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A critical analysis of the application of augmented reality (AR) for monitoring and documentation of construction site progress in the Irish AEC industry.

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Abstract− Building Information Modelling (BIM) is one of the drivers for innovation in the construction industry and can be a key factor for better buildings with the developments of software that will connect model related data with construction workflows. Augmented Reality (AR) technologies and applications can be utilized to complement BIM and work in the same environment to create innovative construction workflows. AR technologies have the potential to provide an improvement in the construction industry and how the construction process can be monitored at varies stages of a project. To better understand the workflows involved between BIM and AR for construction monitoring process, this paper starts with an investigation of the existing literature review of published material. With knowledge gained from the literature review, the paper defines the proposed workflow for monitoring and inspection of the construction process. To test the proposed workflow, the researcher will conduct a field study on an existing development in order to critically examine the use of augmenter reality for construction monitoring and inspection process. The findings of this paper are anticipated to support both the researchers and construction professionals in understanding the AR and BIM workflows that can enhance the construction process.

Keywords−Augmented Reality (AR), Construction Monitoring (CM), Building Information Modelling (BIM), Site Progress,

I Introduction

Building Information Modelling (BIM) tools provide contractors, clients, and architects with ways of coordinating the design and construction process as well as finding gaps in information exchange between multidisciplinary teams [1]. BIM processes and tools present an opportunity to analyse digital models of a building, months before the construction process starts on site. This way, the design team is provided with a tool that eliminates inaccuracies at the early stages of a project. Stakeholders can estimate the outcome of a project and its implications significantly faster than traditional methods of coordination [1].

At some leading construction sites, BIM equipment, and innovations are slowly replacing paper drawings as guidelines for construction workers [2]. Woodward & Hakkarainen describe the Architecture, Engineering and Construction (AEC) industry as one of the most promising application fields for Augmented Reality (AR). Automated systems are now becoming more suitable for construction and new commercial inspection software packages are available to guide site monitoring [2].

Kopsida & Briklakis [3] continue by discussing how latest research has been targeted at automating site progress monitoring in the construction industry and facilitating the use of advanced inspection software packages. These software packages can replace 2D documentation drawings by providing the inspector with on-site access to Building Information Models (BIMs) via a mobile device [3]. With such advancements in today's digital infrastructure, it is beneficial for the Irish construction industry to utilise new technologies to improve site progress monitoring processes.

There are several studies [1-4] published analysing the use of augmented reality tools combined with building information modelling for site inspection monitoring. This research aims to critically analyse the effective incorporation of augmented reality technologies for monitoring and documentation of construction site progress. It is expected that this report will go some way towards filling the void in already published material regarding the effectiveness of augmented reality tools on the construction industry.

Section 2 of this research paper will critically review the reported use of augmented reality in construction monitoring in the Irish construction industry. For this section of the research paper, comprehensive literature review was carried out throughout the distinguished sources such as books, conference and journal papers which related to augmented reality technologies, site monitoring tools and building information modelling in the construction sector. In comparison to more traditional methods used in the construction industry, the effectiveness of AR on the construction monitoring process will be examined.

Section 3 of this paper, through experimental research, will demonstrate the use of building information models and augmented reality technologies for monitoring of construction site progress. In Section 4, through a focus group, the presented artefact will be assessed by the selected industry professionals. The collected data will then be used to evaluate the use of augmented reality technologies for construction site monitoring and documentation process.

In the last part of this research paper, the researcher will conclude the paper and the proposed workflow. The conclusion will synthetise all of the data gathered from the literature review, field study and the evaluation process to provide an overview of the research question.

II Literature Review

a) *Building Information Modelling*

Hardin [1] discusses how the application of BIM has become the catalyst for innovation in the construction industry and proposes that BIM will continue to be a central enabler to better building with the developments of software that will connect the model-related data to construction workflows. Technological advancements will continue to narrow the gap between digital illustration and the physical manifestation introducing real-time information and new ways of working into a builder's day-to-day tasks [1].

Machado [4] proceeds further by identifying a successful combination of Building Information Models (BIMs) and Augmented Reality (AR) to serve as a tool for coordination and communication. Outlined by Machado, AR allows for computer-generated imagery to be superimposed over a physical environment. AR software combines the real world with BIM models, creating a space where computer-generated information is overlayed on the user's real field of vision [4].

In his study, Ahmed [5] is discussing how AR technologies are making an important contribution to the culture of the construction industry and create improvements to the traditional workflows. In his research, Ahmed continues by saying "*AR and VT technologies have many applications that could benefit project with accelerated working site taking and safety, design development and communication with involved parties from owner all the way down to the labourer and help owner's expectations and decrease project costs*" [5]. This line of research is continued further by Kivrak [6] who acknowledges the utmost importance of AR technologies to the AEC industry as a whole as the built environment is intrinsically linked to 3D space, and AEC professionals rely heavily on visualization for communication.

b) *Augmented Reality*

Augmented Reality (AR) technology allows to overlay the digital information on the real environment in real-time and in the correct spatial location as shown in (Fig.1) [7]. AR technologies allows computer-generated digital content to interact with the physical world and facilitate the development of exciting new types of user interface. Paolis [8] explains that AR technology allow the users to see the 3D simulated objects superimposed on the surrounding world, unlike Virtual Reality (VR) which totally immerses users in an artificial environment where they cannot see the real world around them. Instead of fully replacing realism, AR complements the reality and the user experiences that virtual and physical objects coexist in the same place. Usually, the information directed to the user becomes interactive and digitally manipulable using computer-vision techniques related to object recognition [9].

Fig. 1: Example of augmented reality tool on construction site [10].

