-4, and RFI project summary panel (d) in Figure 4-4. All buttons are programmed to perform the designated tasks in the Autodesk Revit environment; the functions of each are explained in the following subsections.

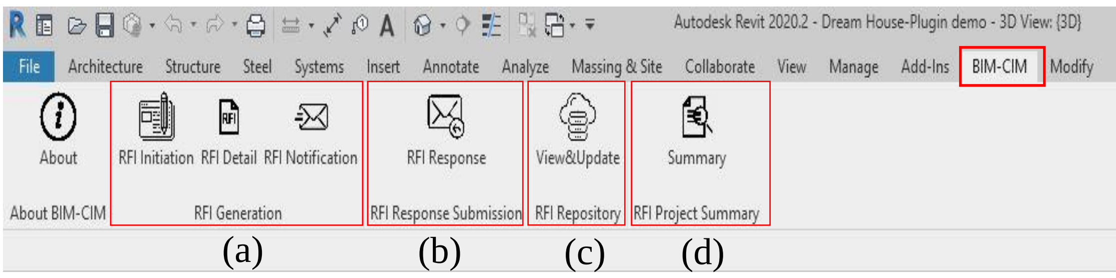


Figure 4-4 BIM-CIM plugin's user interface

4.4.1 RFI generation

RFI management was given less consideration as evident from the past practices [137]. it was assumed to stem from the lack of structured format of RFI in the practice leading to confusion and errors. Thus, in this research, significant importance was given to the RFI process from its initiation and proper documentation till response and storage in the central database. Thus, to effectively manage the RFI process and give it a standard structure, the RFI Generation module is provided with the functions of RFI Initiation, RFI Detail, and RFI Notification. Separate buttons are dedicated to each function as shown in (a) in Figure 4-4.

4.4.1.1 RFI Initiation (Form-A)

RFI Initiation is used to initiate an RFI process. It includes the general information and the information related to the Contractor. BIM-CIM plugin facilitates data security through an access control list which contains the list of stakeholders who have the access rights to write, edit, and respond to the query, as decided by the administrator. Thus, only the contractors with verified credentials are allowed to initiate the RFI process. Attributes in RFI initiation are shown in Figure 4-5

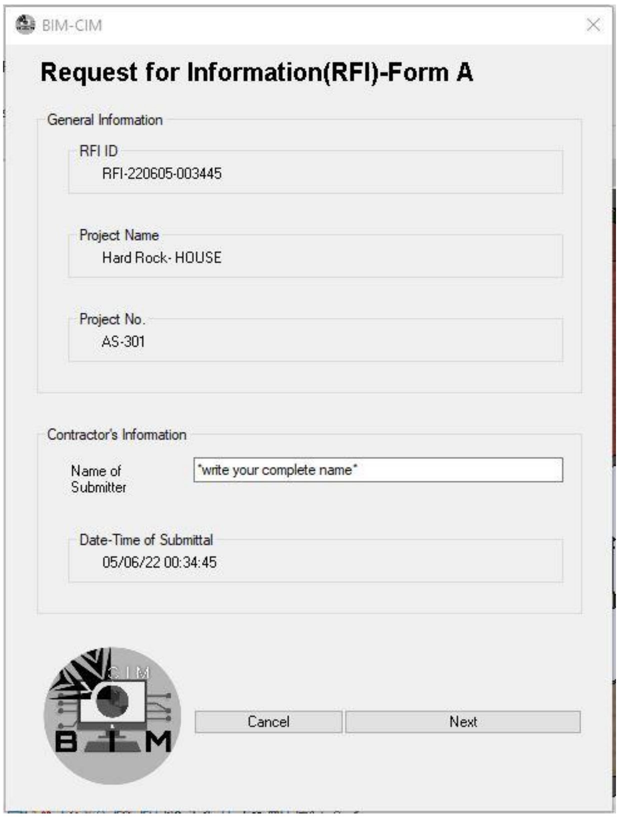


Figure 4-5 RFI initiation interface.

