Framework Based on Building Information Modelling for Information Management by Linking Construction Documents to Design Objects

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Abstract

Most construction project information is stored in unstructured documents, despite its increasing scale and complexity. Owing to ineffective management of construction information, the construction industry is significantly less productive than other industries. Although building information modelling (BIM) is widely employed in the industry, it is difficult to model the project execution phase data owing to its high level of detail. Therefore, this study proposes a framework based on BIM that enables the storing and searching of construction project data through an effective linkage of documents with 3D design objects. The information breakdown structure and spatial breakdown structure, which are the media for integrating construction data with information technology, have been established through the identification and classification of information from unstructured documents from construction sites. The efficiency of the proposed framework in linking documents with 3D objects was validated through a pilot test project and industry survey. The proposed methodology is expected to assist in resolving issues in information management, including enhanced communication, accumulation of know-how, and minimization of disputes, if the utility of the methodology is improved by continuously discovering the best practices at the industrial or organizational level through its extended application.

Keywords: building information modelling; construction information; document management; information technology

1. Introduction

With the increasing scale and complexity of construction projects, the amount of data required is increasing geometrically. However, most project-related data from construction sites are stored in unstructured documents (e.g. daily reports, specifications, material submittals, change order, request for information, and field change notice). Owing to the ineffective management of such data, the construction industry is significantly less productive than other industries (Eastman et al., 2010, USDOC, 2008). In particular, the construction execution phase – in which a building is substantiated based on its design documents – requires the investment of the largest amount of manpower and resources over a long time period; moreover, the largest amount of data is generated in this phase compared with all construction project phases. Building information management during the execution phase would enable efficient construction management and productivity improvement as well as significantly assist the client in maintenance and lifecycle management of the building in the future. Thus, information management during the construction execution phase is essential.

At present, construction sites use various information management technologies to effectively manage construction phase information, and various attempts are being made on effective management of the information from the sites. However, around 80% of the information for work processes at construction sites is stored in unstructured documents, which degrades the efficiency of work processes (Caldas and Soibelman, 2003). Moreover, although information management at construction sites significantly affects efficient construction management, the contents of site-generated information and information flow have not been clearly defined. Furthermore, there is no information management system, which hinders continuous and systematic management. Blockage and loss of information creates difficulties in reasonable and efficient construction management.

Three main problems result from such poor document management. First, the overflow of a myriad of information hinders the successful execution of a project owing to loss or poor management of important documents. Effective utilization of such information through building information modelling (BIM) has
been recently attempted. However, because it is difficult to model the execution phase data owing to its high level of detail, this technique has limited applications in the construction field. Furthermore, the method to establish the information has not been clearly defined, which leads to limited effectiveness (Leite et al., 2011). Second, the vast amount of data from a construction site is scattered after the project is completed. Various documents (e.g., contracts, drawings, meeting minutes, scheduling, estimation, submittals, and change notice) are stored in individual desk drawers unorganized and are bound to be disposed of upon completion. If future problems arise regarding the construction quality or when it becomes necessary to re-check the construction information owing to a client claim, it is nearly impossible to search for or find the information again. Third, construction projects tend to rely on experiences and are mostly one-off occurrences. Moreover, various factors affect a construction project depending on its characteristics. As such, the competitiveness of a construction company lies in how the performance data from a previous project will be reflected in a later project. Because there is no framework established on how such a vast amount of information will be managed and organized, past learnings are not properly recorded and the same mistakes are repeated, reducing the competitiveness of a company. Therefore, this study develops a methodology to reasonably store various data generated during the construction execution phase, establish an information management system for retrieval, and an effective linkage of the information to a 3D BIM model. Such a methodology will assist in effective collection, storage, and retrieval of a vast amount of building information.

2. Literature Review
2.1 Documents from Construction Job Sites

Among all construction processes, the largest amount of information is generated and managed in the construction execution phase. Although the information from this phase is processed in structured forms such as the work breakdown structure (WBS) and cost breakdown structure (CBS), most information is collected in unstructured documents. Therefore, the authors conducted interviews and surveys of a few experienced superintendents and identified the types of documents produced from various areas of construction site management, such as cost, schedule, design, quality, safety, environment, and technology (see Table 1.).

