TOWARDS ADOPTING 4D BIM IN CONSTRUCTION MANAGEMENT CURRICULUMS: A TEACHING MAP

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ABSTRACT

Construction planning and scheduling are vital to ensure delivering the project according to the agreed completion date. With the increasing in adopting technology in construction, the construction planning and scheduling process has been improved. One of these technologies is the 4D Building Information Modelling (BIM), which can be employed to improve construction planning and scheduling. The development of 4D models facilitates the various participants of a building project from architects, designers, contractors to the clients to envision the total duration of a series of events and also displays the progress of the overall on-going construction activities through the lifetime of the project. 4D BIM enables planners to attach the design elements to the corresponding activities, therefore, a simulation of construction sequences can be created. This chapter was designed for educators and students to provide them with adequate knowledge to teach and study 4D BIM, therefore, an introduction about planning and scheduling in construction was presented, followed by, an overview of BIM, then, the process and implementation of 4D BIM were presented in different sections. Finally, we provided educators with a teaching map to enable them to build their curriculums.

1. Project Planning and Scheduling

Construction planning and scheduling are the main processes of construction management which have been developed through the last few decades (Gould & Joyce, 2003). Construction planning includes defining the project activities, estimation of the resources and determining the required durations to perform the required activities and to define the interrelationships among project tasks (Ritz, 1994). On the other hand, project scheduling is about determining the sequence of activities and defining resources needed to execute each activity by identifying the critical/non-critical Paths (Illingworth, 2017). With the growing use of computers in the computational processes, the construction planning and scheduling process have been enhanced by reducing the required time, minimising the errors and better visualisation of presented data such as using Autodesk Microsoft Project (Baldwin & Bordoli, 2014). Similarly, Building Information Modelling (BIM) is expected to significantly improve the lifecycle of construction projects (Abrishami, Goulding, Rahimian, & Ganah, 2014) including construction planning and scheduling, which are known as 4D BIM (Han & Golparvar-Fard, 2015).

The optimisation of the project schedule is vital to exploit all resources and deliver the project with a minimum cost and according to the agreed time. Therefore, optimisation tools could be used to optimise the project duration and levelling the resources.

1.1.Research on evolutionary schedule optimisation

Hegazy (1999) developed a model to reach the optimal schedule path based on resource levelling and allocation simultaneously by embedding genetic algorithm, however, this method did not consider the cost factor. Furthermore, Hegazy and Ersahin (2001) have created spreadsheets to optimise the project schedule based on the resource levelling, cost and time. Another model has been developed by Senouci and Eldin (2004) to articulate a model which considers time-cost trade-off to minimise the project cost. However, this model did not consider multi-possible methods to perform the activity. Regarding multi-objective optimisation by genetic algorithm, Leu and Yang (1999) developed a model that considers the time–cost trade-off, resource-constrained allocation, and the unlimited resource-levelling models. This model was implemented in two stages:the first stage is to reach the optimal cost regardless of the resource levelling constraints, and the second stage focuses on levelling the resources. The shortcoming of this model is that the final results can be adversely affected because the second stage can increase the selected cost.

Ghoddousi, Eshtehardian, Jooybanpour, and Javanmardi (2013) developed a model which considers multi-objectives, namely, multi-mode resource-constrained project scheduling problem (MRCPSP), discrete time-cost trade-off problem (DTCTP) and also resource allocation and resource levelling problem (RLP). Despite the results of this research presented a high level of multi-objective optimisation, the model did not appear to be applicable in a complex project which usually includes many activities with unlimited possible solutions to perform each activity. Furthermore, Elbeltagi, Ammar, Sanad, and Kassab (2016) developed a model to optimise the schedule based on multi-criteria, which are the cost, resources, and cash flow. Particle swarm optimisation method was used to determine the optimal path of activities based on several possible solutions to execute each activity (Elbeltagi et al., 2016). However, the proposed model has the following shortcomings: (1) it relies on collecting data manually to enable implementing the optimisation model, and (2) it cannot be applied in a complex project in which activities are linked manually in the presented model.

After presenting the different attempts throughout the last few decades to use the genetic algorithm and other algorisms to optimise the project duration and resources, it is obvious that all proposed models can be effective for small project and optimisation models cannot be applied to large scale project. Therefore, BIM as we will see can help to optimise the project duration and resources by enabling you to choose the proper construction method.

2. What is BIM?

In this section, an introduction about the BIM process will be presented to enable you moving to the 4D BIM with a good understanding of the BIM process.

Due to the increase in the complexity of construction projects, it becomes more complicated to be managed due to the reciprocal interdependencies between different stakeholders (Alshawi & Ingirige, 2003; Qureshi & Kang, 2015). Therefore, utilising technologies to enhance the management processes have been considered to manage the project communication and information data (Taxén & Lilliesköld, 2008). During last few years, the enhancement in managing project information has been developed and Building Information Modelling (BIM) is one of these developments, therefore, BIM can be identified as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Succar, 2009). Consequently, from 2014 the UK began to recommend BIM as a way to approach projects to reduce transaction costs, as well as, minimise the design errors. The government asked for adopting BIM as a condition for many projects to deliver the project documentations as fully collaborative BIM (Smith, 2014). BIM is not only a geometric model which includes all design elements, but also a holistic process that contains several tasks such as project management tools and techniques, 3D design, contractual issues, and facility management. It helps to streamline the construction activities and maximise the value of a constructed asset (Bryde, Broquetas, & Volm, 2013).