4.4.1.2 RFI Detail (Form-B)

RFI detail is structured as information requested, suggested solution details, and response required. The primary purpose is to generate an RFI which is self-explanatory, eliminating the manual process of cross-referencing the drawings or wasting time by asking the Contractor to give more details about the query. In the developed prototype, all the possible factors which can invoke an RFI by the contractor are inbuilt into the plugin as shown in Fig. 8. There is an option of 'others' as well which permits the contractors to enter relevant cause if it is not available in the existing list. Contractors have the option of attaching the relevant plans, drawings, etc. in the form of pictures. In this template, 11 different categories are available for data entry. Available input categories and their corresponding details are described in Table 4-3 and the interface is shown in Figure 4-6.

Table 4-3 Input attributes for RFI detail function.

Attribute	Compulsory	Mode of data capture	Description	Examples of users' selected values
Select RFI ID	Yes	User-defined	Users select an RFI file to write from a list of already generated RFI IDs, from form-A (*RFI initiation*)	
Select model element(s)	Yes	User-defined	Manually pick the relevant 3D element(s) from the model.	Window
		Automatic	Automatic picking of the selected element's ID, name, type, and category.	702363, Windows, Family Type: 36"x72", Family: Casement 3x3 with Trim.
Select Generation Cause/ Reason (18 elements)	Yes	User-defined	Select a relevant cause.	Design Clarification, Design Change, Design Modification, etc.
Information Requested	Yes	User-defined	Enter all the necessary details.	
Drawing Sheet Reference	No	User-defined	Give the relevant drawing sheet reference.	

Attribute	Compulsory	Mode of data capture	Description	Examples of users' selected values
Insert Image	No	User-defined	Redirects to browse the computer and allows to upload any relevant image.	
Possible Solution	No	User-defined	Suggest the solution, if any.	
Impact of the suggested solution	No	User-defined	Specify how the possible solution will impact the project.	Additional Time, Additional Cost, Both, None.
Detail of impact	No	User-defined	Insert details of the suggested solution's impact, if any.	
Priority	Yes	User-defined	Select the priority of the activity.	Critical Activity Non-Critical Activity
Requested Response Time	Yes	User-defined	Select the required response date for the query.	Within 1 day, < 5 days, < 10 days