In addition to various official documents, countless types of unofficial documents are generated owing to necessity on-site, such as meeting minutes, non-conformance notices, and field correction reports. Various documents are also generated from individual work processes. There are documents that are common requirements for every work package and those that are required for a particular work package. For example, earthwork would require documents for a particular work package, whilst common documents (e.g., contract form, schedule, drawings) exist regardless of the work package.

An input or output protocol has not been defined for the various execution phase data, let alone its management. Therefore, the information is managed by the staff in charge of each individual site. After the construction is complete, the data are either combined in one place or disposed of if there is no obligation for its management.

Table 1. Classification of Site-Generated Documents

| Category | Document Name |
|----------|---------------|
| Cost | Contract form, Notice to proceed, Request for monthly payment, Request for completion payment, Request for completion payment inspection, BOQ of completion payment |
| Schedule | Weekly schedule report, Monthly schedule report, Construction progress photograph, Corrective action report |
| Design | Drawings, Construction details, Specifications, Request for change proposal, Request for information, Field change notice, Change order, List of drawings |
| Quality | Quality control procedure, Quality performance results, Quality test results |
| Safety | Safety report, Safety management plan, Safety daily report, Safety management control report, Safety management detail report |
| Environment | Environmental impact evaluation report, Waste material management list, Environmental agency permission report, Environmental impact committee report, Environmental regulations report |
| Technology | Daily work report, Photography list, Material inspection report, Monthly equipment/labour input report, Material usage report, Inspection test procedure, Inspection results, Inspection checklist, Construction planning, Technical review report |

Furthermore, although the documents from a construction site contain a large amount of duplicate information, these are managed only as individual documents, which render it difficult to use the information from the documents in a comprehensive manner. In other words, the information generated from sites is documented in an archive at a site or stored individually by the person in charge of producing the document, which poses difficulty in searching for and utilizing the documented information. To resolve these issues, documents from construction sites must be accumulated in a database in a systematic manner. Furthermore, a management strategy based on linkage with graphic information is required for more efficient accumulation and management of documents.
2.2 Construction Information and Document Management System

Various data are generated during the execution phase of a construction stage and most of the important information is managed in the form of documents (Chen and Kamara, 2011). Document management involves the fast and accurate processing of data from compilation to disposal. Hajjar and AbouRizk (2000) proposed an integrated document and information management methodology based on a common data model for the company, project, and documents for integrated document management in construction companies. Caldas and Soibelman (2003) proposed systematic document classification based on the construction information classification system in accordance with the master format of the Construction Specification Institute. Park et al. (2009) developed a search system based on an ontology that is useful for searching for construction-related knowledge and proposed a methodology for effective use of conceptual information that may arise from the execution phase to search for construction-related information.

More recently, the interest has shifted towards the exchange of documents, search of accumulated information, and efficient utilization of information and the focus is on how the information from the actual sites can be utilized in an effective manner. To this end, a system for orderly accumulation of construction information and the visualization of graphic information and other relevant information, which enables the intuitive search of documents and its utilization, are necessary.

2.3 Information Technologies and BIM

A large amount of information is generated and managed at construction sites, and various systems and information technologies have been employed for efficient information management. To enhance construction management efficiency by improving the productivity of construction tasks, construction information has been integrated with computer and/or information technologies. Early works on information technologies highlight the combination of the aspects of the project lifecycle, integration of construction systems, and the utilization of information technologies and are devoted to the establishment of an integrated system that includes all stages (from design to maintenance) of construction. However, these works focus on data aggregation and visualization for construction management at a macroscopic scale and practical approaches are lacking for the accumulation and utilization of information from the site, where generation and management of data occurs.

Meanwhile, one cannot exclude the introduction of the BIM technology in the discussion of increased adoption of information technologies in the construction industry. Public organizations in the United States, such as General Services Administrations (GSA), have made the use of BIM in major construction projects mandatory, and the number of projects delivered based on BIM have increased worldwide (Eastman et al. 2010). Although much research is being conducted on all construction phases from the interference check during the design phase to the operation phase, most research during the early years focussed on BIM modelling; however, in the last decade, most researchers have focussed on data management and documentation of BIM rather than modelling. Current research on BIM focuses on establishing a database and producing documents based on the information generated during a construction process rather than using information through modelling. Previous works on BIM mainly focussed on analysis using BIM models, and the works on the use and application of BIM in the execution phase were limited to the generation of cost estimates and bill of materials and process simulation.