After explaining the BIM process, the next section presents the 4D BIM origin, definition and characteristics.

3. 4D BIM

The origin of 4D BIM process goes back to 1980s when Bechtel and Hitachi Ltd collaborated to generate a 4D visual model (Rischmoller & Alarcón, 2002). However, the core of 4D techniques has been developed by Fischer and associates from Stanford University to create a visually supported planning and scheduling (Dawood & Mallasi, 2006). Currently, 4D BIM can integrate several models with the project schedule while loading multiple resources as well as creating logical relationships between project activities (Gledson & Greenwood, 2016). The main function of 4D BIM is to link the 3D BIM model with the project schedule (Gledson & Greenwood, 2016). This function includes several features such as visualisation of model spaces and time of performing the design elements (Büchmann-Slorup & Andersson, 2010; Heesom & Mahdjoubi, 2004; Liston, Fischer, & Winograd, 2003), considering the constructability methods of performing each activity (Koo & Fischer, 2000), and supporting the communication between all stakeholders which minimise the errors (Dawood, 2010).

In recent years, the application of 4D BIM in different construction context has been explored. For example, Gledson and Greenwood (2016) conducted a survey within UK industry firms to measure the applicability of the 4D BIM in the UK. This study shows positive results regarding the level of awareness and experience. On the other hand, most of the research studies explored the application of 4D BIM and the improvement of its features and processes were ignored. Thereby, there is a need to further explore how to improve the functionality of 4D BIM process regarding (1) Proposing a new method to create the list of activities (processes), (2) Proposing an integration way for Genetic algorithm into BIM platforms using API, (3) articulating a new approach to understand/utilise the output of 4D BIM.

4D BIM is defined as the way of improving the function of the planning process (Sloot, Heutink, & Voordijk, 2019). These functions can be concluded as follows (1) the function of extracting the needed planning information from BIM 3D design model (Turkan, Bosche, Haas, & Haas, 2012) ; (2) the function of identifying the activities by analysing the extracted design elements via specific constructability methods (Hartmann, Gao, & Fischer, 2008); (3) estimation and process interdependency functions (Heesom & Mahdjoubi, 2004); (4) planning project resources and site logistic data (Barry and David, 2016). 4D planning is mainly related to link project schedule to BIM 3D design elements to improve the buildability of construction activities. Moreover, there are other capabilities such as visualisation of time and construction process (Büchmann-Slorup & Andersson, 2010), analysing the project schedule to determine the suitable buildability method (Koo & Fischer, 2000), minimising the construction errors through exploiting the virtual simulation before emerging the construction phase as well as improving the collaboration and communication between project parties (Dawood, 2010).

3.1.4D BIM is characterised by the following factors:

- visualisation attributes that can help the non-specialized employer to integrate and involve in the construction process within different stages (Heesom & Mahdjoubi, 2004). This is particularly important because the decision making needs visualisation to clarify the information required to build an effective argument to get an optimum decision (Dawood, 2010)
- efficient communication by building an information channel, which facilitates integrating and combining all project stakeholders in the dynamic panel (Hartmann et al., 2008). The dynamic panel begins to be shaped from the conceptualisation stage by integrating the owner with the architect to set the project outlines. This process requires information from the trade contractors and other specialists (Elghaish, Abrishami, Hosseini, & Abu-Samra, 2020)
- collaborative planning and scheduling (Gledson & Greenwood, 2016)
- claims and dispute resolution by utilising the clash detection feature in the 4D BIM (Sloot et al., 2019).

After we discussed the origin of 4D BIM and its characteristics, the next section shows you the development of 4D BIM for construction projects. Given, we are in the era of automation, therefore, the next section will show you how 4D BIM can be automated regarding the development of the model as well as collected data from construction sites.

3.2.4D BIM automation process

For 4D BIM automation, A Montaser and Moselhi (2015) developed a model which allows users to import data from the MS Project to the developed BIM model using Revit Application Programming Interface (API), coded by C#.NET. The main feature of this model was its ability to correlate between the design elements implementation and the activity start and end dates. Furthermore, the study designed a project progress control methodology through process-based colour coding. For instance, the completed activities are highlighted in green, and the ones under construction are highlighted in another colour. Moreover, the implemented activities for specific construction operations will be hidden once finished to allow the planner to easily follow the project progression (Ali Montaser, 2013).

Omar and Dulaimi (2015) reported that embedding BIM in daily construction activities will help overcome all persisting problems. For example, updating all site-related information in BIM will enhance the productivity and strengthen the relationship between all stakeholders. As such, El-Omari and Moselhi (2011) asserted that using unsystematic procedures in collecting the site data leads to a huge loss of information and will reveal unreliable results. Thus, 4D BIM automation will enhance the quality of the collected data and reduce human interference in the data collection process (Boton, Kubicki, & Halin, 2015; Hakkarainen, Woodward, & Rainio, 2009).

