LEVERAGING QR CODES FOR THE FULL LIFE-CYCLE OF AEC PROJECTS.

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Abstract. Mobile technology is developing and spreading worldwide at a very rapid pace. This has created an increased demand for interfaces like Quick Response (QR) codes that can enable mobile phone and other portable device users with convenient and quick access to building information. QR codes are now widely implemented in a variety of industries. The first section of this research explores how leveraging QR codes from design to construction (3D-5DBIM) can optimize the full workflow from the design to construction of reinforced concrete walls and floors via Revit and Dynamo. This research leverages the cloud storage of information to enable viewing on a smart device. The second section of this research aims to explore how 6D building information modelling (BIM) workflows can be achieved by using QR codes embedded within built projects for the purposes of as-built facility management (FM). Streamlining the processes of preventive and scheduled FM can offer significant cost and time benefits. This research seeks to explore the value of QR codes in a workflow to simplify the means of accessing information of the built form, with the accessibility of a user's mobile device, eliminating the need for individuals to search through an extensive list of drawings. QR codes are proposed to be installed at site locations containing data applicable to those specific building areas with additional security access to all information.

Keywords. BIM; QR Code; Cloud-Based Platform; Reinforcement; Facility Management.

1. Introduction: Research Motivations

Computers and computing are ubiquitous. We are surrounded by digital tools and objects that are equipped with computational capacities and internet connectivity in ways that are deemed 'smart'. Mobile phones are equipped with the latest technologies such as high-speed internet connectivity, high processing speed, and bigger colour displays (Rouillard, 2008). People now use mobile smart devices over desktop computers to access information online. In this context QR code technology has become an increasingly valuable way to efficiently link the physical world with virtual information through a simple scan on a mobile device. Technologies such as QR Codes are now being used more and more due to the rapid development and consumer desire for mobile devices to do more.

As access to digital or virtual data is made easier with technologies such as QR codes this suggests the technology has a broad potential for use in the development of data management and information sharing systems. Data management is a crucial aspect in the AEC industry and QR code technology may be leveraged to play its part. QR codes offer ways to provide access to building information in efficient ways and by using everyday mobile smart devices (Sivakami 2016). In the area of FM the efficient access to accurate as-built data is seen as particularly valuable. Optimising FM workflows is very important as 90% of total building cost occur in the operation phase (automatedbuildings 2017). Information transfer from the design team to the construction team, and later during the hand-over to a FM team can affect the accessibility of as-built information resulting in incomplete or difficult to locate information. For example, when designing and constructing concrete reinforcement for slabs and walls, contractors aim to plan the budget accurately and maintain this accuracy by comparing estimated costs with actual costs, thereby planning as necessary and revising forecasted expenditure and construction programs. In the design and construction phases of projects the inefficiencies inherent in representing a 3D world in 2D documentation are significant. The traditional process of design and constructing reinforcement can be tedious as it is common practice for engineers to provide 2D plans showing rationalized reinforcement layouts. Consequently, the reinforcement scheduler is required to review the documentation carefully and create a reinforcement schedule for the manufacturers. This example evidences the underutilization of BIM tools, that this research argues could be potentially mitigated by creating a 3D reinforcement model and implementing QR technology into every stage of the project lifecycle.

2. Research Aims

This thesis aims to propagate QR code technology in the AEC industry by designing new workflows that integrate QR codes into the design process to capture as-built data that can be made useful for a building's entire life cycle. There are two main objectives in this project:

The first objective of this project aims to change the traditional workflow of designing and constructing reinforced concrete elements in a project. The advancing technologies has led to a change in the way architects and engineers design. This shift in designing buildings - meant that documenting information through 2D representation have become increasingly tedious and difficult to translate and shifted to BIM as it contribute more to process efficiency, and provide superior accuracy than traditional 2D CAD drawings. The subsequent case study aims to link a physical world together with the digital world via QR codes to show all structural reinforcement and its detail associated on a user smart device. When viewing BIM information on construction sites can be beneficial in 2 different ways, (1) visualising the final built form prior to construction, (2) providing guidance on reinforcement locations and the suggested placing sequence, both of which can be visualised on smart devices.