Because the continuous management of information through a linkage between graphic and non-graphic information is an important concept in BIM technology, the research trend in BIM is gradually shifting towards data management and documentation. From this perspective, BIM technology will be advantageous for the accumulation and management of documented information from the sites.

2.4 Linkage Between Graphical and Non-Graphical Information

Structured information has been managed through a linkage between work breakdown structure (WBS) and cost breakdown structure (CBS) in several cases. However, in these structures, unstructured information such as daily reports and meeting minutes are poorly managed. It is also notable that unstructured documents affect the success of a project. Since a building is created based on drawings and specifications in the execution phase, most information is based on an element of the building and the location information. Moreover, for performing and reviewing work at a construction site, only the geometric information of the building is fundamentally required. Linking location information from a 3D model would enable more convenient utilization, management, and review of the documents generated from the construction site.

In a similar attempt to integrate construction information based on building geometry, Chan et al. (2005) developed a project management information system through a linkage between graphical and non-graphical information. Caldas et al. (2005) proposed a methodology that allows searching for related documents using graphical information, and Ding et al. (2012) suggested a strategy for linking graphic information with the project management information based on the case of a railroad construction. However, these previous works were less focussed on graphical information. As such, the input format for non-graphical information was imperfect, posing difficulties in information linkage. Moreover, as the graphic information was established by focusing on objects, it was difficult to manage the graphical information if the lowest-level object was subdivided.
A notable work on model-based document management is that of Caldas et al. (2005). This work attempted to manage documented information through linkage with the design model. For this purpose, the linkage between documented information and models was studied through analyses of a breakdown structure for documents based on the master format and the code structure of the IFC file. The code information from documents was added to a 2D IFC model in the form of references for which the documents were linked through a classification based on the master format. As a range of construction information is linked to a 2D model to manage design documents, the method is advantageous for searching for documents but there are limitations in utilizing the required information efficiently. From these previous works, it can be deduced that the documented information generated from construction sites must be accumulated systematically and the database must be managed based on a breakdown structure for the generated documented information generated to effectively utilize the accumulated information. Moreover, a methodology is required for effectively linking such breakdown structures to a BIM model.

3. Development of a BIM-based Document Management System

3.1 Concept of the System Framework

The construction information generated during the execution phase is related to an element of the building or a location. Therefore, all documents generated on the construction job site can be linked to the 3D model, which is geometric information. This research proposes a BIM-based data linking system for linking these documents with 3D graphical information. As depicted in Fig.1, not only the existing classification systems (i.e., WBS, CBS, and others) but also the spatial breakdown structure (SBS) and the information breakdown structure (IBS) are established in effectively linking the 3D objects. Linking the construction data in this manner enables examining and searching for the required information in real time based on the BIM model.

In Fig.1., the documents generated from a site are compiled by the respective authors (denoted as A) and are reorganized using the breakdown structures for classifying information (denoted as B). The reorganized site documents are stored in a database (denoted as C). The documented information is managed in conjunction with the BIM model (denoted as D), and the stored construction information is utilized by the construction manager or others (denoted as E).

3.2 BIM Linkage of Construction Information

Fig.2. illustrates the concept of accumulating and managing documented information by combining SBS or IBS with the previous breakdown structures such as WBS or CBS. Various documented information generated from a construction site can be linked to the BIM model through a reorganization of the site documents using the SBS or IBS and the previous breakdown structures, denoted as A, B, and C in the figure, respectively. The information on the construction site, denoted as D, includes all information pertinent to space and the breakdown structure for the information. The execution information extracted from the site documents is linked to the design information through the SBS, allowing an integrated management of both design and on-site information. In this way, the information linked to the SBS or IBS and the existing breakdown structures serve as detailed information on the construction site, and this information can be linked using the codes for respective breakdown structures.