The data collection of construction progress has been intensively improved through various technologies such as barcoding, radio frequency identification, 3D laser scanning, photogrammetry, multimedia, and pen-based computers (El-Omari & Moselhi, 2011; Changmin Kim, Son, & Kim, 2013; Talebi, Koskela, & Tzortzopoulos, 2018; Turkan et al., 2012; Turkan, Bosché, Haas, & Haas, 2013). However, the collected data cannot be fully exploited to update the cost information BIM at the moment. Consequently, Hamledari, McCabe, Davari, and Shahi (2017) advised that the progress data must be automatically analysed through advanced information technology. Furthermore, Wang et al. (2016) developed a model that utilises BIM to create project budgeting curve, namely S curve. This model generates an optimised cost budget curve based on multi-criteria, making it more reliable in implementation and giving a realistic indication concerning cost/schedule cases.

Elghaish and Abrishami (2020) developed a new philosophy to develop the 4D BIM model—Planning and scheduling—A BIM library of the project activities is developed to enable the automation of the creation of the project schedule with respect to the 3D BIM design sequence. The optimisation of the project duration is considered to be automated within the creation process using the proposed genetic algorithm model.

Steps for implementing the proposed constructability optimisation method according to (Elghaish & Abrishami, 2020) as follows:

1. The user defines activities that require specific constructability methods, in other words, the activities that can be executed using different tools.
2. Assign the appropriate resources (i.e. different types of equipment) to the selected activities.
3. Select the optimisation criteria from the designed panel (i.e. complexity, degree of uncertainty, etc.)
4. Run the optimisation process, then receiving the proper list of activities corresponding to the optimised cost.

Figure 1 shows the differences between the traditional path of formulating the project schedule as well as the proposed path.

