Developing a framework to Revolutionise the 4D BIM process: IPD-Based solution

Faris Elghaish and Sepehr Abrishami

Abstract

Purpose: The integration of Building Information Modelling (BIM) and Integrated Project Delivery (IPD) is highly recommended for better project delivery. Although there is a methodology for this integration, however, the BIM requires some improvements to foster the adoption of IPD. This paper presents an innovative way to support the 4D BIM automation/optimisation within the IPD approach. Similar to structural, architectural designs libraries, this research proposes a planning library to enable automating the formulation of schedule, as well as, embedding the multi-objective optimisation into the 4D BIM.

Design/methodology/approach

The literature review was utilised to highlight the existing improvement of using 4D BIM, as well as, the multi-objective schedule optimisation. Moreover, using a case study in order to validate the developed framework and measure its applicability.

Findings

The results show that there is a cost saving of 22.86% due to using the proposed automated multi-objective optimisation. The case study shows the significance of integrating Activity Based Costing (ABC) into 4D BIM in order to configure the hierarchy level of overhead activities with IPD approach, therefore, the most level of contribution in managing the IPD project was by the trade package level by 33.33% and the minimal contribution was around 8.33% by the project level.

Originality/value

This research presents 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.

Keywords: Construction planning; 4D BIM; IPD; ABC; BIM-Library.

Introduction

Construction planning and scheduling are one of the main processes of construction management and it has been developed through the last few decades (Gould and Joyce, 2003). The construction planning includes defining the project activities, estimation of the resources and determining the required durations to execute the defined activities, followed by defining the interrelationships among project tasks (Ritz, 1994). Whilst, the project scheduling process is to determine the sequence of the defined activities and exactly which resources are needed to execute each activity by defining the critical/non-critical Paths (Illingworth, 2017). With the growing of utilising the computer 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 and Bordoli, 2014). Similarly, the Building Information Modelling (BIM) is revolutionised the entire construction process through the last few years (Abrishami et al., 2014), the construction planning and scheduling are presented as 4D BIM (Han and Golparvar-Fard, 2015). However, the BIM has adopted the traditional mechanism of developing the planning and scheduling models such as inputting the list of activities manually and there is no a link between the estimating activity duration and the resources in the 3D BIM model.

This research introduces a new philosophy of creating the project schedule within the BIM process. Due to the complexity of the construction process, this requires thousands number of activities in order to schedule the project. Therefore, this research proposed to change the path of articulating the project schedule by emerging attaching the design element and assign the required activity from the proposed plug-in library inside Navisworks. On the other hand, the research introduces a new way to create a complementary schedule by integrating the Activity Based Costing (ABC) method into 4D/5D BIM in order to add the overhead activities into a 4D model. Subsequently, the hierarchy of consuming the project resources have been categorised by the level of activity inside the core team organisation which begins by the core team level to the daily task level. Therefore, the visualisation/animation features will be more efficient and effective as this research includes a model to determine the contribution of each party or member by the duration of appearing the chosen colour of his level in the animation video relative to the total duration. Additionally, the framework proposed a library of activities be embedded into 4D/5D BIM Navisworks platform, this library includes different construction activities and each activity is loaded by all possible method to perform it under different circumstance. Therefore, the overall optimisation for the construction schedule will be attainable due to select the multi-criteria from the proposed browser and the process will be carried out automatically by using genetic algorithm optimisation method.

The literature review has been used in order to highlight the gap by exploring all existing research to support the 4D/5D automation, as well as the extant research to integrate 4D/5D in order to generate an integrated budget. Fan et al. (2015) have developed a model to exploit BIM to generate an integrated budget, however the researcher proposed an improvement to their research by developing another model which allow linking between BIM element and the cost directly with overriding the schedule in this stage and then link the BIM element with its cost to the schedule (Fan et al., 2015). Therefore, this research adopts this issue and introduced a method to manage it. Moreover, Montaser and Moselhi (2015) developed a model to correlate between the BIM 3D design elements and the activity start/end dates in order to track the project, however, this model relies on multi-platforms as it requires to link the Microsoft Project by Revit in order to carry out the proposed task. Nevertheless, the proposed framework in this research will support the dynamic/single source of data by performing all tasks using Navisworks by programming all tasks via Navisworks Application Programming Interface (API), coded by C#.NET.

Regarding the multi-objective scheduling optimisation, Elbeltagi et al. (2016) proposed a model to optimise the schedule based on multi-criteria such as time, cost, resources, and cash flow. The method was particle swarm optimisation in order to reach the optimal schedule. However, the proposed model depends on collecting data manually in order to enable accomplishing the optimisation model, additionally, since activities are linked manually in the developed model, therefore the real-life application for a complex project will not be applicable, particularly for construction projects.

As aforementioned, the proposed framework in this research will consider all factors to automate planning/scheduling process towards implementing and exploiting 4D BIM capabilities. The proposed model has an innovative way to exploit 4D BIM features such as animation and simulation feature in the proposed model has been linked with the overhead activities which generate overhead costs. Since BIM supports the automation in design by offering structural, architectural, mechanical, etc. libraries, subsequently, this research introduce a planning/scheduling library for the first time in 4D BIM optimisation.