Documents generated from the site contain information on both "space" and "work". This information is newly defined, as shown in Fig.3., through the "SBS", "IBS", and "Existing Breakdown Structures". The information classified in this manner can be linked to the objects in the BIM model. During this process, if it is difficult to structure documented...
information from the site into the forms specified by the breakdown structures, the site document itself can be converted into an electronic document, which can be managed effectively.

3.3 Spatial/Information Breakdown Structures

SBS, proposed in the aforementioned framework, is required for linking the documents from a site to each object of the BIM model. It classifies the graphical (geometric) information based on the building units and building parts that form the space of a building. SBS was compiled by integrating the building elements. It can be divided into six levels: (1) Project, (2) Building, (3) Floor, (4) Unit, (5) Part, which is a basic unit that comprises the space, and (6) Member, which forms the object in the IFC file format of the BIM model. The documents from a site can be effectively linked to the BIM model using the SBS. For instance, a document related to reinforced concrete work can be linked to the SBS that corresponds to "Floor" in order to link the documented information, and the information on the finishing work on the interior wall of a bedroom can be linked to the Member so that the information is linked to the BIM model.

IBS was used to classify documents based on the type and subject in order to manage the information from the site in a more systematic manner. This enhances the utility of the documents generated from the site. For instance, among the job-site documents, the request for progress payment document is a general type of document, while its subject can be classified as "on-site management." By classifying the content of the site document in accordance with the IBS, various documented information from the site can be accumulated while being classified into categories such as reference, specification, contract, and drawing, which is expected to allow a more efficient management of the various information generated. Among the 16 classification criteria of the international standard using the Uniclass classification system, the authors considered "A. Form of Information" and "B. Subject Disciplines" capable of classifying the information generated from the site into a structural form.

Using the IBS, the documents from the site can be classified in terms of type and subject, which allows systematic management of information from construction sites. For example, "Procedure for Quality Control!", a document generated from the site, can be defined as having Uniclass A information type of "A820, Plan" and Uniclass B subject of "B360, Quality Planning". When the information is classified based on these criteria, a code name of "A820-B630" can be assigned during the classification process.

Fig.3. illustrates the management process of a daily report using the classification system proposed in this study. Using the IBS, the information from the daily report is classified as "Document – Planning", as shown in the top right hand side of Fig.3., and the SBS is used to record "Project Name", which is a type of project information, as well as "Date", "Weather", and "Temperature", which are general project information. The location information of the job, as specified in the daily report, is stored at levels of "Project-Building-Floor-Unit-Part-Element" of the SBS. The last job information is classified in accordance with the previous WBS and then stored. The information of the document classified this way is stored in the database. Note that the information is stored in two separate forms of structured and unstructured documents to complement the inflexibility of the breakdown structures.

3.4 Framework of the BIM-Based Construction Information Database

To expedite the BIM-based document management for on-site construction information, a database (DB) structure has been designed. Fig.4. illustrates the relationship between each DB in the construction information.

Fig.4. Linkage Structure of Construction Information DBs

The construction DB structure mainly comprises four sub-DBs, including work information DB, SBS DB, IBS DB, and document DB (denoted as A, B, C, and D, respectively, in Fig.4.). For example, if information is generated through a daily report at the construction site, the data that can be extracted is automatically entered into the work information DB in A, SBS DB in
B, and IBS DB in C. The information that is difficult to convert to data is stored as a whole in the document database (denoted as "D"). During this process, the site documents entered as a whole are reorganized with respect to the type and subject of the information using the IBS (denoted as "C"). The spatial classification codes of the information in each database are linked through the data table of the "Object Link" in the figure and the project information ("Project Info" in Fig.4) is automatically linked to the corresponding object.

The authors established a construction information DB structure to accumulate construction information and designed data tables that comprise the database structure and the entities of each table. Microsoft Access 2016 version was used to design and manage this construction information database. The entities in each data table were connected to project codes, and the entities with element information were linked to the spatial classification codes again. The entities and attributes in each data table were defined but are not included owing to space constraints; interested readers may refer to Lee (2016).