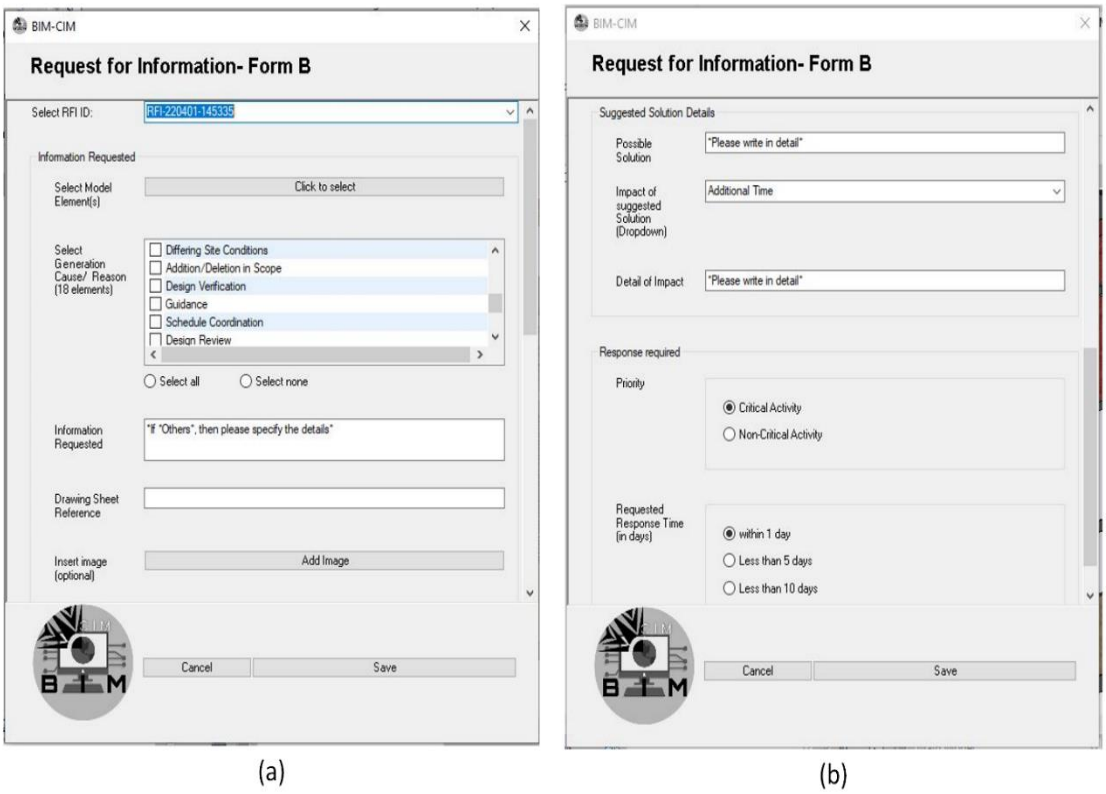


Figure 4-6 Interface for RFI detailing.

4.4.1.3 RFI Notification and RFI Response Submission

There is a considerable delay observed in the typical process when an RFI is generated and sent to the consultant [163]. In the developed prototype, significant consideration is given to eliminating such unnecessary delays. An email is generated by the contractor through the RFI notification button, notifying the consultant about the RFI, with an option to attach a pdf intimating all the details of an RFI. Information is retrieved from the database and is arranged automatically so it can be effectively converted to a PDF file. A sample of the pdf of the current-RFI is shown in Figure 4-7(5). Available input attributes and the corresponding details of the notification feature of BIM-CIM are shown in Figure 4-8. Thus, upon receiving the notification through email, consultants review the query and respond by invoking the RFI Response Submission under the BIM-CIM plugin. The response of the consultant is updated automatically in the RFI project ((2) of Figure 4-7) and RFI current files ((3)-(4) of Figure 4-7).

