Building Information Modeling for Quality Management

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Abstract: Building Information Modeling (BIM) has grown tremendously and used in each stage of construction project life cycle. This research focus on integrating BIM with quality management for innovative development and improve performance efficiency of the quality management system in the construction stage. First, this study proposes an application framework for BIM in the AEC (Architecture/Engineering/Construction) filed. Basically, this framework emphasizes the application of different BIM models with different special requirements during different phases of the project life cycle. Second, based on this framework, a QC (Quality Control) model system prototype is established. The QC model is utilized in the construction stage with Autodesk Revit API (Application Programming Interface) to code the add-ins, which can record onsite quality defects immediately and display the 3D elements of these defects. Moreover, users can also print the QC reports with this system or use A360 to produce the panorama or stereo panorama to check the positions of the onsite quality defects using mobile devices. The system efficiently documents construction quality defects while improving communications regarding quality information.

1 INTRODUCTION

Generally speaking, the nature of construction involves lengthy construction period and multiple interfaces. Therefore, the graphic information that needs to be documented, revised, shared and transmitted are vast and complex. Inadequate or insufficient data transmission often leads to project failure. Changes occurred or derived from the site during construction, in particular, may lack efficiency due to limitations of time and storage if information is shared through paper copies only. On the other hand, science and technology is advancing with each passing day. To most people, Building Information Modeling (BIM) was only a name representing a state-of-the-art concept few years ago. Now, it is popular and often applied in the Architecture/Engineer/Construction (AEC) field. The research of Singh (2017) indicates that in the US, 72% of the construction firms are believed to be using BIM technologies for significant savings on project costs. The NBS sixth National BIM Report 2016 from the UK states that BIM adoption in the UK had reached 54%, and over 80% of those surveyed by the NBS are expected to have adopted BIM in 2017. According to a McGraw Hill Construction Report on BIM, 90% of project owners in Germany either often or always demand the use of BIM. Meanwhile, 78% of the contractors are using BIM in South Korea. France decided in 2014 that it would develop 500,000 houses using BIM by 2017. The development of BIM signals the presence of new possibilities for the construction industry. BIM has countless advantages. It detects design conflicts quickly, creates consistent construction messages and it is compatible with 4D. The addition of cloud and big data, and integration of the virtual and real world are bringing tremendous impact to the operation of the traditional construction industry.

This study focuses on the application of BIM on quality management. Achkar (2016) mentioned that the core concepts of quality management include quality control, quality assurance and communication protocol. The communication protocols encompass 1) Organizational structure and responsibilities of project stakeholders; 2) Communication channels; 3) Frequency of information exchange. Lee et al. (2014) indicates that the Quality Assurance (QA) and Quality Control (QC) tasks to be conducted onsite include the review, testing, inspection, quality control

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documentation and record keeping in the file management system. It is evident that construction companies need to deal with the onsite tasks involving certain degree of complexity in order to reach higher quality. Hence, project efficiency can be enhanced on site with sufficient tools and support. Therefore, it is crucial to promote the utilization of BIM in the construction stage, combine it with quality management to develop innovative approaches and improve performance efficiency of the quality management system.

Public works in Taiwan adopts the Three-level Quality Management System (TQMS) as a framework for quality management. TQMS encompasses three levels, the first is quality control (QC), the second is quality assurance (QA), and the third, quality audit. A more efficient application of TQMS is also an important issue that is worth exploring. To achieve such efficiency and improve performance, this research proposes an application framework for applying BIM in the AEC field, especially in quality management. Meanwhile, a quality control system prototype (QC model) for Revit system is developed with a focus on the first level of TQMS - QC for contractors.

2 LITERATURE REVIEW

The development of BIM is maturing in recent years. Love et al. (2014) mentioned that BIM can improve the quality of design information and interoperability; reduce construction costs and tendency of changed orders; assimilate project systems, data and teams; and enhance whole life-cycle asset management. Lee et al. (2014) claimed the collaboration, coordination and communication in horizontal construction projects may benefit from the application of model-driven approaches to QA/QC. Quantity evaluation is the subject of multiple studies, including Cheng, 2013; Monteiro and Martin, 2013; Wei et al., 2017. Wang et al. (2014) developed a systematic approach to conduct fitness review for BIM model using predefined standards, and built a system prototype to demonstrate the functions of flight path control. Chen and Luo (2014) established a product, organization and process (POP) data definition structure to explore the advantages of using 4D BIM on quality applications in accordance with construction codes. Lin et al. (2016) provided a BIM-based Defect Management (BIMDM) system by onsite quality managers during the construction phase.