In a number of application domains, AR technology is dynamically expanding. For example, in architecture, enhanced visualization of future projects can be accomplished. With the use of AR tools, the device driver can directly control virtual components while detecting possible clashes between the to-be-assembled and existing elements within the real world [11]. Lei & Wang continues by saying this technology allows the user to not only communicate with the actual environments but also interact with the Augmented Environment (AE) that is developed to compensate for the partial sensory loss which can be acquired within VR. In addition, extra non-situated elements such as voice recordings, animation and video imagery can be introduced to the assembly process to maximize the input from augmentation [11].

The vision of the user is generally a camera image of the physical environment. The screen display, which can be a head-mounted display (HMD)(Fig.2) headset or a handheld device, is augmented with digital information and displayed over real-life environment [12]. Zollmann continues further by saying *"such an overlay allows for the presentation of information that is relevant to a specific task right on-site and aligned to the objects of interest"* [12].

To perform image recognition of a certain spatial geometry, AR software requires computer vision. Usually, points or targets of interest are first identified as a placement and levelling reference and are then tracked during the operation phase of the application [9]. Evangelos [9] continues by analysing how different types of applications differ depending on the number and quality of required sensors, the accuracy of detection and virtual object alignment and positioning, the speed of scene response and image processing, and overall realism of the output.

Current AR applications use two major monitoring configurations that can be divided into two types called ''marker-based'' and ''marker-less''. Marker-based monitoring software is used to detect a reference point that can be accurately identified by mobile cameras. In addition, marker-based technology can ensure effective synchronization to allow for instant alignment and accurate tracking of the superimposed imagery [13]. In comparison, marker-less technology recognizes geometry elements of the surrounding world without any previous knowledge of the environment such as walls or interactions points. This type of configuration allows the use of a global position system (GPS), location-based orientation, image detection or even 3D maps. The emergence of advanced camera technology, mobile operating systems and sensor accuracy advancements in mobile devices has contributed to making AR applications more available. Smartphone or tablet users can easily experience mark-less augmented reality technologies.

Augmented reality systems can be referred to as hardware components, software and algorithms [11]. These systems can be explained as follows:

- Hardware combines of a processor, digital display, sensors and input/output devices such as head-mounted display (HMD) or a mobile phone (Fig.2).

- Software and algorithms apply to the major components of how realistic the augmented reality visualization can be accomplished; input devices are the instruments by which the user communicates with the virtual world.

Fig. 2: Example of head-mounted display (HMD) [14].

As explained by Xiao Li [11] augmented reality system software is a combination of instruments and software technologies for the design, creation and management of simulated realities and the repository of gathered information. In his research Xiao Li indicates, that the augmented reality system could be designed and programmed accordingly to the specifications of a particular task such as construction monitoring process, to obtain a particular degree of immersion or interaction for successful operation on site.

c) Construction Progress Monitoring

As-built construction drawings and documentation are an important form of paperwork required to be submitted at the end of a construction project and are used during the facility management stage [15]. These records are continuously being generated and updated during the duration of the construction period. The process is generally manual and error-prone, which prevents effective information management [16].

Construction inspectors require assistance in inspection preparation to guarantee inspection objectives are correctly defined, to decide which inspection solutions are beneficial in deploying inspection resources [17]. Construction progress monitoring is important to enable decision-makers to recognise discrepancies between the as-planned and as-built stages of a project to take immediate action where appropriate [18]. The collected data directly enables the tracking and management of site progress and, if automated, can have a huge influence on the performance of a project.

In his research, Golparvar [18] states that current methods for site data collection, processing and representation of information are time-consuming and labour-intensive. The traditional methods of site inspection require manual collection of data and complete as-planned and as-built information extraction from schedules, construction drawings and reports produced by the design team and contractors. In his research, Maalek [19], mentions that in order to reduce the time and cost involved with traditional methods of progress monitoring, a small amount of on-site data is obtained, which restricts the ability of the project manager to evaluate the causes of delays and schedule inefficiencies.

The analysis of as-built and as-planned data facilitates an accurate evaluation of the progress and measures project performance. Project management processes, such as coordination reviews and progress monitoring and construction quality evaluations require latest 3D software and technologies to segment the as-designed and as-built data [20]. Turkan mentions that the three-dimensional building information models are more extensively utilized by the project stakeholders to facilitate construction monitoring and facility life cycle management. The same line of research is presented by Bhatla [15]. In his research, Bhatla states that "*technological advancements make it possible to generate 3D models to asses as-built conditions for construction monitoring purposes, such as verifying conformance to baseline project schedules and contract specifications"* [15].

Several methods and technologies have been proposed to support construction workers in monitoring construction jobs, allowing the collection and documentation of construction site data more effective [21]. A recent technique in automating site progress monitoring is presented by Golparvar [18]. The first step is to obtain a large amount of image data (point clouds) using laser range scanners (Fig.3). By documenting the point clouds using an iterative closest point (ICP) algorithm, they can be then combined with the 3D geometrical model. This allows the user to then analyse the as-planned model against the combined model which contains up to date information from ongoing site operations. [18]. Advanced laser scanners can collect high-precision 3D data. As reported by Bosche [22], laser scanner resolution can be as accurate as approximately 3mm at 50m spot size and precision of individual scanned points of roughly 12mm at 100m can be achieved.

Fig. 3: Example of laser scanner on construction site.