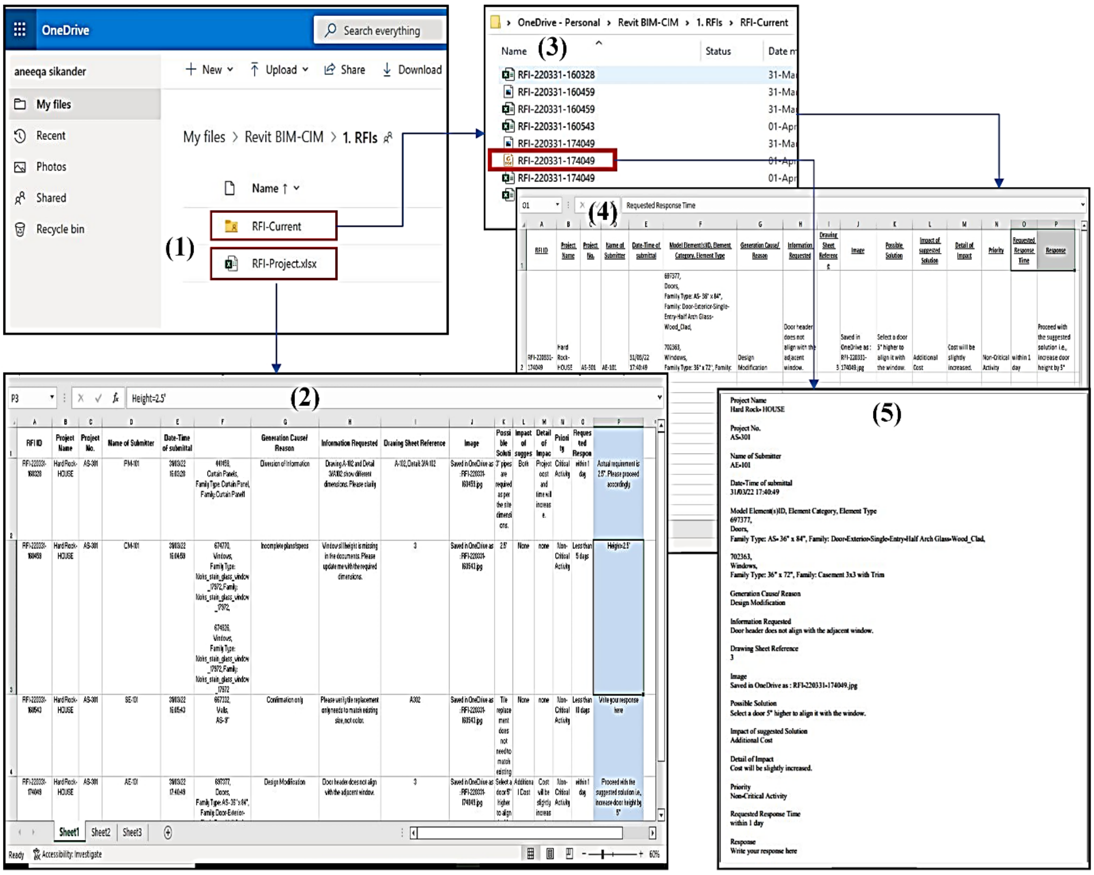
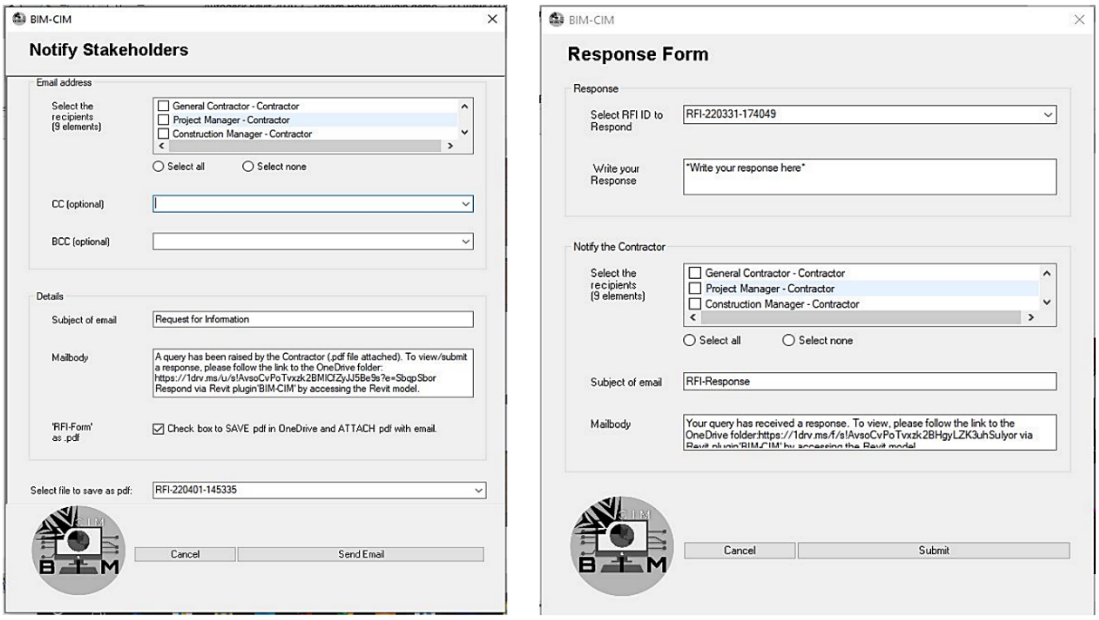


Figure 4-7 BIM-CIM database.

BIM-CIM has also an important feature of confirming the status of the emails, sent successfully or not, by a pop-up dialogue box. Available input attributes and the corresponding details of the RFI response feature of BIM-CIM are also shown in Figure 4-8.



(a) (b)

Figure 4-8 Interface for RFI notification and RFI response submission.