The second objective seeks to explore the value of QR codes in the post construction life-cycle of a project. One aspect of this involves accessibility of drawings on user's mobile device, eliminating the need to go searching for drawings as QR codes will be installed at site locations with embeded data applicable to those specific building areas with additional security access to all information. This research will investigate how BIM data can be transmitted into QR codes for Cloud based documentation storage which are compatible with smart devices such as smartphones and tablets that are readily accessible and used on building sites. The outcome of this research will allow users to access and review both 3D and 2D documentation at their comfort (Afsari, Eastman, Shelden, 2016). With QR codes on site, information and data can be directly viewed in an instant. The ability to achieve this would be beneficial for all maintenance officers when undertaking building inspections as well as assessing and undertaking any refurbishment work.

The "results indicate that providing BIM information in a 3D representation on projects can reduced the error rate for an assembly task by 82%", QR codes together with smart devices may be one method to facilitate this progression.

3. Research Questions

From the information gathered by precedence, the application of QR codes has not been realised in the Built Environment. QR codes are primarily utilised for advertising and marketing purposes (Sivakami 2016). despite the increasing technological advancements in visualisation representations. A lot of architectural, engineering and construction firms are still only 2D documentation for construction. What this research aims to investigate is:

How QR codes can represent a valid alternative or integration to the conventional workflow from 3D to 6D BIM and made beneficial for the AEC industry?

This research explores many advantages of implementing QR codes in a workflow for the designers, construction team and suppliers when working together with BIM digital models. The evaluation of this research is made on criteria of efficiency and design clarity in comparison to the traditional methods. An assessment of the amount of presentable data and ease of accessibility to such technology is also made (Thompson and Horne, 2009).

4. Methodology

4.1. QR CODES FROM DESIGN TO CONSTRUCTION (3D – 5D BIM)

Within the Action Research framework, the methods of this research include developing a tool to maximise the process from design to constructing reinforcement on a project. This research methods will address how shifting from 2D line drawings to 3D BIM modelling for reinforcement documentation will be beneficial for the AEC industry. In the majority of situations construction is conducted at a bare site and in the specifics of the site being used for this case study, it is similar. Traditionally Architects and engineers often rely on drawings and models of their projects to aid in their work. Although 3D modelling software is common practice the detailed elements of documentation is often just detail lines with no BIM data. Since the industry relies on 2D documentation to construct from, modelling detail items such as reinforcement in reinforced concrete structures is not common place. In this research Dynamo a scripting software integrated with Revit has been used to improve the efficiency, accuracy and provide more detailed information such as bar lengths, schedules and bar layout sequences.

A methodology of maximising the process from design to constructing reinforcement is divided into five different stages [figure 1]. First stage will be focussing on maximizing the speed process of making reinforcement a solid visible object inside Revit. This process will eliminate the need to use the standard tools inside Revit as it is very tedious to use and time consuming. The second stage will aim to control the cover offset via type instances within Revit via dynamo. This process has the advantage of providing the user the option to change multiple objects at once instead of one at the time function that Revit originally provide with. The third stage continues from previous stage by expanding the possibility of reinforcement visibility. This stage will focus on assigning each reinforcement layer with a different colour code. This will provide the user with a sense of clarity as each layer will be in different colour when viewing the model inside the cloud. This stage will also be focussing on creating element type ID for each reinforcement layer, this will be beneficial when tagging reinforcement and creating a schedule sheet inside Revit and construction team will now have a better understand of which reinforcement bars belong to which layer. Fourth stage will be focussing on linking specific views and drawing sheets onto the cloud to avoid overlaying too much data inside the cloud and making it impossible to view via smart devices.