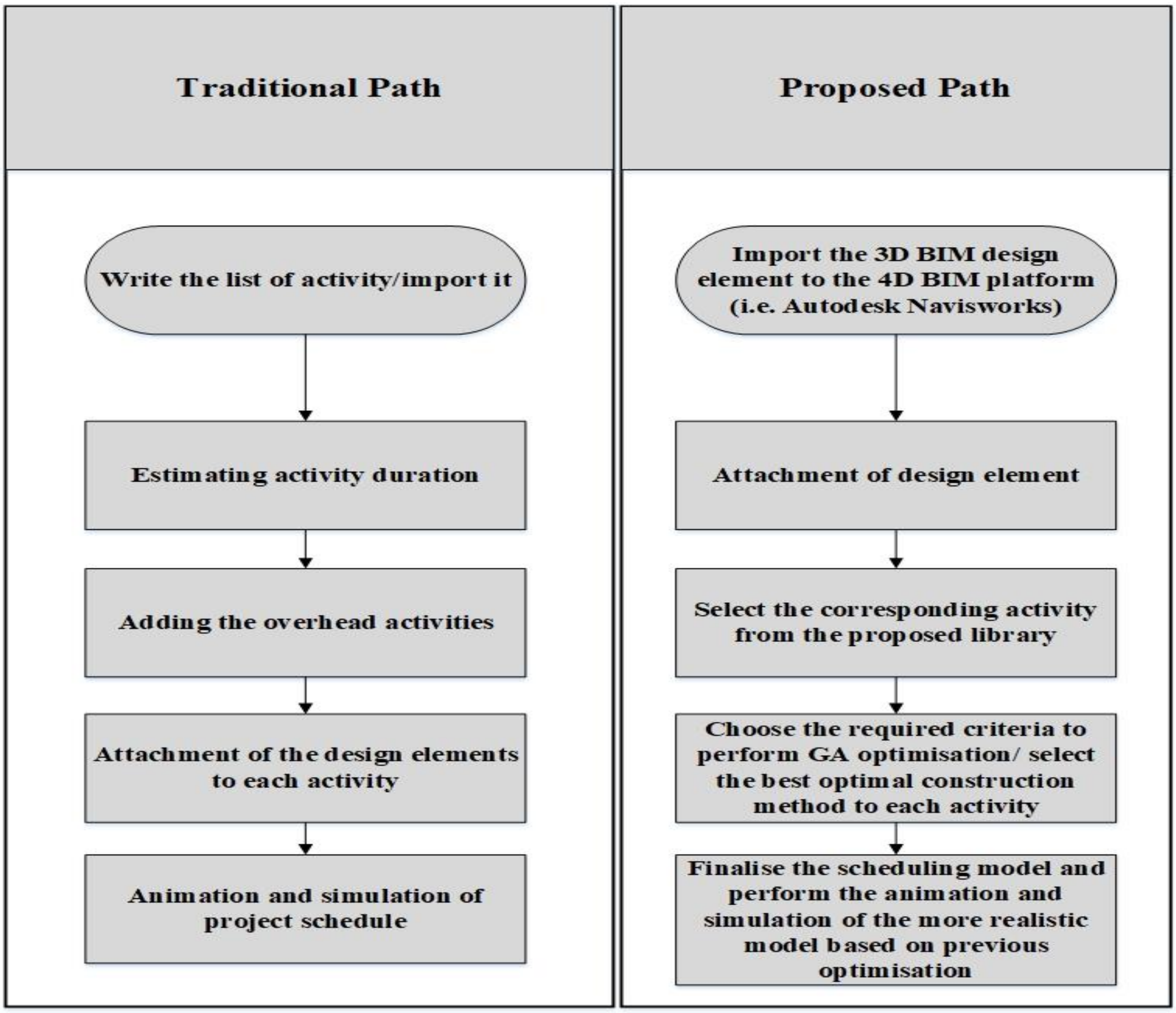

Figure 1. Comparison of traditional/proposed scheduling paths (Elghaish & Abrishami, 2020)

According to (Elghaish & Abrishami, 2020), Figure 2 includes all tasks (1, 2, 3 and 4) to shows how the proposed framework can be implemented. The process begins by importing the 3D BIM model to Navisworks and thereafter creating the list of activities and conducting the optimisation process for different construction methods. All the mentioned tasks will be implemented in a single platform (Navisworks). Figure (2-1) shows the configuration of Navisworks hierarchy level which helps the 4D planner to track all consumed resources in the project as well as assign the right responsibilities to all project stakeholders. On the other hand, when the animation option works each type of activity has two distinct colours as the appearance colour during the execution and the another colour when the activity has been accomplished, therefore this configuration could help to check the performance of each resource in the project by measuring the duration of appearing in the animation video. the price of materials, equipment, and labour are updated to the library.

Figure 2-2 shows The proposed library that was embedded into Navisworks by using Application Programming Interface (API) which has been coded by C# .NET. This can support the dynamic/single automation process by using a single platform, rather than exporting the data to several platforms in order to perform each task such as import the list of activities from Microsoft Project to emerge creation of 4D model as well as back to export the 4D BIM model to Microsoft Project in order to extract the Budgeted Cost of Work Schedule (BCWS) which represent the project budget. Currently, by adopting the proposed model, the planner will be able to finish all planning and scheduling tasks on the same platform. On the other hand, when the construction process starts, the 4D/5D BIM manager will be able to track the project by using the same platform as well. The criteria to enable GA to work can be selected from the proposed browser as it can be seen from the below figure 2, section 3.

The figure 2, section 4 shows the output of the genetic algorithm optimisation process so that each activity has three construction methods which these methods could survive during several iterations and the successful method will achieve the minimum required value to perform the construction process as it can be seen from the figure (2-4).