Despite extensive research into automated spatial information gathering, spatial data collection using these advanced laser scanners is often restricted and still limited due to the construction site conditions [23]. Physical components in the scanners field of vision interrupt the collection of information of a specific element which results in inaccurate point cloud creation. The constant movement of machinery and site workers interferes with the registration of the scanner. Also, the operation and relocation of scanners is not easy and can result in loss of accuracy. As mentioned by Golparvar [18], the quality and accuracy of data captured significantly decreases as the distance between the laser scanner and the physical objects increases. Since these scanners are hard to move and operate, they cannot be effectively used for scanning indoor components. Due to logistical factors, the application of laser scanner has not yet been noticeably observed in the AEC industry [18].

In contrast to the laser scanner technique, Golparvar, in his other research paper [24], proposes a framework where 3D geometrical models are combined with daily progress images to facilitate the creation of 4 Dimensional Augmented Reality (D4 AR) models [24]. As explained, the D4 AR models are composed of " *new image-based modelling techniques for visualising progress monitoring wherein progress discrepancies between as-planned and as-built construction performances are visualised through the superimposition of 4D as-planned models oversite photographs using different visualisation techniques"*[24].

The framework presented by Golparvar, suggests that BIM-AR implementation can provide a consistent and reliable process for coordination and collaboration. Visual presentation of the construction site connected with the proposed model can facilitate the process of recognition and prevention of clashes [4]. Moving augmented reality technologies from laboratory to construction site is possible with new advancement in mobile technologies. Their ability to display on-site information, where appropriate, has several advantages for technical applications [2]. In his research, Delgado [7], praises the technological advancements in the augmented reality field and mentions that for the AEC industry as a whole, AR and VR technologies are of paramount significance as the built environment is directly connected to 3D space, and AEC professionals depend largely on visualisation for communication. For several decades, research on both AR and VR has been carried out. However, with the technological limitations, the AEC industry never implemented this technology. The field has recently re-emerged, encouraged by the emergence of new, more advanced head-mounted displays (HMDs) and mobile devices [7].

d) Project Discover – Augmented Reality tool for inspection of prefabricated buildings.

In order to support construction site operation workers, several proposals have been made to superimpose 3D geometry information using head-mounted displays (HMD's), augmented reality glasses and hand-held devices [25]. Technologies for displaying instructions, 3D models and installation simulations using display screens have been developed in recent years. As mentioned by Choi et al [25], there is a lot of promise and opportunity that augmented reality technologies present for the construction industry.

A different approach is presented by Garcia-Pereira et al [26]. In their research, Garcia-Pereira et al present the workflow and the development of an augmented reality tool which equips the site inspector with an advanced AR application designed to assist during an inspection of prefabricated buildings. They start with a description of what prefabricated building elements are and point out the key tasks required to be carried out by a group of experts to inspect the modules. Some of the tasks performed during the inspection process include the review of measurements, visual analysis of the finished product and textual documentation of potential faults [26]. As mentioned in Garcia-Pereira's paper, the evaluation procedures had typically been documented on paper with the addition of digital photographs. By carrying out the inspection using the traditional methods, it takes a lot of time and effort to complete each task, which can drive the cost and poor quality of the final inspection report. Garcia-Pereira et al continue by describing the new technologies now available to the construction industry as a key advancement, which can be incorporated to the inspection of prefabricated buildings, providing the digitalization of information and effective management of defects.

In their study, Garcia-Pereira et al aim at developing an augmented reality tool designed for automation of the inspection process and documentation of the collected data. The tool is developed to evaluate the real environment and aid real-time visual comparison of the as designed and as-constructed building modules. Garcia-Pereira et al describes the proposed tool by saying *"Our AR application allows to establish a spatial relationship between the virtual information and the elements of the real world during the inspection of prefabricated building"* [26]. As mentioned by Garcia-Pereira, the AR tool was developed by using the Unity3D gaming platform [26].

Next, they outline the importance of new technologies such as the iPad. For the proposed AR tool to be successful, the equipment used during the inspection process needs to be equipped with an Occipital's Structure Sensor which allows to turn mobile devices into a real portative 3D scanner. With the availability of a 3D building information model of the prefabricated module, Garcia-Pereira et al point out that it is important to position AR markers in the prefabricated modules in order to accurately superimpose the digital model on the real environment [26].

Prior to Garcia-Pereira et al research, the use of augmented reality technologies in the construction industry had been reported by other researchers. Diao et al [27] proposes the Augmented Reality Maintenance System (BARMS) which provides the MEP maintenance crew with a tool for inspection and illumination function of the 3D animated plumbing service systems. In their research, Portales et al [28], go further by implementing a structure scanner attached to the computational tool (iPad). This solution allows acquiring the depth information in the form of images. These images are then used to compute 3D layers of points with RGB and IR values [28]. Though, there are several lines of research on how to implement augmented reality tools and applications in the construction industry, Garcia-Pereira et al provide both the tool and workflow for the inspection of buildings.

The proposed tool developed by Garcia-Pereira et al, also allows the user to use the alpha channel integrated in the application [26]. This provides the user with the option to control the degree of transparency visible on the screen enabling the simulation and comparison of the real world against the virtual model. This feature is essential for evaluating and comparing the build component with the proposed model and therefore for detecting potential geometrical variations of the prefabricated module.

Garcia-Pereira et al, conclude their research by planning to generalize the tool so it can be utilized by inspectors related to the industrial sector. They continue by proposing the future upgrades to the tool and mentioned a multi-platform solution that could be developed with the advancements to the ARKit and ARCore libraries [26].

III EXPERIMENTAL RESEARCH

a) Methodology

The research for this paper is based upon the design science research (DSR) methodology for the assessment and implementation of BIM processes as proposed by Kehily & Underwood [29]. The methodology of design science research is to use the gathered information to solve problems, create, adjust or strengthen the current solutions and create new knowledge, observations and scientific theories [30].