### 3.5 Linkage of BIM Objects and Documents

The information extracted from a document generates the reorganized information through the application of the breakdown structure proposed in this study and the classified information is stored in the respective database. The classified information can be regenerated from the combination of new information stored in the database. Moreover, electronic document information can also be stored in the database although it cannot be structured by storing the document itself. Hence, the problems with storage and management of documents at sites (disposal or loss of documented information) can be resolved.

The documented information must be linked to achieve a one-to-one correspondence between documents and individual objects of the BIM model, which would allow an effective management of the documents. There are three methods of linking the BIM model to the SBS of construction information: using the individual ID within IFC files of the BIM model, using object IDs provided by different BIM software, and using the layer IDs of the objects. Fig.5 illustrates these three methods.

To link a BIM model with documents, the objects for each construction work must be modelled. This is because BIM accumulates and manages information through the objects of the 3D model. For instance, when a bill of materials is generated using the BIM model, the quantity of concrete is calculated based on the walls in the 3D model using the parameters related to the volume. However, because scaffolding, a temporary structure, is not generally modelled, it is impossible to calculate the quantity.

Overall, the appropriate level of detail (LOD) must be set given the purpose and objectives of the model prior to modelling. LOD of modelling is typically divided into five stages from LOD 100 to LOD 500 (Leite et al. 2011). For accumulating and managing information generated during the construction phase using a BIM model, the LOD of the BIM model must be defined for effective accumulation of construction information. LOD 300 lacks the LOD for accumulating the information for construction work at the execution phase as it is only at the level of detailed design. Although LOD 500 specifies a highly detailed model and hence can collect all information generated from the site in the 3D model, it requires significant effort and resources for correction of the model and accumulation of information if used on-site. Therefore, in this study, the LOD of the BIM model for establishing the BIM-based information database was set as LOD 400. Once the BIM model and the information database are linked, the project information is stored in each object of the BIM model and the information can be searched and examined through the BIM model. For instance, when there is a crack on the wall, the project information and general project information of the wall in question can be identified through the SBS and WBS of the relevant member. This will be examined in the case study.

This document management framework can be utilized in the construction information and history management of a building through effective accumulation of the execution information. Moreover, by storing the documents generated during the execution process together with the model, the construction information during each execution process can be conveniently examined. In particular, in the case of issues such as a claim, it is expected that the framework will assist in the collection and management of documents related to the claim.
4. Case Study of the BIM-based Document Management System

To validate the applicability of the proposed methodology, a hypothetical project has been selected. The project is a residential apartment project, where it is assumed that cracks occurred on some walls during the construction process (see Fig.6.).

BIM modelling has been performed using Autodesk Revit Architecture. While there are various BIM modelling tools, Revit Architecture has the advantage of convenient addition of new parameters. Through the modelling process, a new parameter, SBS, was added to a wall object, and the parameter values of the object were specified. In this manner, the parameters that allow linkage with the construction information database were added as element characteristics of the object ("Family" in Revit Architecture), and the added parameters were written through the linkage to the construction information database. Moreover, to allow convenient manipulation of the construction information database linked to the BIM model, a user interface (UI) was developed using Visual Basic Applications (VBA). The UI was designed such that the SBS can be linked to the IBS through an electronic document linked to the SBS. As shown in Fig.6., the project information and general project information of the wall with cracks can be identified through the SBS and WBS of the relevant concrete member. For example, it can be identified that the member in question is object Wall 1 in Bedroom 1, Unit 2 on the first floor of Building 202. Moreover, it is possible to analyse the relevant specifications, daily report, and technical drawings, which are the linked documents to identify the cause of the crack.

In this manner, it is also possible to enter the documents linked to the 3D model of the example site, including daily reports, specifications, technical drawings, construction schedule, and quality management plan. The construction staff may identify problems during the concrete placement by repeatedly checking if the documents from the project in question are linked to the 3D object. As a result, the staff may discover which company was in charge of the work and how the work was being supervised and launch an investigation to prevent similar incidents in the future.

As shown in Fig.6., by searching the SBS of the member with cracks, the space information, work information, and project information of the member appear in relation to the SBS. Moreover, it can be seen from the right hand side of the figure that electronic documents linked to the member, including contract documents, specifications, drawings, and various reference documents, can be viewed. Therefore, it was possible to review whether the plan for the work in question has been followed or whether the quality control measures were complied with. It was found that the minimum temperature during the work was $-4^\circ$C and there was no suitable curing process.