4.4.2 RFI Repository and RFI Summary

Goedert [164] discussed the effort involved in the collection and organization of information, as a large chunk of information is transferred in boxes or put in file cabinets and also organized in a format that is inconsistent with the user's interest. In the developed prototype, considerable importance is given to the proper organization of the stored data. The database of BIM-CIM has separate files for RFI-Project which documents all the RFIs generated throughout the project and RFI-Current includes the details of the current generated RFI only as shown in Figure 4-7. All data is stored in the database in each step. The details are saved in the plugin's database, so any correspondence made in RFIs at any time is also stored for future use. The repository module is linked with the cloud database i.e., Google Drive through dynamo to store the data input from RFI Generation and RFI Response Submission module. The RFI log is also stored within the Revit software under Project Schedules. Stakeholders can view the list of RFIs of the whole project in the form of a table as shown in Figure 4-9.

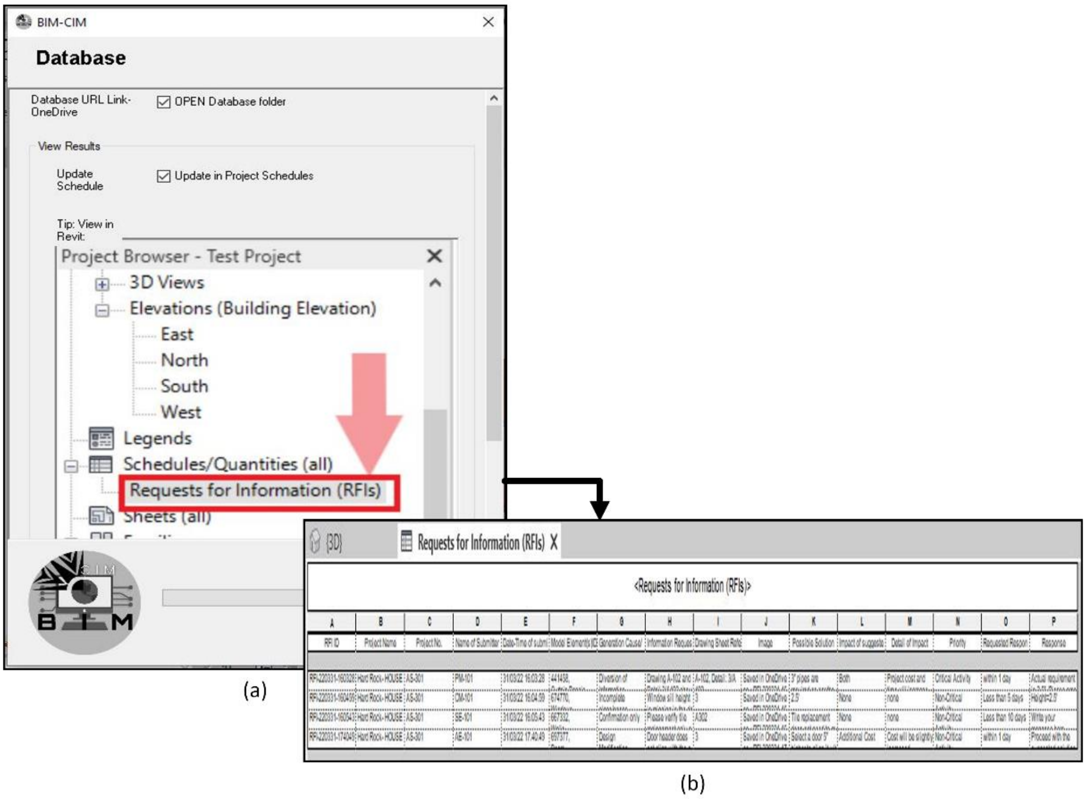


Figure 4-9 Interface for RFI repository and Revit project schedules

Figure 4-10 shows a summary report showing the status of queries as well as the number of RFIs generated against each cause during the project execution. This will help in the development of a robust feedback system.