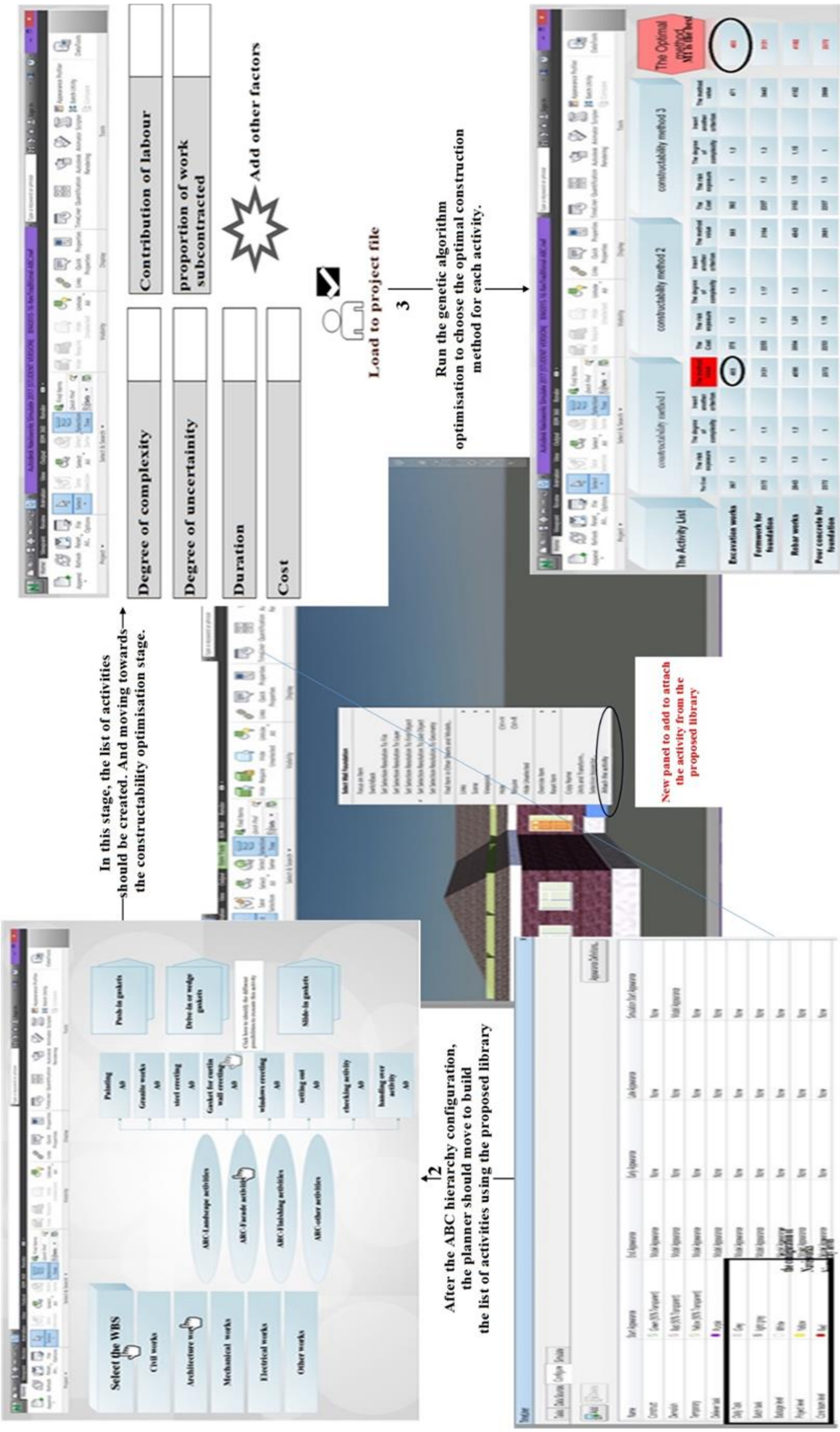

Figure 2. The 4D BIM process according to (Elghaish & Abrishami, 2020)

Given, 4D BIM can be used in integration with other technologies such as Unmanned Aerial Vehicle technologies an immersive technologies, therefore, the next sections present the application of these technologies with 4D BIM.

3.3.Unmanned Aerial Vehicle technologies and 4D BIM

Unmanned Aerial Vehicles (UAVs), through their advanced data collection capabilities, are revolutionizing a wide range of construction-related activities (Asadi et al., 2020). In terms of accuracy, efficiency and cost-effectiveness, UAV-based application surpasses conventional methods on construction sites (Greenwood, Lynch, & Zekkos, 2019).

UAVs are becoming an essential component of virtual design and construction (VDC), giving architects and engineers new and efficient ways to visualize and analyze structural requirements from the ground upwards. During the past two years, integrating UAV technology to enhance information management and visualization has drawn much attention. Lu and Davis (2018) proposed a framework to integrate unordered images, geometric models and the surrounding environment on Google Earth using two major components: UAV-centric image alignment and processing, Keyhole Markup Language-based (KML) image, and 3D model-management system. The proposed system is aimed at providing construction engineers with a low-cost and low technology-barrier solution to represent a dynamic construction site through information management, integration and visualization. Puppala, Congress, Bheemasetti, and Caballero (2018) developed the three-dimensional models using UAV-based photogrammetry studies to provide the health conditions of the structure, with a focus on material performance. Different image datasets about the conditions of various infrastructure assets were collected using a visual range camera mounted on a UAV. The 3D models were then developed to visualize the collected data and analyze the health conditions of the structure. Ajibola, Mansor, Pradhan, and Shafri (2019) developed a model that integrates a weighted averaging and additive median filtering algorithms to improve the accuracy and quality of the Digital Elevation Model (DEM) produced by UAV. Analysis of the result shows a remarkable increase of 88% in the accuracy of the fused DEM. Li and Liu (2019) presented improved neural networks to extract road information from remote-sensing images using a camera sensor equipped with UAV. P. Kim, Park, Cho, and Kang (2019) proposed a UAV-assisted robotic approach that can significantly reduce human intervention, as well as the time for data collection and processing. This approach is to enable cluttered environments to be frequently monitored, updated and analyzed to support timely decision-making. Ham and Kamari (2019) proposed a new method of automatically retrieving photo-worthy frames containing construction-related content that is scattered in collected video footages or consecutive images. The proposed automated method enables practitioners to assess the as-is status of construction sites efficiently through selective visual data, thereby facilitating data-driven decision-making at the right time.

Liu, Chen, Hu, and Zhang (2019) proposed a safety-inspection method that integrates UAV and dynamic BIM. A dynamic BIM model is created by aggregating timely updated safety information with a BIM model in the Web environment. The synchronous navigation of UAV video and dynamic BIM is realized by matching the virtual camera parameters with the real ones. The proposed method enables the off-site managers to view the inspection video and make timely and comprehensive safety evaluations with the support of dynamic BIM. de Melo and Costa (2019) developed a conceptual framework for integrating the resilience engineering (RS) and UAS technology into construction projects to support the safety planning and control (SPC) process. This framework highlights the fact that UAVs can be used to perform regular safety inspections. Such inspection provides information to help managers' decision making, especially in tasks which involve a high risk of accidents. The visual assets collected with

UAVs can also be used for feedback about the SPC and to increase workers' awareness through safety training. Finally, Gheisari and Esmaeili (2019) conducted a survey study to determine the effectiveness and frequency of using UAVs in improving safety operations in hazardous situations. The results indicated that the most important safety activities that could be improved using UAVs were the monitoring of boom vehicles or cranes in the proximity of overhead power lines, monitoring activities in the proximity of boom vehicles or cranes and the monitoring of unprotected edges or openings. In terms of the UAV technical features required for safety inspection applications, the most important features were camera movability, sense-and-avoid capability and a real-time video communications feed.