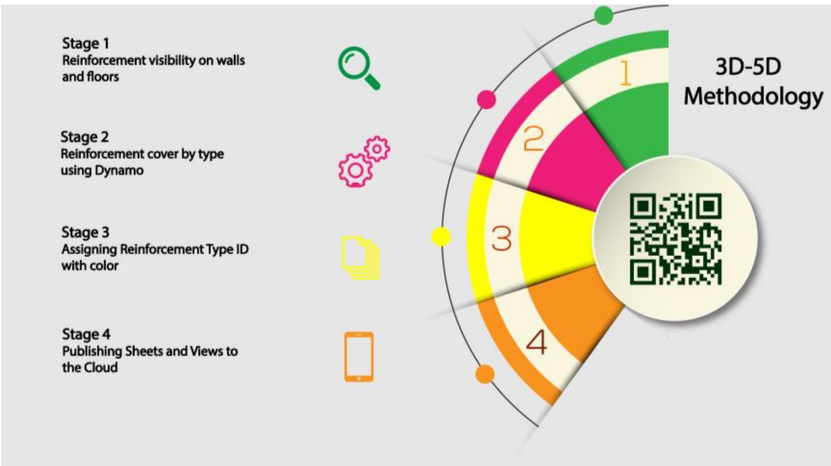

Figure 1. Reinforcement modelling and representation methodology

4.2. QR CODES IN FACILITY MANAGEMENT (6D BIM)

Within the Action Research framework, the methods of this research include developing a workflow for the specific FM context of accessing mechanical information in a virtual environment as the detail and accuracy of mechanical model as MEP modelling software became mature enough to be used on major projects, demand in 3D representations were already set for similarly detailed MEP models to also be viewed on the emerging smart devices (Plant Engineering 2017).

Working with Aurecon, the methodology of this workflow is divided into five different stages [figure 2]. The first stage focuses on data transfer between BIM model and Cloud-based platform. The second stage will focus on differentiating and extracting BIM data, commonly known as layers and families within Autodesk Revit, and exporting these elements into a 3D view to reveal information about what is essential for display on mobile smart devices. The third stage will involve utilising QR codes as a self-navigation tool, this intends to increase processing speed as the user will no longer be relying on instruction from staff members. The final stage is to provide an adaptive feedback report, allowing user to work with smart devices instead of traditional hardcopy documents, this will eliminate the workflow that are often tedious and time consuming.

Figure 2. Maintenance methodology

5. Background Research

QR Codes are becoming a very important tool for marketing purpose all over the world, and act as the link between the physical world (leaflet, brochure, newspaper) and the digital world (website, contact information and other digital information). They also make communication a lot easier (make a call, send text message and send an email). All these applications make QR codes a very good operational tool that is ready to be utilised in the AEC Industry. Research suggest that QR code are a much better tool to use when comparing to a standard barcode. Standard barcode will only be readable at 0% damage while QR code has error correction to each block which increase the readability up to 30% damage. This demonstrate the potential of making QR code a suitable tool to use in a built environment from 3D-6D BIM. As mentioned earlier, QR code are heavily used across other industries but have yet to be fully utilized in the AEC industry.

A great example illustrating a good use of QR code is a research paper form “A Design of e-Healthcare Authenticaion Framework with QR Code” a health industry utilising QR code in security system for non-registered user to view requested information (Tiranant, Lee 2013). This theory can be applied to both case study as the built environment should always require security access for important drawings and datasets. Another great use of QR code are illustrated in the automotive industry from “Mercedes-Benzes”. Mercedes plan to provide a rescue map for every vehicle type, this will be accessible via QR codes on their vehicles. This map contains all the information necessary to rescue any injured occupants speedily (Endgadget 2017). This principle is explored for the AEC industry in this research paper. One immediate example is that building owners and tenants will often request building refurbishment works. For example, a client might want to drill more holes into a reinforced concrete slab for installations of pipes or insert an inter storey stair within a tenancy. Through incorporating BIM together with QR codes, feasibility studies can be made easily and the construction team can begin works with confidence, avoid critical areas of heavy reinforcement area through a quick scan of the QR codes placed on the form.

6. Case Study

For this project, we used www.qr-code-generator.comto generate our codes. After the codes have been generated, they were printed on A4 sheet and used on sites. The first case study will involve a current Aurecon project for a series of apartments in Wentworth to test the potential of applying QR codes from design to construction. This case study solution created together with Aurecon is a nonstandard approach and has been computationally generated using Dynamo. The second case study involves the process of creating a more efficient maintenance workflow via QR code are a completed BIM model example provided by Autodesk Revit.

6.I. QR CODES FROM DESIGN TO CONSTRUCTION (3D – 5D BIM)

This case study is focused on improving the process from design to construction with a focus on reinforced concrete structures but with far reaching future applications. By utilizing BIM software’s, portable smart devices together with QR code technologies, building data information can now possibly be viewed in real time on construction sites.