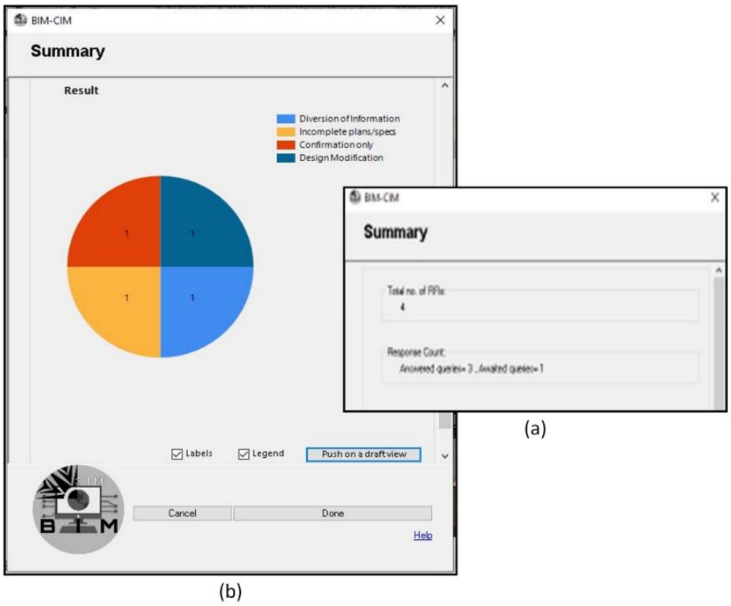


Figure 4-10 Summary report of RFIs interface.

4.5 BIM-CIM evaluation

Experts were demonstrated the BIM-CIM plugin implementation on a BIM model of a residential house. Table 4-4 shows experts' responses to questions about the need, and possible implementation of BIM-CIM in the construction industry, its interface usability, the overall effectiveness of BIM-CIM to improve the RFI communication and information management process [151], and the performance of the construction project [152].

Table 4-4 BIM-CIM evaluation by the industry experts.

Evaluation Type	Evaluation Parameters	Min.	Max.
Physical	BIM-CIM interface usability	3	5
Affective	BIM-CIM need in the construction industry	3	5
	BIM-CIM effectiveness to improve the RFI management process	3	5
	BIM-CIM to improve the performance of the project	3	5
Cognitive	BIM-CIM implementation	3	5
	The overall experience of using BIM-CIM	3	5

The criteria for evaluation were selected due to the project requirements, and the parameters can be reduced or extended in future studies. Each subject question was asked relative to the expert's experience with the BIM-CIM [165]. Table 4-5 displays the RII value (Equation 2-1), and the mean value of the inefficiencies [154] that BIM-CIM can resolve effectively.

Table 4-5 BIM-CIM effectiveness in resolving problematic inefficiencies in RFI communication and information management.

No.	Inefficiencies in RFI communication and information management	Evaluation scores for BIM-CIM	
		RII	Mean Value
1.	Poor record-keeping	0.778	3.889
2.	Poor document preparation	0.778	3.889
3.	Manual search and cross-referencing of relevant documents and/or drawings	0.867	4.333
4.	Poorly captured information	0.822	4.111
5.	Slow responses	0.800	4.000
6.	No proper mechanism for document tracking	0.822	4.111
7.	Batch/Bulk Information handling without proper management	0.778	3.889
8.	Lack of standardization for construction information	0.756	3.778
9.	Too many face-to-face meetings	0.822	4.111
10.	Lack of integration and co-ordination	0.756	3.778
11.	Irrelevant overloaded information	0.733	3.667
12.	Unable to analyze the cause	0.622	3.111
13.	Manual re-entry of data	0.778	3.889
14.	Slow information flow	0.711	3.556
15.	Delayed delivery of relevant amounts of information	0.756	3.778
16.	Lack of feedback system	0.733	3.667
17.	Inaccessibility of information	0.733	3.667
18.	Ineffective reporting system	0.622	3.111
19.	Lack of adequate representation for project stakeholders	0.711	3.556
20.	Multiple similar queries	0.733	3.667

4.6 Discussion

Experts agreed that the plugin BIM-CIM is an effective tool to deal with the RFIs (Table 4-4). They shared the view that the 'usability' of the BIM-CIM interface will not pose a problem in its use. However, they scored low on the possible BIM-CIM implementation in construction projects where BIM models are required to use BIM-CIM. This suggests that concrete measures should be taken to remove such barriers in its implementation. The problematic issues in RFI communication and information management which can be addressed using BIM-CIM are discussed below.