The use of DSR methodology, in this research, is presented by studying an existing theory on the use of augmented reality for construction monitoring process and applying the six rules listed below to develop an artifact that will be presented as an alternative, to the existing theories.

- Identification and Recognition – define the specific research problem and propose a solution,
- Objectives of a solution – create objectives for solution from the problem definition,
- Design and Development – create the artefactual solution,
- Demonstration – show the efficacy of the artefact for addressing the problem
- Evaluation – measure the efficacy of the artefact for addressing the problem
- Conclusion – conclude and communicate the importance of the artefact for the problem

This research paper is structured to follow the DSR methodology rules as described by Hevner. Section 1 focuses on gaining knowledge and awareness of potential problems related to the use of augmented reality in the construction industry. In Section 2, current processes of construction progress inspection are described and research was carried out to find potential advancement in the field.

To thoroughly investigate the proposed theory, the researcher divided the delivery of the methodology into 5 key sections demonstrated below;

1.) Development of a proposed construction program to identify the sequence of activities and sectional completion dates of structural components;

2.) Design and modelling of a phased 3D building information model containing information and construction sequencing taken from the construction programme;

3.) Combining the 3D building information model with the construction programme to create 4D simulation to visualise site progress;

4.) Export the phased 3D building information model to Industry Foundation Classes (IFC) format and upload it to the augmented reality application;

5.) By conducting a field study, analyse the proposed AR application workflow for monitoring and inspection of construction progress.

To evaluate the proposed solution/artefact, a focus group involving industry professionals is proposed. Presentation of early findings will demonstrate the proposed workflow and the use of augmented reality application for construction monitoring process. In the form of a questionnaire, the industry professional will answer multiple questions regarding the artefact and the gathered data will be then used to evaluate the artefact before concluding the results of this study.

b) Mercantile Hotel

The field study part of this research was carried out in the city centre of Dublin, where the future reconstruction and refurbishment of the existing Mercantile Hotel building is proposed. The analysis of the proposed AR application workflow for monitoring and inspection of construction progress will be carried out on the proposed development of the existing Mercantile Hotel by visualising the sectional completion of construction activities. Augmented reality application will be used to superimpose the as planned 3D geometrical model on real surroundings to guide the construction team with the inspection and monitoring of proposed on-site activities.

The location of site is the existing Mercantile Hotel 25-28 Dame Street and Dame House 24-26 Dame Street. The site is on the junction of Dame Street, South Great George’s Street and Dame Lane. The latest development of the Mercantile Hotel will result in the expansion of the existing hotel and change of use of Dame House, 24-26 from office use to hotel. The proposed scheme comprises of the development of the site to a 99-room hotel (currently 29) and all necessary front and back of house hotel services, while retaining existing uses at ground floor level such as the bar and food outlet.

Fig. 4: Proposed Mercantile hotel refurbishment render.

c) *Construction Programme*

To begin the experimental part of this research paper, the first step consisted of creating a construction programme. Developing the proposed construction programme was necessary to plan out the construction activities on site. The construction programme was an important document to show the project breakdown and visualisation of the project progression from commencement to completion. The key construction milestones were broken down to smaller tasks and number of days were assigned, required for completion of each individual activity.

In consideration of the fact, the actual commencement of the construction is expected to begin in June, the construction programme has been designed to facilitate the as planned activities. The field study was carried out prior to the actual construction of the building which allowed the researcher to field test the application and proposed inspection processes.

In the form of Microsoft Excel spreadsheet, the construction programme was built with the use of key attributes which allowed for development of a realistic schedule of tasks and to create a direct link between task activities and geometric components. The parameters used in the construction programme were as listed below:

- Task ID – a unique number identifying each individual task;
- Task Type – text identifying the reason for the task (existing, construct);
- Task Title – text identifying what the task is;
- Duration – number of days necessary to complete each individual task;
- Expected Start – commencement date of the task;
- Expected End – completion of the task.

The construction programme was used to not only identify tasks but also pick the key milestones of the project. For the purpose of this research, three major stages of the project have been identified in order to visualise the construction progress of the proposed development. Stage 1 of the project was proposed to show all new steel components in their final locations to allow the construction team to plan out the installation of the new brick and curtain wall façade as shown in Fig 5. The construction programme identifies the new external façade with the new floor construction as Stage 2 (Fig 6). The last key stage of the construction programme schedules the completion of the new mansard roof along with the new plantroom (Fig 7). Those three key milestones will be used during the field study part of this research to use the augmented reality application to visualise and monitor construction process of the building.

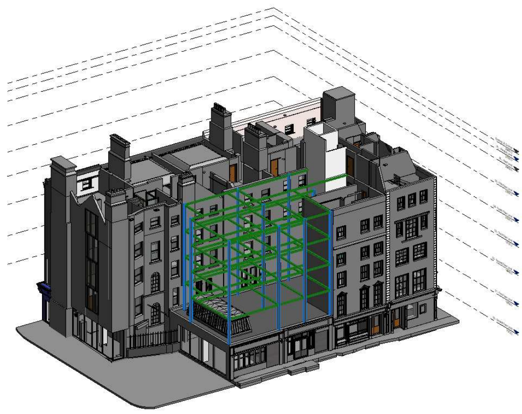


Fig. 5: Construction programme key milestone 1.

Fig. 6: Construction programme key milestone 2.

d) *Building Information Model*

The second part of the experimental research involved creating a building information model (BIM) of the proposed development as shown in Fig 7. The building information model was used to visualise the proposed building in the three-dimensional environment and to create a workflow process to enable construction sequencing. Due to the fact a simple model was already created for the planning stage of this project, the basic outline and modelling was already completed. To facilitate the more advanced techniques used in this study, further development of the existing model was required. To progress the already existing model, it was necessary to integrate the construction programme with the planning model, to identify the required modelling and development of missing parameters.