6.1.1. Reinforcement Visibility

Reinforcement visibility inside Revit has always been a challenging and time-consuming task for structural engineering to work with. It requires the user to manually filtering all the layers inside a project before making reinforcement visible in a view. This is the reason why engineers often document reinforcement with 2D detail lines indicating where reinforcement is on a floor plan. Together with Aurecon, we seek the potential of investing into creating a 3D reinforcement model as this will effectively reduce the time builders and contractors are required on site which ultimately minimize the project labor costs, which in developed countries are a large portion of the overall construction fee. To minimize the workflow of this task, scripting software such as Dynamo with external package like BIM4Struc are required. We aim to provide a tool for users to refer to and use without any scripting knowledge. [figure 3] is the result of this case study.

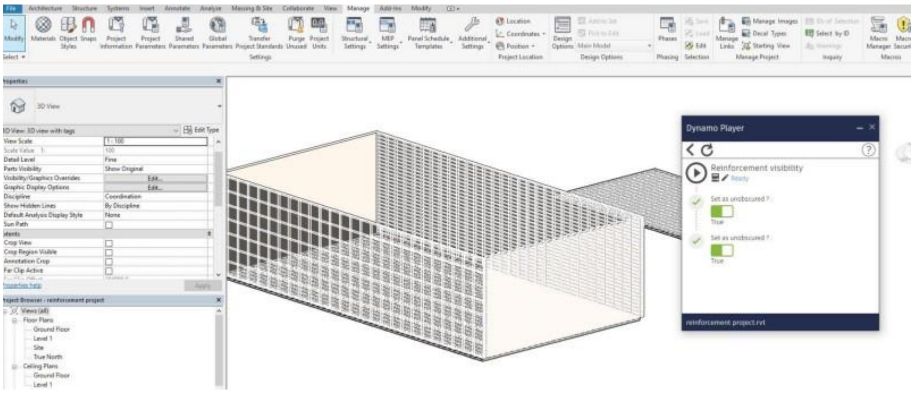

Figure 3. Reinforcement visibility in a 3D view

6.1.2. Reinforcement Cover by Type with Dynamo

Adjusting reinforcement cover inside Revit are very tedious as it Revit are restrained to one by one modification only option. this present a big issue when a large project with hundreds of internal walls with reinforcement cover needed to be change. Together with Aurecon, we seek the potential in creating a one output script that will be beneficial for structural engineers to utilize with when designing structural floors and walls inside Revit. This process will ultimately enable the user to change multiple objects at once by reinforcement cover type as shown in [figure 4].

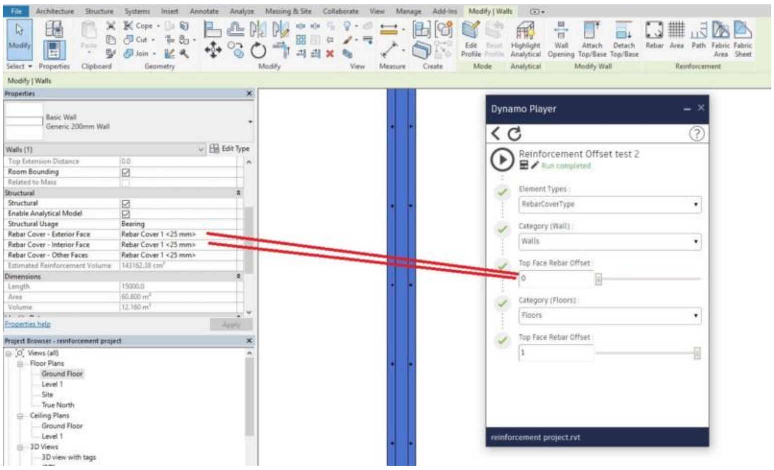

Figure 4. Reinforcement cover type with Dynamo

6.1.3. Assigning Reinforcement Type ID with color

This case study has developed from the theory "6.1.1. Reinforcement Visibility". At current state, reinforcement appearance by default has same color for all layers and has no data information to them. This case study seeks the opportunity to creating element type ID for each reinforcement layer and assign each reinforcement layer with a different color code. This will give the user a sense of clarity when viewing the model from the cloud. This will greatly benefit the construction team as it notifies the builder an indication to where each reinforcement bars are according to the 3D model. The outcome of this case study will eliminate the need for 2D printed drawings on construction site [figure 5].