Additionally, some researchers discussed the applications of cloud technology to address the large exchange of information and data. Jiao et al. (2013) presented an integrated cloud AR framework that consists of a cloud BIM engine, a cloud BSNS application, and an online AR system. Kivimäki and Heikkilä (2014) proposed a new approach in which 3D design surfaces are established and kept on a central collaboration cloud system. Ding and Xu (2014) proposed a BIM cloud storage system, which greatly improves collaborative work while effectively reducing costs at the same time. Afsari et al. (2016) provided a comparison of current cloud-based BIM interoperability architectures. Juan and Zheng (2014) presented a cloud service model and a cloud-based Open BIM building information interaction framework, and further illustrates the architecture of cloud deployment pattern and the information interaction process

3 APPLICATION FRAMEWORK OF BIM IN AEC

Cloud is critical in the AEC field because of effective and efficient exchange of information throughout the project life cycle. Basically, cloud service is divided into public, private, and hybrid cloud based on security levels. There are also three additional types of cloud services: 1) Software as a Service (SaaS): The cloud service providers supply a cloud platform from which users may rent or use the software service. A typical example would be Autodesk 360. 2) Platform as a Service (PaaS): Services are delivered by a cloud provider in the form of hardware and software tools. The provider also hosts the hardware and software on its own infrastructure. Salesforce.com's Force.com is an example of common PaaS vendors, while Amazon Web Services (AWS) Elastic Beanstalk, Appear IQ, Google App Engine and Heroku are examples of PaaS platforms for software development and management. 3) Infrastructure as a Service (IaaS): The hardware, software, servers, storage and other infrastructure components are all hosted by a third-party provider on behalf of its users. In addition, the provider maintains the users' applications and handles tasks such as system maintenance, backup and resiliency planning (TechTarget 2017). The criteria for determining the cloud service include corporate resources and needs for security and reliability.

In order to thoroughly implement the concept of BIM, the revision, exchange, and sharing of related data should be updated immediately through the cloud services. The focus of this study is the

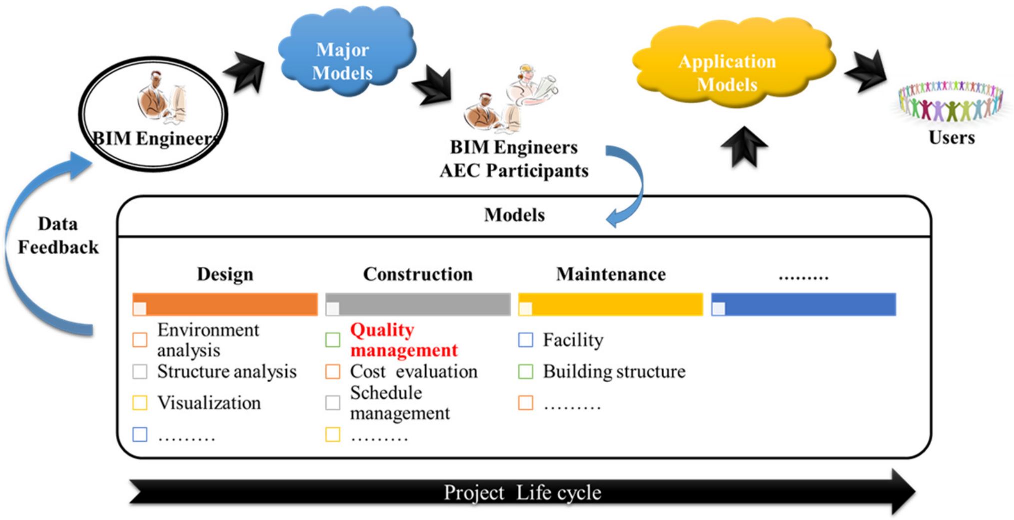

Figure 1: Application Concept of BIM in AEC.

application of BIM on quality management. However, the model and data transfer process during a project life cycle using BIM is discussed first to give readers an overview about the applications in quality management.