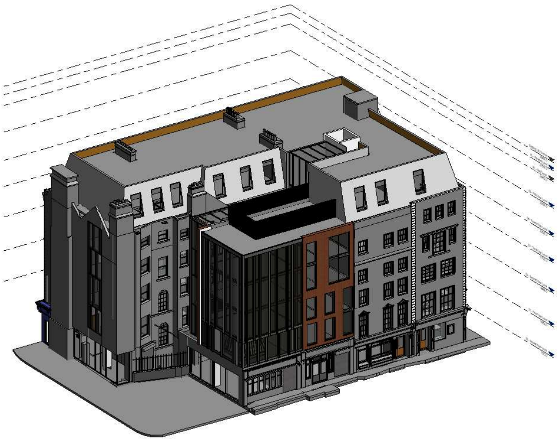


Fig. 7: Construction programme key milestone 3.

The list below demonstrates the approach taken to develop the already existing model:

- Model the geometric elements which are existing or constructed
- Create the shared and project parameters to control the geometric elements;
- Create project phasing for geometric elements to visualise the three key milestones identified in the construction programme.

To establish the function of the main geometric elements, it was important to precisely divide the model into groups and assign the unique Task ID to the individual components. When the existing and constructed groups where designated, project parameter was used to attach a number value to all individual components as shown in Fig 8. The number value directly corresponds to a construction task activity proposed in the construction programme. This process enables to create a link between the construction programme tasks with an individual geometric component and also allowed to prepare the building information model for the construction sequencing using an external software.

Lastly, to facilitate the visualisation of the three key milestones of the development, project phasing was utilized. Three phasing parameters were used to break down the model to display the key milestones of the project to demonstrate and establish progress made during the construction stage.

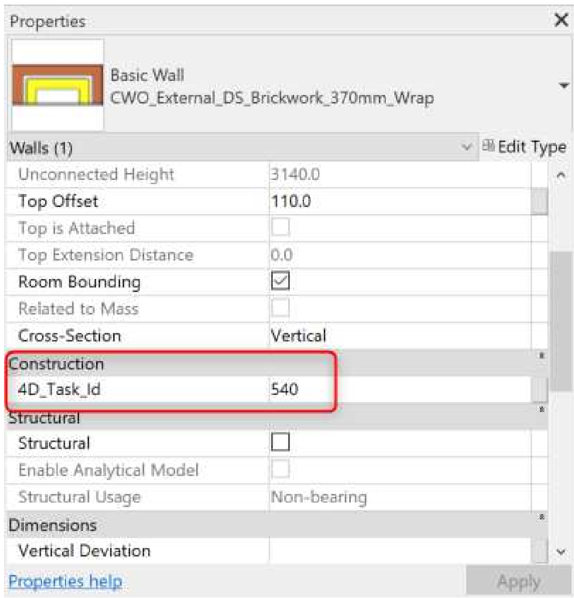


Fig. 8: Geometric element Task ID parameter.

e) 4D Simulation

Once the building information model has been developed further and the geometric components along with the project parameters were finalised, the construction sequencing of the development was used to create a 4D simulation of the proposed site activities. In order to create a construction sequencing animation, the building information model has been exported to Autodesk Navisworks native file format (NWC).

To facilitate the construction sequence in the Navisworks Manage software, it was necessary to create the geometric element sets and to associate those sets with a construction task. In order to create the group sets, the geometric elements were found with the use of a built-in parameter. The search of the geometric components was defined by their element category, Task ID property parameter and the number value associated to an element as show in Fig 9 and Fig 10. It is important to point out, the set groups were assigned to a binocular search system which dynamically updates the search as new geometric elements are added to the building information model, using the same parameter and number value. To achieve a direct connection between the construction programme, geometric elements and the set groups, the number value of the Task ID parameter had to be correct to match the activity sequence.

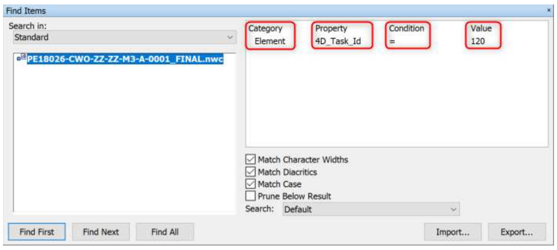


Fig. 9: Search display for geometric elements by the built it Task ID parameter.

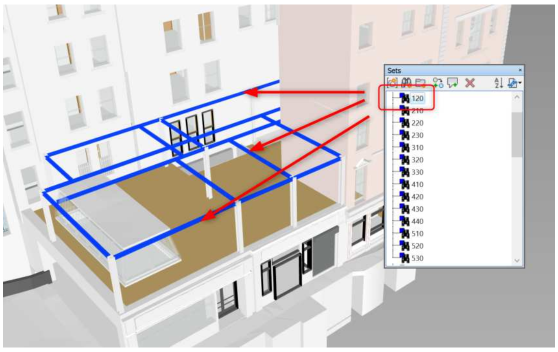


Fig. 10: Binocular search set group (120) and associated geometric elements with that set.

To strategically connect the construction programme with the Navisworks Manage software, it was essential to import the construction programme, in an CSV file format, into Navisworks Manage Timeliner tool. The construction programme, in CSV format, contained attributes as outlined in the previous section of this report to recognise the activities proposed in the Navisworks software. To create the direct link between the CSV file and Navisworks Timeliner, field selector dialog was used to map the field names in the CSV file to the column names within the Navisworks field selector. This process can be seen in Fig 11.