For the issues related to the documentation of the RFI process, the majority of the experts scored favorably i.e., strongly agreed or agreed. Hence, all such issues are likely to be resolved by using BIM-CIM in the RFI communication and information management process. The top-ranked problematic issue of 'Manual search and cross-referencing of relevant documents and/or drawings' can be eliminated through BIM-CIM. Other issues such as 'Poorly captured information', and 'No proper mechanism for document tracking' were reduced as compared to the other issues. This is because of the ability of BIM-CIM to easily store all the information-related documentation as it provides a standardized format for the RFI process [164, 166]. Issues such as 'slow information flow' still pose to be a problem [159] and are ranked the second last. According to the experts, such delays are due to the behavioral attitudes of the contractor and the consultant and were ranked among the last issues being addressed by BIM-CIM.

With RII values > 50% or more, and favorable average scores, BIM-CIM can minimize 'Poor document preparation', 'Batch/Bulk Information handling without proper management, and other related issues. This is ascribed to the provision of a realistic and easier way to access updated and all previous records, and an enhanced and fast communication platform among stakeholders using BIM-CIM to determine the causes of queries in a project [167]. On average, experts agreed favorably that BIM-CIM can save effort and time in 'manual search and cross-referencing of the relevant documents and/or drawings' needed to initiate RFIs and notify the consultant from the central database; therefore, it is ranked as one of the top issues being resolved using BIM-CIM [168].

Among all the stated issues, the lowest rank issue is ‘Ineffective reporting system’, with an RII value of 0.62 and an average score of 3.11 respectively. This can be ascribed to the fact the developed system cannot be the alternative to the competence and experience of the experts. Thus, these problems will yet prevail in the industry unless relevant personnel is hired. Issues such as ‘Lack of standardization for construction information, and ‘Lack of integration and coordination are likely to be addressed as BIM-CIM facilitates the digitalized platforms for fully computer-operated documentation [169]

According to the practitioners, issues pertaining to inaccessibility of information can be resolved by utilizing the centralized database of BIM-CIM in RFIs management [170], essentially, because of the access to view the RFI log and its details. Similarly, all the generation causes which can initiate an RFI are built within the developed, thus, the problem of ‘unable to analyze the cause’ is fixed.

Overall, BIM-CIM is attributed as an effective tool to address the issues in the communication and information management of an RFI process to a great extent[171], except for those that are related to the personal abilities of the contractor and the Engineer.

4.6.1 Benefits of BIM to the Construction Industry

BIM-CIM facilitates effective communication and information exchange for the fragmented natured construction industry. Because of its dynamic dissemination and merging of information, it is equally useful for small and large-sized BIM models. Through its user-friendly platform, BIM-CIM facilitates an efficient capturing and managing of RFIs communication in the construction industry. BIM-CIM also exploits the benefit of scalable cloud storage whose size can be conveniently increased to improve the performance or can be decreased to save cost, depending upon the project requirements and the size of the BIM models. BIM-CIM has the feature of automatic data partitioning to be stored in the centralized database facilitating the division of data and thus, a single query can be sent to the concerned stakeholder only. One of the major impacts of this study and the BIM-CIM solution is its ability to facilitate information flow [98] which is described as the panacea for the digital revolution within the construction industry.

4.6.2 BIM-CIM Roles and Responsibilities

In BIM-CIM, the roles and responsibilities have been assigned to the stakeholders according to the standard practices in the construction industry i.e., the contractor prepares and submits a query to the consultant, while the consultant assesses and responds to the query within due time as requested by the contractor [135]. But the optimal use of BIM in a multidisciplinary collaboration requires changed roles and relationships of the owners, contractors, and consultants, and re-organized collaborative processes are needed [172]. Ali et al. [173] proposed the new role of stakeholder as a 'BIM manager' who is a qualified person and has the access to the central database and leads the BIM team working on a project [151].