Figure 1 illustrates the application framework of BIM in AEC. Starting from the top left, BIM engineers finish the initial BIM model (major model) and upload it to the cloud. During the project life cycle, the AEC participants in different phases can download the major model for modification or revision according to their special requirements. For example, during the design phase, designers places more importance on environmental analysis or visualization, while onsite engineers focus more on the 4D or quality management function during the construction phase. Different considerations would prompt the AEC participants to develop different models (application models) based on the major model. In order to ensure that the initial information obtained by all AEC participants in different stage is correct, the major model cannot be revised arbitrarily. Hence, when the AEC participants want to share the information on their application models, they have to upload the model to other storage space (as shown on the top right of Figure 1). Users and authorization to revise within this domain would differ from that for the major model. Of course, the AEC participants can provide feedback on related information to the major model in a timely manner. Major “models” referred in Figure 1 take into account the different versions of major models which encompass new information as time progresses. The different versions provide efficient tracking and review late on.

4 BIM FOR TQMS

TQMS clearly delineates the responsibilities of the owner and contractor. All project participants must follow TQMS when performing operations public works related tasks unless otherwise specified. It includes three levels:

- Quality control (first level): Contractors are responsible for quality control.
- Quality assurance (second level): Project owners conduct construction quality assurance.
- Quality audit (third level): Public Construction Commission (PCC) or Government authorities are in charge of quality audits.

Quality control is the most essential and urgent element in TQMS. Contractors may prevent wasted time and resources on redoing or re-inspecting the work with proper quality management at this level. Figure 2 shows the TQMS structure and the performance process with BIM. The engineers in construction companies can upload the Quality Control Model (QC Model) to the clouds of project owners or government authorities, who can then check the quality and ask the contractor to submit related reports. The following chapters provide in depth discussions on construction quality defects, the development of application model (QC model) during the construction stage, and the protocol for QC modeling with a case study.

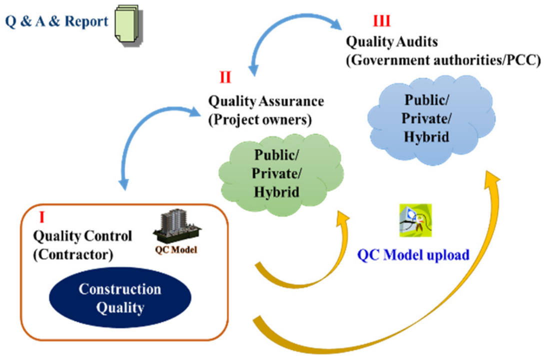

Figure 2: Application Concept of BIM in TQMS.

4.1 Construction Quality Defects

Construction Quality defects are often derived from poor workmanship or inadequate site supervision. Be it existing and latent, construction costs would increase as a result due to project delay, loss of productivity and material costs. The worst case scenario could even threaten building safety, leading to bodily harm and property damage. Common construction quality defects include: 1) Poor quality control system: The authority or supervisory agency does not have an inspection system in place or does not fully implement such system. There is insufficient documentation for the supervision, audit or inspection process and results as well as the tracking records for improvement. The construction company does not effectively implement quality control on a voluntary basis or not complete the self-checklist. 2) Poor construction quality: Such defects include inadequate concrete mixing and rebar spacing. The focus of this study is to apply the BIM models toward the construction quality defects. According to the quality inspection scoring reports from the Public Construction Surveillance Unit of PCC, subjects related to quality management include concrete, rebar, steel structure, formwork, environmental and ecological conservation, earthwork, regular construction, onsite management, and lastly, inspection and review system. This study focuses on building QC models for common structural defects found in reinforced concrete, rebar and formwork, for instance. The defects are listed in Tables 1. The "no#" column indicates numbers corresponding to the original point system form.

4.2 QC Model

The QC model provides a new platform for recording the building quality defects on site. Database development of the model incorporates the three-schema architecture while Microsoft Access and Visual Studio C# are used to code the API of Autodesk Revit and to build the quality system prototype. The three-schema architecture was developed by the ANSI/X3/SPARC Standards Planning and Requirements Committee in 1978. It incorporates three levels, as shown in Figure 3

Table 1: Construction Defects.