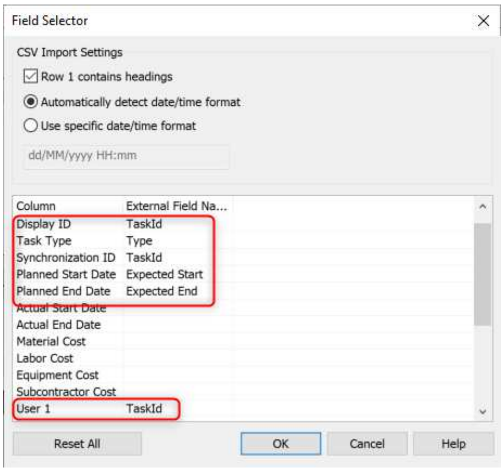
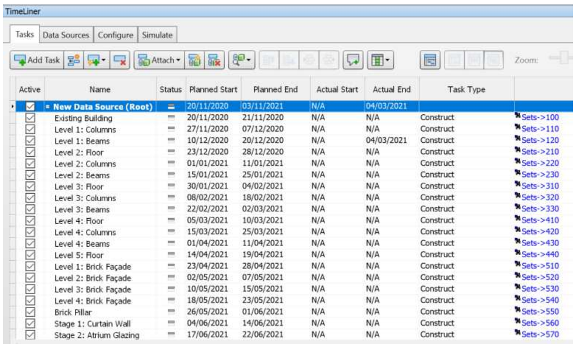


Fig. 11: CSV import and field selector options.

It was important to correctly assign the fields within the field selector to create an automatic link detecting columns in the construction programme. The critical step in this process involved assigning "User 1" field correctly. This parameter was used to map the number value Task ID parameter entered in the building information model components to match with the Task ID's in the construction schedule.

In order to create and attach the CSV file to the Timeliner, it was necessary to rebuild the hierarchy of the task structure and data associated with the source file. Once the hierarchy list was rebuilt, the construction programme was incorporated into the Navisworks Timeliner as presented in Fig 12.



Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Task Type	
☑	New Data Source (Root)		20/11/2020	03/11/2021	N/A	04/03/2021		
☑	Existing Building		20/11/2020	21/11/2020	N/A	N/A	Construct	Sets->100
☑	Level 1: Columns		27/11/2020	07/12/2020	N/A	N/A	Construct	Sets->110
☑	Level 1: Beams		10/12/2020	20/12/2020	N/A	04/03/2021	Construct	Sets->120
☑	Level 2: Floor		23/12/2020	28/12/2020	N/A	N/A	Construct	Sets->210
☑	Level 2: Columns		01/01/2021	11/01/2021	N/A	N/A	Construct	Sets->220
☑	Level 2: Beams		15/01/2021	25/01/2021	N/A	N/A	Construct	Sets->230
☑	Level 3: Floor		30/01/2021	04/02/2021	N/A	N/A	Construct	Sets->310
☑	Level 3: Columns		08/02/2021	18/02/2021	N/A	N/A	Construct	Sets->320
☑	Level 3: Beams		22/02/2021	02/03/2021	N/A	N/A	Construct	Sets->330
☑	Level 4: Floor		05/03/2021	10/03/2021	N/A	N/A	Construct	Sets->410
☑	Level 4: Columns		15/03/2021	25/03/2021	N/A	N/A	Construct	Sets->420
☑	Level 4: Beams		01/04/2021	11/04/2021	N/A	N/A	Construct	Sets->430
☑	Level 5: Floor		14/04/2021	19/04/2021	N/A	N/A	Construct	Sets->440
☑	Level 1: Brick Façade		23/04/2021	28/04/2021	N/A	N/A	Construct	Sets->510
☑	Level 2: Brick Façade		02/05/2021	07/05/2021	N/A	N/A	Construct	Sets->520
☑	Level 3: Brick Façade		10/05/2021	15/05/2021	N/A	N/A	Construct	Sets->530
☑	Level 4: Brick Façade		18/05/2021	23/05/2021	N/A	N/A	Construct	Sets->540
☑	Brick Pillar		26/05/2021	01/06/2021	N/A	N/A	Construct	Sets->550
☑	Stage 1: Curtain Wall		04/06/2021	14/06/2021	N/A	N/A	Construct	Sets->560
☑	Stage 2: Atrium Glazing		17/06/2021	22/06/2021	N/A	N/A	Construct	Sets->570

Fig. 12: Timeliner representing the construction programme using the CSV file in Navisworks software to create a simulation of construction.

To progress the development of the construction sequence, the next step involved combining the created geometric sets and attach model elements with the tasks as outlined in the construction programme. This was achieved by using the predefined rule option which allowed for creating and editing rules that assign Timeliner tasks to the created geometric sets within the model. The rule "Map Timeliner Tasks from Column Name to Selection Sets with the same name, Matching case" was utilized. Furthermore, to map the Timeliner tasks, the column "User 1" which contained the Task ID number value, was used to correspond with the selection sets with the same name. Once the rules were applied, the different tasks in the Timeliner had a search sets associated to them to automatically connect the geometric components with the construction programme activities.

The final stage of this process, involved defying the specific settings for the 4D simulation. As shown in the Fig 13, settings such as interval size, playback duration and view type were used to create an accurate and precise animation of the on-stie activities for visualisation of construction process.