After we discussed how UAVs can be used to collect data from the site and compare the collected data with the 4D BIM, immersive technologies will be presented in the next section to illustrate how BIM can be benefited from Mixed Reality (MR) and relevant technologies to enhance the understanding of construction processes for all project parties.

3.4.Immersive technologies and 4D BIM

Meža, Turk, and Dolenc (2014) highlighted that Augmented Reality (AR) on a tablet, personal computer or mobile is the best option for monitoring and tracking a construction project. They also clarified how AR technology can facilitate the visualization and estimation of the work performed on-site and to compare it with the proposed schedule of construction projects. Park and Kim (2013) added another application to schedule monitoring by connecting AR material tracking to ensure that the necessary materials are located on the project site.

Combined immersive technologies and 4D BIM can be also used for safety monitoring by improving the situational awareness of construction workers (Cheng & Teizer, 2013; H. Kim et al., 2017). There were few studies found that focused on project scheduling. One was that by H. S. Kim, Kim, Borrmann, and Kang (2018), who developed an AR-based 4D CAD system which connects 4D and 5D (Cost management dimension) objects with a real field image and an AR object to implement several types of schedule information and enables the use of constantly changing schedule information through AR objects. Another study was by Ratajczak, Riedl, and Matt (2019), who developed a unique field application that integrates a location-based management system (LBMS) into BIM and an AR platform. This was to (1) detect scheduling deviations easily by visualizing construction progress in AR, (2) provide daily progress information, (3) provide performance data regarding construction activities, and (4) provide context-specific information/documents on scheduled tasks

Construction projects involve collaboration between several project disciplines, including contractors, designers, managers and more. A successful partnership confirms that a project will be completed on time, as per the proposed budget. However, not all project teams involved in a project are always present on a job site. If any error occurs that requires immediate action to be agreed by all parties involved, immersive technologies allow users to take notes and share views of an error and to send information to remote teams in real-time (Elghaish, Matarneh, et al., 2020). Pejoska, Bauters, Purma, and Leinonen (2016) realized in comparison with more traditional information sources the accessibility of on-site project information and effective communication are significantly improving with the utilization of immersive technologies. However, some studies appeared to focus on collaboration and communication in construction projects. For example, some studies focused on using immersive technologies to facilitate collaboration and communication between the design team. A study by Goulding, Nadim, Petridis, and Alshawi (2012), demonstrated the need for integrating collaborative design teams to facilitate project integration and interchange by applying a game environment supported by a web-based VR cloud platform to facilitate collaboration and decision making during the design process. Another is by Chalhoub and Ayer (2018), who examined the application of MR technologies in communicating electrical designs by comparing the performance of 18 electrical construction personnel who were tasked with building similar conduit assemblies using traditional paper. Du, Shi, Zou, and Zhao (2018), meanwhile, developed a real-time synchronization system of BIM data in Virtual Reality (VR) for collaborative decision-making. The system is based on an innovative cloud-based BIM metadata interpretation and communication method to allow users to update BIM model changes in Virtual Reality (VR) headsets automatically and simultaneously.

Other studies focused more on facilitating communication between project parties. For instance, Lin, Liu, Tsai, and Kang (2015), proposed a visualized environment to facilitate the discussion among parties by using a stationary display called BIM Table, which displays public information. The proposed visualized environment uses AR technologies to connect the BIM Table and the mobile devices. Zaker and Coloma (2018) investigated the application of a VR-based workflow in a real project. A case study of VR integrated collaboration workflow was used to serve as an example of how AEC firms could overcome the challenge of collaboration between a project's teams. Du et al. (2018) also developed a cloud-based multi-user VR headset system called collaborative virtual reality (CoVR) that facilitates interpersonal project communication in an interactive VR environment. Another study, conducted by Boton (2018), proposed an immersive VR-based collaborative 4D BIM simulation to provide a supportive environment for conducting constructability analysis meetings.

The capabilities of immersive technologies to pool digital data and documentation with the physical view is a game-changer. Examples include Yeh, Tsai, and Kang (2012), who presented a wearable device that could project the construction drawings and related information to help engineers to avoid carrying bulky construction drawings to the site and to reduce the effort required in looking for the correct drawings to obtain the information needed. X. Zhang, Arayici, Wu, Abbott, and Aouad (2009) developed a system to facilitate the accurate exchange of project information among field personnel, using existing and already available camera-equipped mobile devices. Changyoon Kim, Park, Lim, and Kim (2013) developed a comprehensive system using mobile computing technology to provide construction stakeholders with a sufficient level of project information required for task management, including the visualization of task location in an AR environment. Chu, Matthews, and Love (2018) evaluated the effectiveness of BIM and AR system integration to enhance task efficiency through improvement in information retrieval process during construction by developing a mobile BIM AR system with cloud-based storage capabilities.