No#	Construction Defects	
5.01.01	Concrete	Cold joints/ Honeycombs/ Pinholes/ Bugholes/ Blowholes
5.01.02		Drying shrinkage
5.01.03		Finished concrete surface are non-compliant(vertical/ horizontal variance)
5.01.04		Debris are left on the concrete surface
5.01.05		Expansion joint/ Movement joint is inadequately placed, constructed, not installed
5.01.06		Bursting during concrete pouring
5.01.07		High-Flow Concrete segregation and bleeding
5.01.08		Sedimentation of aggregates in Self-Compacting Concrete
5.01.99		Other construction defects
5.02.01	Rebar	Main rebar/ Stirrups binding is non-compliant
5.02.02		Incorrect rebar size/ quantity/ spacing/ No detail drawing
5.02.03		Inadequate lap length/ Column rebar congestion due to splicing
5.02.04		The hook has inadequate angle or length for straight extension
5.02.05		Not using spacer and cushion blocks, and the protective covers are non-compliant
5.02.06		Not installing starter bars/ Not leaving adequate length/ Spacing is too large
5.02.07		The spacing is too tight (less than 25mm)
5.02.08		No strengthened rebar at openings or corner/ Proportion is non-compliant
5.02.09		The beam-column connector anchor is not curved beyond the center of the beam
5.02.10		The anchorage of beam's rebar does not exceed 15 cm
5.02.11		Serious corrosion/ Oil stains or concrete residue on the surface
5.02.12		The welding of steel cage is non-compliant
5.02.13		The coupler is poorly installed or highly rustic
5.02.99		Other rebar defects
5.03.01	Formwork	Overused/ Does not meet specifications
5.03.02		Not organized/ Not finished with concrete form oil/ Applied with poor quality black oil
5.03.03		Leakage of concrete grout
5.03.04		Brace/Horizontal or Diagonal Lacing defects
5.03.05		Tilted formwork
5.03.06		Opening/Embedded conduits are not properly installed
5.03.07		Not cleaned/ No access opening is installed
5.03.99		Other formwork defects

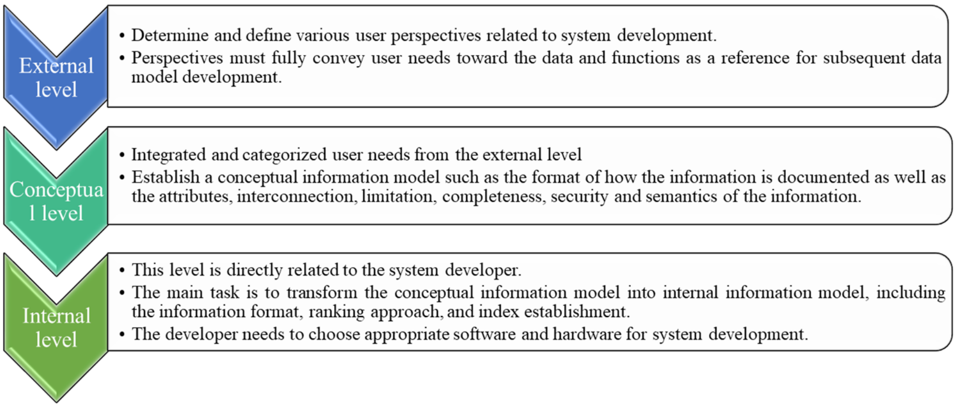

Figure 3: Three-schema architecture.

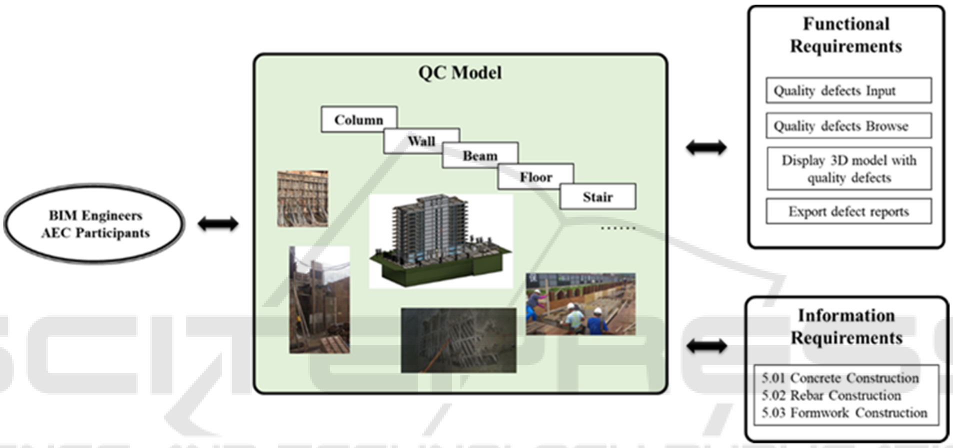

Figure 4: Relationship between information requirements and system requirements.