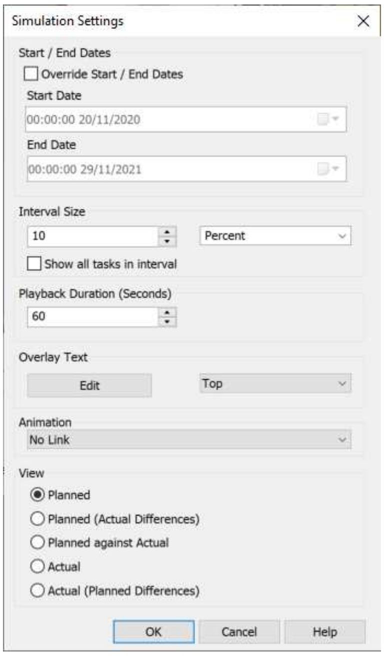


Fig. 13: 4D simulation settings.

f) Augmented Reality Application

In order to begin the field study, it was necessary to export the building information model with the pre-defined parameters to Industry Foundation Classes (IFC) format. This stage was required to connect the building information model with the proposed augmented reality application, which was used to conduct the field study part of this research. To export the building information model, number of essential settings were required to be finalised. The process of determining which settings are going to produce the most accurate and precise IFC export file was excessive, and multiple options were used to select the best performing combination.

To gain a better understanding of the export settings and the best performing combinations of the available options, it was necessary to conduct analysis of the AR application. The native website of the application was used to earn more insight into the best practice for exporting building information models to IFC format for the augmented reality application use.

The support section of the website suggested to use the IFC 2x3 Coordination View 2.0 version of the IFC export as highlighted in Fig 14. Furthermore, it was important to modify the standard export settings of the selected export version. Under the tab ‘Additional Content’, it was necessary to use the ‘Export rooms in 3D views’ selection. This option directly allowed the user to select the room/area of the building in the AR application, and to manually align the AR image to the real surroundings. The other two key settings that were used are highlighted in Fig 15 and Fig 16. Those two options allowed to transfer the property sets and GUID parameter information to the AR application which resulted in the IFC file to be more accurate and contain the required information of the geometric elements.

Once the IFC file was exported, the last step involved uploading the file to the cloud-based portal of the AR application. This process is presented in FIG 17.

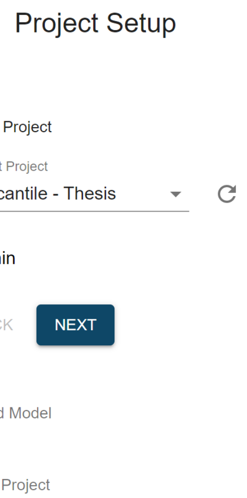


Fig. 17: Cloud-based project upload.

g) Field Study Analysis

The workflow developed by integrating the BIM model with the construction program in order to generate a construction sequence animation to visualise and monitor construction progress allowed for the identification of key project milestones and to communicate the proposed project timeline to all project stakeholders. This workflow can be beneficial for design teams and project stakeholders to create visualisations of on-site activities prior to construction commencements and help in predicting unforeseen clashes. To progress the research further, it was necessary to introduce the augmented reality technologies into the workflow to superimpose the phased geometrical model over the real surroundings.

The filed study part of this research was carried out on the proposed Mercantile Hotel development to visualise the construction process with the use of the latest augmented reality technologies. To conduct the study, it was necessary to choose the latest AR application that suited this research and was also adaptable for external use. To conduct the research, GAMMA AR application was selected to progress the proposed workflow for construction monitoring. The main benefit of the application is its marker-based technology which lets the user to align the proposed BIM model with the real surroundings quickly and precisely as shown in FIG 18.

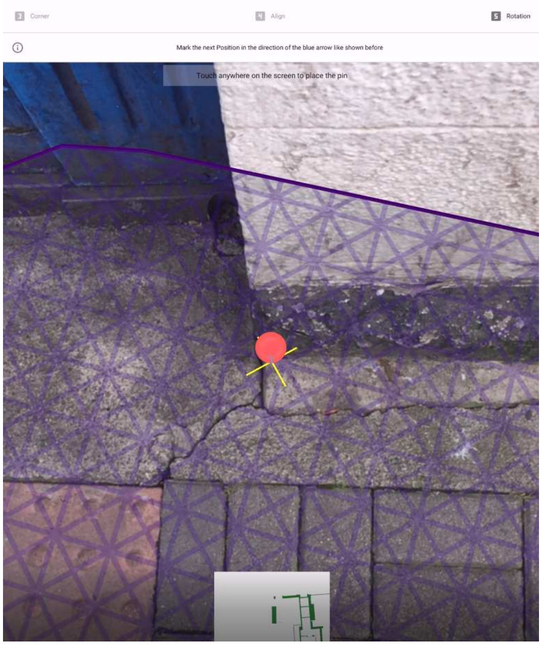


Fig. 18: Marker-based alignment technology.

In order to present the monitoring workflow, the phase 1 of the BIM model was selected and superimposed over the Mercantile building. The filed study allowed the researcher to carry out several tasks within the augmented reality application and showcase all the features available to the user. Below are the tasks carried out by the researcher to analyse the workflow and the augmented reality application for monitoring of site progress;

- The use of marker-based manual alignment of the BIM model over the real surroundings;
- Interaction between the superimposed BIM model elements and the real surroundings;
- Selecting the BIM model to gain access to digital information from geometric elements;
- Adding and removing elements to create clear image presentation;
- Using the transparency settings for clearance of elements;
- Recording of progress through photographs and attachments;
- Creating site reports and assigning the responsibility to team members.

By examining the proposed augmented reality application, we can discover more about the external use of this tool. In an attempt to test the application, the process of selecting the correct spatial position was required. Variants such as weather, surroundings and site location were all important aspects. For effective analysis and testing of the application, it was important to carry out the field study accordingly to what the user would experience on a day-to-day activity.