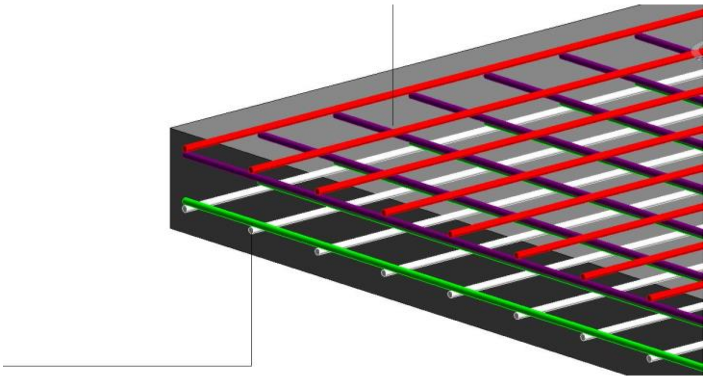

Figure 5. Reinforcement type id with colour assigned to each layer

6.1.4. Publishing Sheets and Views to the Cloud

When viewing projects stored in the cloud, not all sheets and views are needed for every QR code. To make viewing projects on smart devices feasible, extracting and stripping back data from the model and consideration to which sheets and views are suitable for certain cases is important. This case study uses “Publish Settings” and “Manage Cloud Model” to publish the desired sheets and views. Construction team can now quickly access necessary documents in real time.

6.2. QR CODE IN FACILITY MANAGEMENT (6D BIM)

This case study aims to provide instant access into building data information in a more efficient way by utilizing portable smart devices together with QR code technologies to ease the workflow involved in facility maintenance duties.

6.2.1. Linking BIM Model to the Cloud

When building maintenance or refurbishment works is required, a considerable amount of time is required for a facility manager to locate drawings and documents and understand which drawings are relevant to the various areas within the building. The current storage of this documentation is in a large pile of papers in a facility storage rooms. Cloud storage systems [figure 6] on the other hand, using Autodesk 360 (A360) together with “Collaboration for Revit” a cloud-based platform to store and retrieve documentations in real time. This process is much more efficient as it enables users to link and update drawings to the cloud. Facility managers can now quickly access necessary documents eliminating the need to search for documents in a storage room.

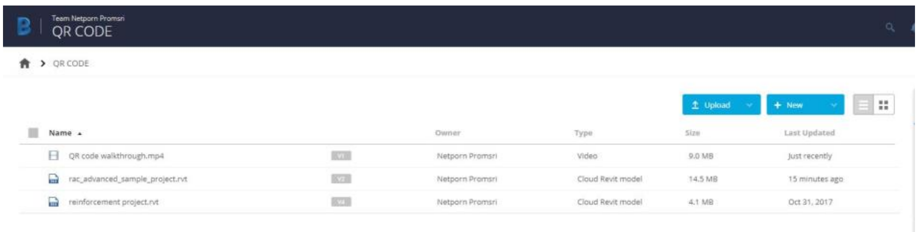

Figure 6. Cloud file storage

6.2.2. Extracting Revit Elements with Dynamo

After linking a project to the cloud, opening a large model file with a smart device is particularly time consuming and often unreliable as there is a vast amount of information compacted into a single display. This can become overwhelming and confusing to read on smart devices. Too much data can cause a delay when opening a model or due to graphics limitations may not be plausible to view at all. In order to extract information from a BIM model, scripting software such as Dynamo is implemented to transform a currently tedious task within Revit to a much quicker and more efficient interface as shown in [figure 7]. Key Revit elements such as floors, walls, columns etc. are to be stored inside the cloud, with the outcome of this process is a reduction in the amount of data being imported into the cloud. The ability to visualize only the relevant data at the correct resolution without overlapping of excessive information, is a necessary task to link BIM models to hand held devices and may be applied for other purposes in the AEC industry.