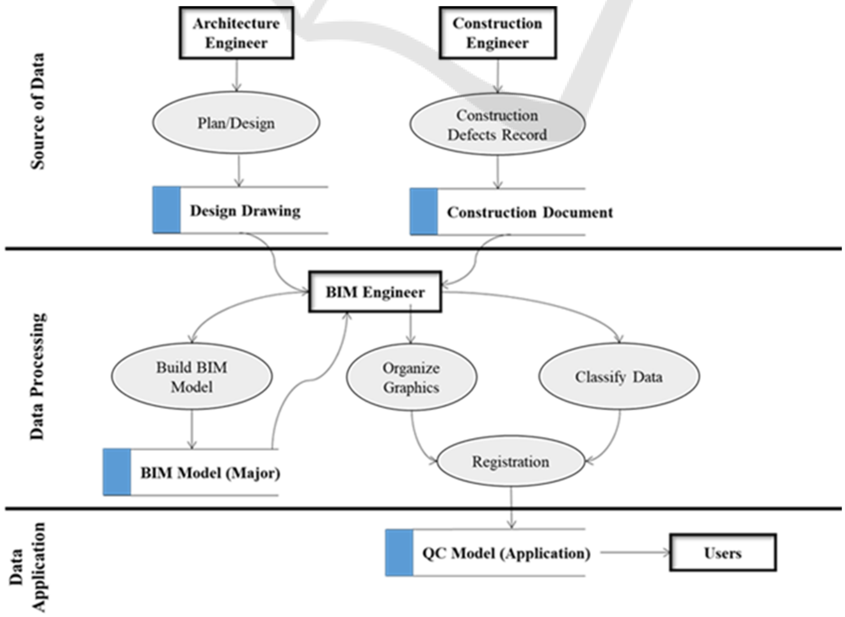

Figure 5: Data flow diagram.

(Hansen, 1992), to build the information system. The content is as follows:

- External Level: Figure 4 shows the relationship between information requirements and system requirements. The detail of information requirement is shown in Tables 1.
- Conceptual Level: This stage focuses on attaching quality parameters to the BIM elements. Element ID in the BIM model is the critical key. Table 2 shows the quality parameters added in Revit for the QC model with additional QC parameters added. Figure 5 shows the data flow diagram.
- Internal Level: Microsoft Visual Studio C# is used to write the API of Autodesk Revit and this study will focus on walls to build the system prototype.

Table 2: Quality Parameter type.

Parameter	Type
Date	String
Floor	Integer
X – wayGrid	String
Y – wayGrid	String
Quality Defects	String
Picture #no	Integer

4.3 Application

A case study is adopted to build the revit model and introduce the operational environment as well as the process of QC model. The project, CEO, is adopted to test the QC model system prototype. CEO, a project with 5,438 square meters of construction area and 31,623 square meters of total floor area, is located in Linkou, New Taipei City, Taiwan. It is a RC structure with 4 stories underground and 12 stories above. The construction budget is approximately NTD $1,200,000,000 and the main structure was completed in 2014. Figure 6 shows the Revit 3D model for the case (major model).

When the user starts Autodesk Revit, the CEO model appears on the center of the screen, which shows that **Quality Information** on the ribbon top. The functional structure of QC model is shown in Figure 7. Click on Quality Information, and push buttons for **Basic Attributes**, **Browse**, **Export** appear, so does the Split push button with **Concrete construction defects**, **Rebar construction defects** and **Formwork construction defects**. When using the system for the first time, users must start with the Add New push button in Basic Attributes to add attributes to the quality of an element. The attributes will be added automatically in Properties Palette (as

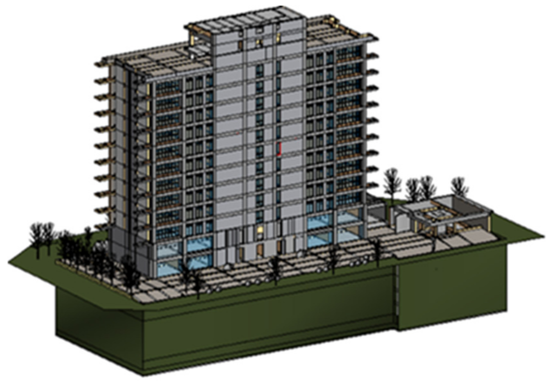

Figure 6: CEO Revit 3D model.