As mentioned above, different movables such as people, vehicles or sunlight can affect the use of the application and its accuracy. Often, variables can have a negative but realistic impact on the analysis of the proposed workflow. It was important to include the realistic scenarios in this study in order to present an artefact that can be as close to real life events as possible. This then allowed the researcher to evaluate and examine the application for monitoring of construction site progress.

IV Focus Group

In order to evaluate the proposed workflow of the experimental part of this research, data was gathered through a qualitative focus group including industry professionals and the team members that worked on the Mercantile Hotel development. A panel of 7 participants was selected and consisted of; Head of Construction, Architect, Conservation Architect, BIM Coordination, Architectural Technologist, Interior Designer and BIM manager.

Prior to the commencement of the focus group, all research participants have received and read the research participant information sheet. A brief overview of the research was provided and the structure of the focus group was laid out as described below;

- Research introduction and overview;
- What is augmented reality;
- Current construction monitoring practises;
- The Mercantile Hotel;
- Workflow 1→3 presentation;
- Workflow 4→5 presentation;
- Discussion and questions.

The first phase of the focus group was centred around the introduction of augmented reality technologies in the construction industry and the current methods of monitoring of site progress. During the next stage of the presentation, the Architect involved with the design of the Mercantile Hotel provided more insight and information regarding the client's criteria, project milestones and software/technologies used at the planning stage of the project. This was an important step in order to compare the workflows used during the planning stage to the proposed workflow with the introduction of augmented reality technologies. The main objective of the focus group was to present the proposed workflow for monitoring of construction progress with the use of augmented reality technologies and gauge the positive and negative feedback to explore if the demonstrated workflow could potentially be utilized on a construction site.

In order to evaluate and critically analyse the application of augmented reality technologies for monitoring and documentation of construction site progress in the Irish AEC industry, the feedback received from all participants was reviewed and examined. As mentioned above, the feedback was collected from both the semi-structured questions during a presentation and post focus group survey.

When asked about the demonstrated workflow and the use of the latest technologies and software's as well as augmented reality technologies during the construction stage of the project on a scale of 1-10, 10 being the most effective, the average response was 8. This was a very positive feedback to an overall reception of the proposed workflow. This result proves the industry is currently using the latest technologies and software's and the project stakeholders do see the benefit of utilizing those to enhance their day-to-day tasks. To follow up and evaluate the workflow further, the participants were asked about the effectiveness of combing the construction programmes with the building information model in order to create a geometrical sequence of construction activities. The average response to that question was 8.83. With the participants experience, this was a very promising result. Geometrical sequences are becoming a very useful tool for visualising the construction activities on site prior to the project commencement.

When asked if the proposed workflow would significantly reduce the time spent during monitoring of construction site progress compared to the traditional methods. The average response to that questions was 5.67. In order to critically evaluate the presented workflow, it was important to evaluate the time involved with carrying out such task. Compared to traditional methods, the participants did not see a major time saving with using the proposed workflow. This could be related to learning the new software and processes. Perhaps a different application could be used to carry out the same workflow to improve the time saving. To clarify the differences between the traditional methods and the proposed workflow additional question was asked. In contrast to the previous question, when asked if the proposed solution would result in more accurate site progress reports. The average response to that question was 7.17. It was a common agreement across the research participants that the presented workflow increases the accuracy of site reports. The technologies and processes presented were very understandable, and good amount of information was captured when creating a site report.

In order to evaluate the possible adoption of the augmented reality technologies at today's construction sites by all of the project stakeholders, majority of the participants agreed that the construction industry is ready to utilized new technologies, however, additional training and possible extra cost could hinder and slow down the adoption.

With regards to the main objective of the research, when asked if the participants thought that the use of augmented reality technologies for monitoring and documentation of construction site progress could be utilized successfully during the construction stage of a project, majority of the participants said yes. Given the initial observations of the proposed workflow, the participants were asked how likely they would be to utilize the presented workflow in their day-to-day construction site visits. The average response to that question was 7.

The collected results were mainly positive and the presented workflows proved to be effective. Comparing the proposed workflows to the traditional methods, there was a common agreement that the construction industry could be ready for the use of augmented reality combined with building information modelling for the day-to-day tasks on a construction site.

V Conclusion

In this research paper, a proposed workflow for monitoring and documentation of construction site progress with the use of augmented reality technologies was critically analysed. A developed solution for visualisation of construction site progress was presented with the use of construction programme, building information model, geometric sequence and the introduction of augmented reality application.

A field study was carried out on the existing Mercantile development which allowed to thoroughly test and examine the external use of the proposed marker-based augmented reality application.

In order to critically evaluate the proposed workflow, a focus group discussion was carried out including industry professionals with a different range of experience in relation to building information modelling and augmented reality technologies.

In order to mitigate the low adoption of augmented reality technologies in the construction industry, this research presented a two-step workflow where the design team members can combine the construction programme with the building information model to create a geometrical sequence called 4D BIM. Then, with the introduction of AR application, the BIM model can be taken to a construction site, visualised on a hand-held device and then superimposed over the real surroundings for monitoring and inspection of site progress.

While the results of this study have been promising, the proposed solution has several limitations. As recommended by the focus group participants, in their opinion the proposed workflow would not result in the reduction of time spent during monitoring of construction site progress compared to the traditional methods. Another limitation that could hinder the adoption of the presented workflow is the fact the augmented reality technologies are regarded as expensive and hard to use.

With the everchanging nature of the construction industry, the adoption of BIM and AR processes as shown in this study, are brining advancements to the traditional construction workflows. As recommended by the focus group participants, it is important to investigate how AR workflows affect the work efficiency, accuracy of inspection reports and productivity on site.

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