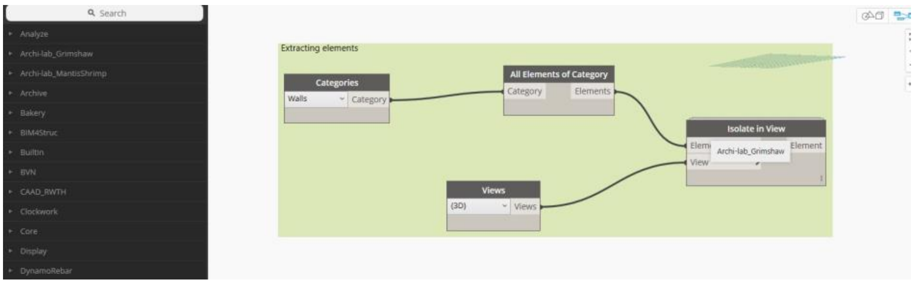

Figure 7. Extracting specific Revit elements with dynamo

6.2.3. Self-navigated walkthrough

The current process for a maintenance officer to locate a particular piece of equipment in a building can result in a loss of valuable time. Maintenance officers will often rely on the facility manager for instructions of where the units are located. This also has an impact to the facility manager roles as he is required to be on site at all times of maintenance. Together with Aurecon, we seek this as an opportunity in creating a QR code to create a better experience for both the maintenance officer and the facility manager by making a self-navigation tool that can be viewed from smart device given upon arrival [figure 8]. This process will guide the maintenance officer to the correct location eliminating the need to wait around for instructions.

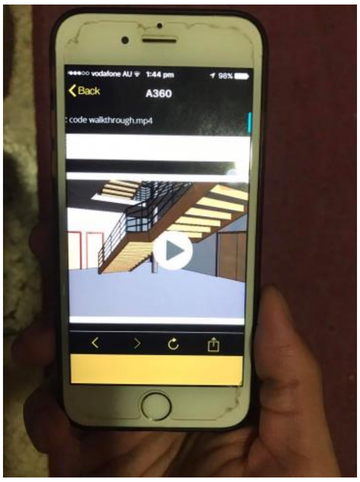

Figure 8. Viewing walkthrough on smart device

6.2.4. Smart Maintenance Report

A current issue when performing a maintenance inspection report is that each maintenance company engaged would have their own specific report format. This leads to inconsistencies in the reporting data as there will not be the same facility maintenance company that will come for every inspection. Together with Aurecon, we seek this as an opportunity to create a much more efficient maintenance report that forces the facility maintenance officer to use the format created for each report. A smart maintenance report is designed as a multiple-choice questionnaire with sections for more descriptive inputs with the purpose of collecting useful individual and collective data for future analytics. Individual data from smart maintenance report are shown in [figure 9].

session	Email	First Name	Last Name	Custom	CustomB	Responded	Bounced	Opt-out	Opened	Sent	Taken	Reminder Sent	Complete	Edit	Delete	View	PDF	Mark
13600535	Untracked	-	-			YES	NO	YES	NO		2017-10-11	NO	NO					
13585946	Untracked	-	-			YES	NO	YES	NO		2017-10-04	NO	YES					
13572011	Untracked	-	-			YES	NO	YES	NO		2017-09-27	NO	YES					
13558929	Untracked	-	-			YES	NO	YES	NO		2017-09-20	NO	YES					
13558913	Untracked	-	-			YES	NO	YES	NO		2017-09-20	NO	YES					
13558912	Untracked	-	-			YES	NO	YES	NO		2017-09-20	NO	NO					
13557341	Untracked	-	-			YES	NO	YES	NO		2017-09-19	NO	NO					
13557336	Untracked	-	-			YES	NO	YES	NO		2017-09-19	NO	NO					
13557333	Untracked	-	-			YES	NO	YES	NO		2017-09-19	NO	YES					
13557304	Untracked	-	-			YES	NO	YES	NO		2017-09-19	NO	NO					
13557037	Untracked	-	-			YES	NO	YES	NO		2017-09-19	NO	NO					

Total: 0 Items: Page:

Figure 9. Individual report data

7. Research Significance

The use of QR codes in the Built Environment have various aspects that the author has focused on. The two main categories explored are: The design to construction and the post-construction phases of the architecture and engineering practice (Abboud, 2013).

7.1. QR CODES FROM DESIGN TO CONSTRUCTION (3D – 5D BIM)

Incorporating BIM with QR codes from design to construction represents a new paradigm within AEC. The AEC industry have always desire to reduce project delivery time, decrease project cost while increase productivity and quality. The significance of this case study aims to improve current methods of structural documentation by replacing reinforcement 2D detail lines with 3D modelling and geometrical items. Traditionally, engineers design reinforcement layout on a floor plan via 2D detail lines and sections, these drawings are then later sent to the steel schedulers to process and manually schedule each individual reinforcement bar required in a project, this information will then be sent to the suppliers for reinforcement order. When reinforcement is delivered on site, the construction team would have to Check the bars against the plan requirements for proper grades, lengths, sizes, numbers and bends. With this, the construction team would constantly refer to drawings when placing and positioning reinforcement. This process has led to unexpected errors between the interfaces and at times lead to project delays (Fdot 2017.