shown in Figure 7 with green block). The user can use the Split push button based on actual conditions to correspond to the actual quality defects (as shown in Figure 7 orange block). After selecting the defect, the system will highlight the interior and exterior of the wall in red and record the defect in the attribute of Quality Defect. Click on the particular element, followed by clicking the Quality Attribute push button under Browse, and the dialogue box will appear the quality defects of the certain element (as shown in Figure 7 blue area block). BIM engineers may upload this QC model to the cloud anytime during construction and provide real-time information to those who need it. The quality attribute information added is tied to the Revit database, and therefore, users can export the added quality information with the Revit database for analysis. Finally, users can print QC reports as shown in the yellow block in Figure 7. The reader can refer to the research by Cheng (2017) to gain deeper understanding of the operation details of QC model system prototype.

Additionally, the QC model can produce virtual reality images through related technique to improve communication efficiency among the engineers. Figure 8 illustrates the process. The engineers adjust the position to be displayed in the Revit software, and then upload to Autodesk® A360 rendering to produce the panorama or stereo panorama. When the image is completed, the QR code for the linked video is displayed with the result, which users can scan to browse the panorama on a mobile device and to check the positions of the quality defects.

5 CONCLUSIONS

This study proposes a framework for application for BIM in the AEC field. During the study, BIM is

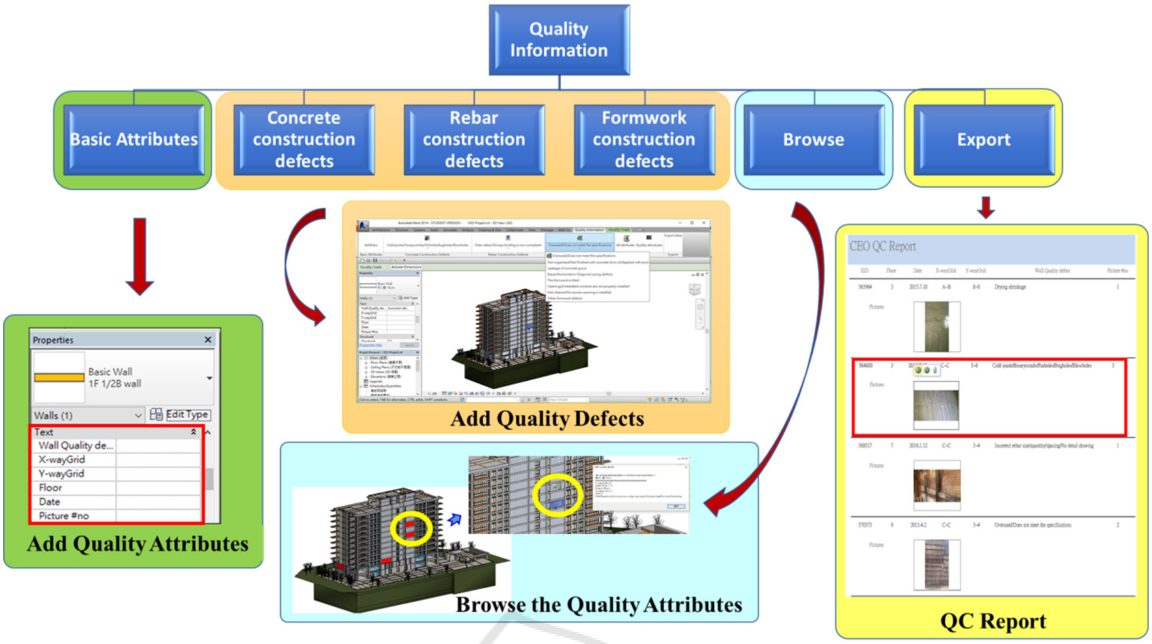

Figure 7: QC Model functional structure.

Figure 8: QC Model vs. A360.

incorporated to demonstrate its ability to record and examine construction defects for contractors. A quality system prototype is established using Autodesk Revit API to code the add-in, which displays 3D elements with onsite quality defects. In addition, engineers may upload the quality defect models they wish to share to the cloud for those who need the information. At the current stage, this study only focuses on the discussion of building the quality management system prototype for walls. Subsequent studies may explore other elements, such as earthwork and environmental defects, or applications in infrastructure. With endless potential, the effective integration of BIM with construction management such as cost, safety and so on may lead the future efforts. With the development of VR (Virtual Reality), AR (Augmented Reality), SR (Substitutional Reality), and MR (Mixed Reality), future studies may also focus on techniques that deliver quality defect information realistically in the virtual world.

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