4.6.3 Barriers to the BIM-CIM Implementation

While conducting semi-structured interviews with the practitioners, the following limitations to the implementation of BIM-CIM in the construction industry were also identified. To operate BIM-CIM, the basic knowledge of BIM is necessary which the stakeholders are not fully equipped with. Thus, an effort is needed to educate people on BIM and its usage. Similarly, the implementation plan of BIM-CIM requires the stakeholders to define their new roles and responsibilities and also outline the required training or additional resources [174]. BIM-CIM adoption in a construction organization can be difficult because of the increased cost of modern equipment and proper training. The dynamic nature of the construction industry involves various stakeholders having their own goals and responsibilities which makes it difficult to adopt. Sometimes, the vested interests of the stakeholders impede them to accept a transparent central repository system [175]. Lastly, as the database of BIM-CIM is recorded on an online server, there is a chance of hacking and removing or modifying the data [176].

4.6.4 Strategies for BIM-CIM implementation

BIM-CIM implementation in the construction industry requires earnest efforts for the education and training of the industry persons. Educational institutes and construction organizations can play a considerable role in this regard. Contracts among stakeholders need to be amended to ascertain the modified roles and responsibilities of the stakeholders to use BIM-CIM in a project. Likewise, to determine the long-term benefits of BIM-CIM adoption at the organizational level, the rate of return on the initial investments needs to be analyzed [177]. Similarly, another important barrier is an unserious and nonchalant attitude to deal with the RFIs. This is related to the behavioral attitude which can is associated with the will of the person. Lastly, a safe online server should be purchased, and security pins should be incorporated to make the data less prone to hacking [178]. Thus, these strategies will help in overcoming the barriers to the implementation of BIM-CIM if they are adopted efficiently [179].

CHAPTER 5
CONCLUSIONS

5.1 Conclusions

The use of ICTs is tremendously facilitating the stakeholders in achieving a higher success and productivity rate in the construction industry. BIM has effectuated a paradigm shift by improving the performance of all areas related to the construction industry. In this paper, a novel BIM-based system is formulated and developed for improving the RFI traditional process of communication and information management of projects. It follows a systematic methodology to observe the evolution of inefficiencies in the construction communication and information management pertaining to RFIs, before and after the use of BIM. Through an extensive literature review, inefficiencies in the RFI communication process were identified at first and then verified by the experts. Since BIM platforms do not have the native tools and processes to deal with RFIs, therefore, in this research, by utilizing API provided by Autodesk Revit, a prototype was developed namely BIM-CIM. A centralized database was created, and a link was established by utilizing the platform provided by Autodesk Revit software. BIM-CIM manages RFIs covering all the possible causes of RFI generation. It was then evaluated by the practitioners by conducting semi-structured interviews. Results indicate that BIM-CIM has a significant potential for managing the RFI process. It can resolve almost all the identified inefficiencies in the RFI communication and information process except for those having the direct involvement of stakeholders. Practitioners suggested the BIM-CIM need in the construction industry and also identified some barriers to BIM-CIM implementation in the construction industry. Experts also suggested a few improvement areas to increase the effectiveness and usability of BIM-CIM. These recommendations suggested by the experts can also be realized as a way forward for future work. The experts made a few suggestions to enhance the BIM-CIM functionality in the construction industry. Experts suggested increasing the stakeholders' representation in the system to cover the stakeholders from all domains. An expert suggested adding the feature of attaching the relevant images by the contractor in the form-B of RFI detail as it is the most frequent practice in the traditional process. Another expert suggested that the generated pdf should also be attached with the email by the contractor to facilitate the consultant in directly sending the query to the person concerned. All these suggested features have been incorporated into the BIM-CIM as they were increasing the functionality of BIM-CIM towards the better management of RFIs. Since BIM-CIM has been validated by the experts and professionals of the construction industry, it can now be implemented in construction projects to resolve forthcoming inefficiencies in managing RFIs.

5.2 Recommendations and way forward

In the next phase of this research work, the BIM-CIM could be upgraded to deal with other prevalent modes of communication in the construction project. i.e., instructions, notifications, etc. A future study focusing on open BIM standard that includes information from different domains of AEC could enhance the interoperability for improving communication and information management in construction projects. Last but not least, the application of BIM-CIM on a real construction project can be carried out.

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