Therefore, for this work, the subcontractor repairs and reinforces the crack and inspects the entire concrete placed during the work. This was deemed significantly effective in problems that can be prevented in advance.

As such, by accumulating relevant construction documents in a database while linking to the SBS of the member, construction history can be viewed in real time. Moreover, the storage of relevant construction information in the construction information database through the IBS will be useful in the systematic management of information on the construction. By continuously utilizing the present methodology in information management during construction works on-site, documents can be effectively managed and conveniently searched, which not only saves time and effort but also minimizes risks due to poor information management as no data is lost or disposed of.

5. Validation with In-Depth Interviews

In order to validate the effectiveness of the proposed framework, the authors conducted in-depth interviews with the industry practitioners (O’Leary, 1991). To assure validity, it is recommended that the number of respondents should be at least 8 to 10, and they should each have at least five years of professional experience (Hallowell and Gambatese 2009). The questions were divided into two categories: Internal and External validity of the proposed framework. The agreement scores were quantified with 5- Likert scales (1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree).

Table 2. Detailed Questions and Average Score of In-depth Interview

| Category | Interview Questions                                                                 | Average Score |
|----------|-------------------------------------------------------------------------------------|---------------|
| Internal | 1. Does 3D-object-based data processing successfully assist in real-time data storage and search for on-site management? | 4.81          |
|          | 2. Do SBS and IBS successfully assist to search for the required information in the construction execution phase? | 4.36          |
| External | 3. Does the proposed system improve on-site data management?                           | 4.36          |
|          | 4. Does the proposed system improve the accumulation of on-site know-how and minimize disputes? | 3.81          |
|          | Total Average Score                                                                  | 4.34          |
In the pilot test project, the unstructured documents were identified and classified for on-site management. The proposed methodology is applicable to effective on-site storage, management, search, and retrieval of documents generated on-site, a standardized breakdown structure (SBS, IBS) would be inapplicable unless the company or industry-wide support is guaranteed.

6. Conclusion

While a greater amount of information is generated during the execution phase among all phases in the project lifecycle, on-site information is difficult to manage owing to the lack of appropriate information management systems. The execution information generated during a construction process is stored and managed in an archive with unstructured documents by the individual authors. Hence, there are problems in communication owing to the loss or disposal of site documents, and lack of accumulation of know-how on execution owing to one-off management, where the information disappears after construction completion.

Therefore, this study established a document management framework that uses a BIM-based construction information database for efficient accumulation and utilization of on-site project information. The proposed methodology is applicable to effective on-site storage, management, search, and retrieval of documents containing various data generated during a construction process. To effectively manage the numerous documents generated on-site, a standardized breakdown structure must be adopted. For this purpose, this study developed a framework for document management where 3D/BIM objects are linked to the breakdown structures, i.e. the SBS, IBS, and others. The efficiency of document management has been validated through a pilot test project. By applying the proposed framework to an actual project, it was found that the mechanism identifies and extracts the required information through linkage with numerous documents generated from the 3D/BIM objects.

The industrial and academic contributions of this study can be summarized as follows.

• The information in unstructured documents has been identified and classified for on-site management, where the proposed data-linking framework between documents and 3D/BIM objects can be effectively associated.
• The proposed framework allows real-time data storage and search for object-oriented construction information during the project execution phase.
• In the pilot test project, the unstructured documents were effectively retrieved in terms of the magnitude of the association of the documents with the 3D/BIM objects.

However, although the validity of the system has been conducted by industry practitioners, it is expected that the effectiveness will be even greater if a detailed methodology for linking documents to 3D objects can be established through a diverse set of tests. Another limitation is that the SBS and IBS must be standardized so that the efficiency may be enhanced through a protocolization at the industrial level beyond the one-off site-level approach. Finally, to extend and advance the proposed framework, the methods of linkage with the breakdown structures should be applied in a holistic manner and the best practices at the organization-level should be discovered and disseminated to other organizations so that the framework can impact the industry-level performance.

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