This research study aims to fast track this process by incorporating QR codes from the design to construction phase as we shift away from traditional 2D methods and moving towards smart 3D BIM modelling. In contrast with 2D drawings, a BIM models contains precise geometry and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize the building (Ascelibrary 2017).

7.2. QR CODE IN FACILITY MANAGEMENT (6D BIM)

Over the past few years, the AEC firms have shown the value of BIM in building maintenance and operations. Research shows that approximately 80% of a building lifecycle cost occurs during the building maintenance phase. This shows that finding efficient ways to collect, access and update BIM information are an important factor. Documentation is traditionally stored as rolls of drawings from architects and engineers, and maintenance reports are similarly stored as physical copies. FM documents are often located in the basement office and difficult to access. There is a large amount of time spent locating and verifying specific facility and project information from previous activities. As-built drawings from both the constructions and maintenance operations are a common example that the drawing records which may not be up to date.

These are some of the issues that FM face on a daily basis. To improve this issue, the research solution aims to leverage QR codes as a primary tool to gain access to documentation and drawings that have been transmitted into the cloud. This will allow FM to view and verify drawings in an instant. to achieve this, internet connectivity, smart devices and a QR code scannable reader app are the only tools required. This would be beneficial for all facility officers when undertaking building inspections and other similar tasks (Teichplz, 2013).

8. Evaluation of research project

Using QR codes for the entire building life-cycle was prototyped in this research. The objective of first case study was to create a 3D reinforcement model which was relatively accurate while providing engineers with the ability to quickly simulate a schedule straight from the software itself. The process from design to construction has now changed as a scheduler is no longer required in this process. By incorporating Building Information Models with QR codes the outcome is a detailed yet simplified representation of reinforcement and building information. This ensures that builders, reinforcement fixers and structural engineers will all have the same understanding when reading structural documentation. With this approach, any person on site doesn’t have to trained to read structural drawings as 3D models are provided on site in real time and are intuitive. This will generally save construction time on site and associated cost, as labour costs is a substantial contributor to the overall project cost. The objective of the second case study was to make an improved maintenance workflow for the maintenance officer to work with. The process of creating a better experience for the maintenance officer will benefit the owner of the built form in the long term as this research forces the user to use one unified reporting format. The outcome of this approach will allow the FM and building owners to collect consistent collective and individual report data from each bit of maintenance performed. These two prototypes solutions are just some of the ways in which QR codes can benefit the AEC industry. It has now become apparent that there will be a place for smart devices and applications such as QR codes within the whole building life-cycle.

9. Conclusion

2D QR codes and other bar codes have been in used for a long period of time. The popularity of the technology in Asia has been rapid and it's increasing its popularity in America, Europe and Australia. More and more consultancies are now integrating QR codes in their everyday business activities making their data management much easier. it is evident that utilizing QR codes and smart technologies have strong potential to aid the understanding of the construction process even at a fundamental level.

This research project focused on two main case studies with the objective of utilizing BIM data and QR codes for the full lifecycle of AEC projects. The first case study focused on leveraging QR codes in the design to construction phases, 3D – 5D BIM. The second case study focused on utilizing QR codes for building maintenance purposes, 6D BIM level. Both case studies aim to provide a better workflow for the AEC industry from the use of software and technology that are now available to us such as Revit, Dynamo and smart devices. The methods of both case studies are just two prototypes which demonstrate how QR codes may be leveraged to improve the full lifecycle of projects in the AEC industry. Both case studies provide easily accessible information in a virtual environment as the detail and accuracy of BIM software are becoming mature enough to be used on major projects. Demand for 3D BIM representations of a 3D world will continuously be pushed by industry.

One of the core strengths of using this technology are the user's ability to interact with BIM data via smart devices, integrating QR codes to its extended potential on the idea of visualizing projects with VR and AR experiences. More and more smart phones and touch Pads are being produced today. People tend more than ever to use their mobile phones and other portable devices instead of their laptops or desktops as information can now be accessed anywhere and anytime with internet access. Therefore, the demand to link the physical world to the digital world is ever increasing and QR codes may soon become a necessary tool to facilitate this movement for the AEC industry. Acknowledgements

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