3.5.Internet of Things (IoT) and 4D BIM

Given, we are in the era of industry 4.0 that is associated with utilising IoT to automate all processes and reduce human interference to complete tasks. As such, in this section, the utilisation of IoT with 4D BIM will be highlighted.

The IoT concept was earlier utilized in measuring project progress by employing Radio-frequency identification (RFID) technologies (readers and sensors), particularly for "health and safety" and for evacuation planning during the construction stage (Kiani, Salman, & Riaz, 2014). This research proposed valuable extensions for the developed system to enhance and support the visualization and reliable data acquiring for construction health and safety management tasks. Subsequently, significant research has been conducted to cover a wide range of IoT applications for measuring construction project progress. C Zhou and Ding (2017) utilized the IoT to provide automated warning systems, as well as safety-barrier strategies for underground sites to avoid accidents. However, even though the system was tested using a case study – the Yangtze River-Crossing Metro Tunnel – the health and safety regulations are different from one country to another. Therefore, more applications and extensions to this system are still needed to maximize the benefits.

Kochovski and Stankovski (2018) explored how edge computing applications, such as video communications and construction process documentation, can support the movement to smart construction with high Quality of Service (QoS). However, the security of the data was an issue, and this is why the researchers recommended the integration of the presented applications and blockchain technology. Further case studies have been conducted to measure the significance of the IoT in managing smart buildings. Cheng Zhou, Luo, Fang, Wei, and Ding (2019) developed a cyber-physical-system-based safety monitoring system for metro and underground construction, particularly for blind hosting. A case study was conducted to measure the validity of the system in a complex site environment. The findings show that the integration of BIM models and physical activities can provide real-time feedback information for all movements of equipment on-site, enabling risks to be identified automatically. However, the authors recommended that studying and optimizing the relationships between safety issues and construction conditions could enable the development of simulations in future to predict similar issues. More utilizations of the IoT in health and safety have been presented, such as using IoT-based architecture to automate non-hard-hat-use (NHU) testing (H. Zhang, Yan, Li, Jin, & Fu, 2019). The researchers proposed a system that relied on an infrared beam detector and a thermal infrared sensor for non-intrusive NHU detection to deal with the problems of employing traditional sensors which were not efficient enough to detect human movements.

Construction mobility for industry 4.0 requires an ecosystem to utilize the IoT in the entire construction operation rather than utilizing it in a single operation (Woodhead, Stephenson, & Morrey, 2018). This research revealed that there was a contradiction between acquiring a highly secure IoT environment and sharing data and a set of new processes and systems should be developed to enable the utilization of IoT in the construction industry, such as new information workflow and new business models.

4. Teaching map of 4D BIM

To teach 4D BIM to undergraduate or postgraduate students, the teaching process should be systematic to enable students to absorb the required theoretical knowledge before moving to the practical and sophisticated applications. The following steps should be followed to prepare/adopt 4D BIM in any educational institute:

- **Teaching Planning and Scheduling Process:** It is suggested that the project planning and scheduling tools and techniques (e.g. Critical Path Method) should be taught before moving to the 4D BIM implementation procedures. This is particularly important because 4D BIM is based on project planning and scheduling concepts.
- **Teaching clash detection process using traditional approaches:** 4D BIM includes clash detection to investigate coordination problems between different disciplines. It is expected that students are aware of techniques that were used traditionally for such a purpose so students will better understand the value of 4D BIM.
- **Teaching 4D BIM implementation process:** After students understand all essential theoretical knowledge, 4D BIM then can be introduced systematically through (1) teaching the process of developing the list of activities, (2) teaching how the durations of activities can be estimated in a different method (i.e. Parametric estimation), (3) teaching how activities can be linked with corresponding design elements to create a simulation of project works, (4) teaching students how to create scripts and viewpoints to enhance the animation of the project works in the virtual environment, (5) teaching how to create a clash detection report as well as the mechanism of writing a report and solving the discovered clashes in the 3D BIM model.
- **Teaching the advanced 4D BIM integrations with other technologies:** given, BIM can be integrated with several technologies such as immersive technologies and blockchain, it will be useful to show how 4D BIM can be enhanced by using these technologies such as using mixed reality to help project parties to compare between the

performed works and the designed works and using drones to collect data from the site, subsequently, compare this data with the 4D BIM model to evaluate the progress of the project.

Figure 3 shows the process of teaching 4D BIM to students, all teaching procedures, tools and techniques are also highlighted. The process of teaching was divided into three main stages as seen in figure 3.

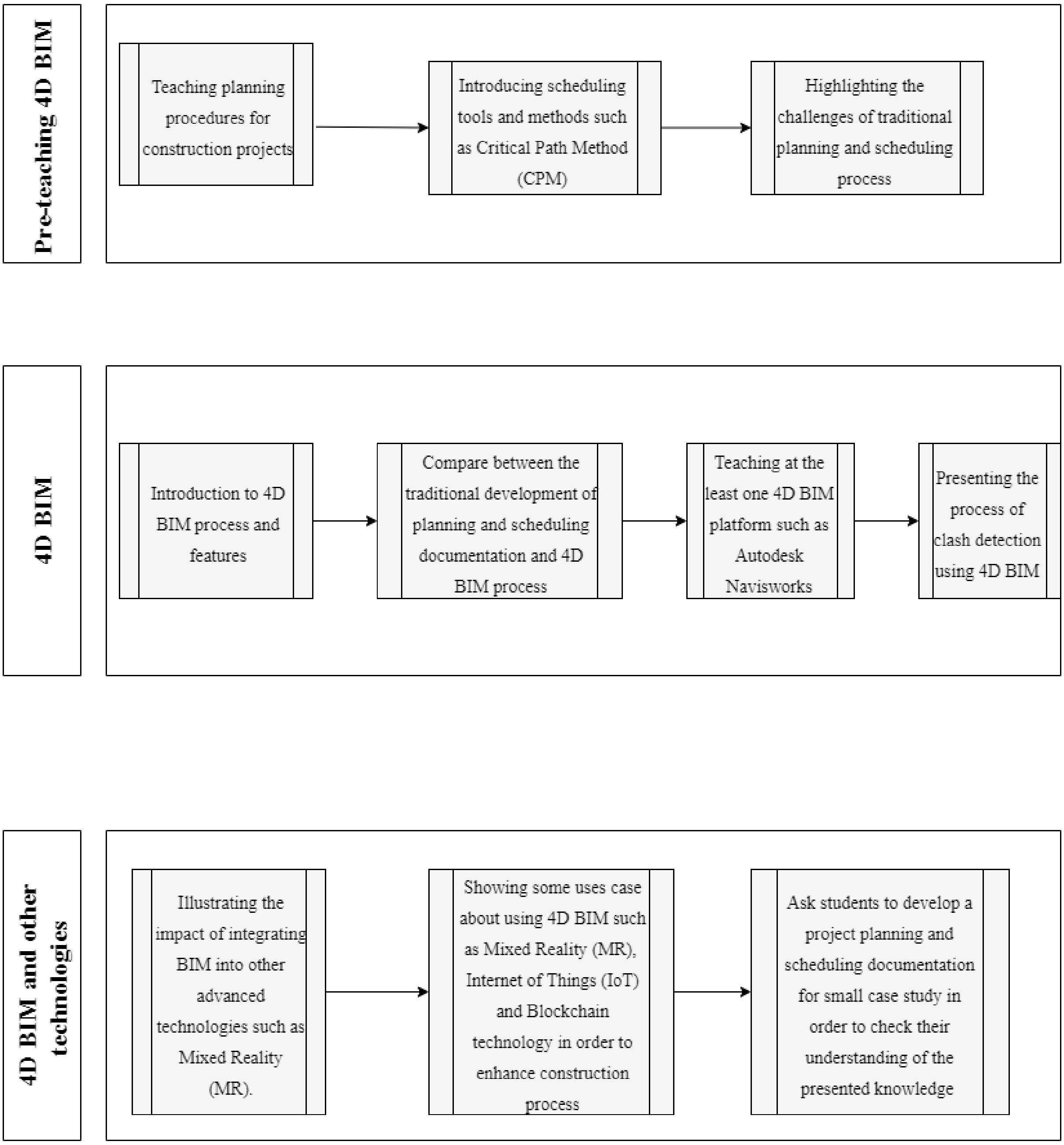

Figure 3. 4D BIM teaching map

Summary

The AEC industry is currently moving towards heavily relying on the various BIM services. The BIM services like clash detection and coordination services are high in demand, and they can be utilised throughout the project life cycle. This chapter presented a brief overview of 4D BIM uses in the various construction phases and shed some light on its benefits and challenges. During the pre-design phase, 4D BIM supports strategic planning. When all the required information is available, the best strategies can be successfully shaped. The 4D BIM can also be implemented for deciding the sequences and for the best use of construction schedules. During the design development phase, with the support of 4D BIM A/E can enhance the design constructability. The 4D BIM can also optimize the construction schedules with the help of the model which can also benefit the contractors by showing the phasing plans to the owners.

Also, 4D BIM can be integrated with other technologies such as immersive technologies (e.g. virtual reality) to help project parties visually observe differences between the performed works and the designed works. Also, 4D BIM can be integrated with data collected from drones to monitor the project progress by comparing the collected data from the site with BIM

Finally, this chapter proposed a map that includes steps to facilitate 4D BIM teaching and to enable students to absorb the required theoretical knowledge before moving to practical and sophisticated BIM applications.

Questions

1. What are the main features of 4D BIM?
2. What are the differences between the traditional planning and scheduling process and 4D BIM?
3. What are the use cases of using Virtual Reality (VR) and Mixed Reality (MR) with 4D BIM?
4. How the UAV can be used to collect data from construction sites?
5. Draw a flowchart to describe the features of 4D BIM and how it can be implemented in a construction project?
6. What are the use cases of integrating IoT into 4D BIM?

7. List various technologies that can be integrated with 4D BIM?

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