Theoretical background

4D BIM

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

4D BIM is characterised by (1) The visualisation attributes that can help the non-specialized employer to integrate and involve in the construction process within different stages (Heesom and Mahdjoubi, 2004). Moreover, the decision making needs visualisation to clarify the information which needs to build an effective argument to get an optimum decision (Dawood, 2010), (2) efficient Communication by building an information channel, which facilitates to integrate and combine all project stakeholders in the dynamic panel (Hartmann et al., 2008). This 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 another specialist (Hakkarainen et al., 2009, Hamledari et al., 2017), (3) collaborative, planning, scheduling, and constructability (Gledson and Greenwood, 2016), (4) Claims and Dispute Resolution by utilising the clash detection feature in the 4D BIM (Sloot et al., 2019).

Related research for a 4D/5D automation process

For BIM 4D automation, Montaser and Moselhi (2015) developed a model that allows users import data from 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, the ones under construction are highlighted in another colour, etc.. Moreover, the implemented activities for specific construction operations will be hidden once finished to allow the planner to easily to follow the project progression (Montaser, 2013).

Furthermore, Omar and Dulaimi (2015) reported that embedding BIM in daily construction activities will help overcome all persisting problems. Moreover, automatically updating all site information will enhance the productivities and strengthen the relationship between all stakeholders, increasing the trust in the site collected data. 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, BIM 4D automation will enhance the quality of the collected data and reduce human interference in the data collection process (Boton et al., 2015, Hakkarainen et al., 2009).

Lawrence et al. (2014) developed a model to automatically update the cost data according to any changes in cost parameters such as; quantities change due to any change in design or project scope. However, (Eastman et al., 2011) argued that there is no comprehensive BIM-based cost management platform that can perform all the cost-related processes namely; estimation, budgeting and control. As such, Lee et al. (2014) recommended that BIM cost systems should participate in decision making rather than generating only Bills of Quantities (BoQ). For instance, the platform should be able to select among different types of material based on pre-set criteria (i.e. cost of each type of material). Even though the data collection of construction progress has been intensively improved through different kinds of technology such as; bar coding, radio frequency identification, 3D laser scanning, photogrammetry, multimedia, and pen-based computers (El-Omari and Moselhi, 2011, Kim et al., 2013, Turkan et al., 2013, Turkan et al., 2012), the collected data remains not ideally exploited in AEC industry. Consequently, Hamledari et al. (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 with respect to cost/schedule cases.

Integrated Project Delivery (IPD and the Importance of an Early Decision Making

Integrated project delivery (IPD) is characterised by the early, collaborative and collective engagement of key stakeholders through all phases of delivering a project (Ashcraft, 2014, Ahmad et al., 2019).). Rowlinson (2017) states that there are some criteria which distinguished using IPD in BIM projects, these criteria such as multiparty agreement; early involvement of all parties; and shared risk and reward (Ashcraft, 2012, Ballard et al., 2015). Moreover, Bedrick and Rinella (2006) assert that BIM has enhanced the efficiency of the construction process by enhancing the collaboration among a wide range of project participants through different stages whether design or construction. Therefore, comprehensive decision making must be considered in the early design stage (Ashcraft, 2008). Subsequently, implementing IPD can optimise the delivery timeline of construction projects by reducing waste within better planning and shared risk/rewards (Ahmad et al., 2018, Rowlinson, 2017). Therefore, the optimisation of 4D BIM can play a vital role in reducing cost and enhancing the entire efficiency for construction process (Han and Golparvar-Fard, 2015).

Target Value Design (TVD) is recommended as an effective solution for IPD projects (de Melo et al., 2016, Pishdad-Bozorgi et al., 2013). A successful TVD requires extensive collaboration among designers, builders, quantity surveyors and trade partners (Alwisy et al., 2018): all these parties must be at the table and offer continuous feedback to influence the design and achieve the owner's goals while complying with the set budget, as argued by Pishdad-Bozorgi et al. (2013) and Allison et al. (2017). This collaboration is based on multiple interactions and rapid circles of suggestions, analysis and feedback to allow continuous improvements and to find the solutions that meet the client's – or multiple stakeholders' – definition of value (Alves et al., 2017, Silveira and Alves, 2018). Therefore, TVD is implemented with the support of lean management tools to facilitate effective collaboration and make possible these rapid circles of conceptualisation, analysis and estimation (Meijon Morêda Neto et al., 2019, Alwisy et al., 2018, Alves et al., 2017, Allison et al., 2017).

Activity Based Costing

Construction projects typically rely on a fragmented structure—of participants. And this fragmentation leads to an increase in overhead activities, and accordingly overhead costs (Ashcraft, 2008, Mignone et al., 2016). There are several traditional cost accountant methods: Resource-based Costing (RBC) that relies on resources' cost; Volume-based Allocation (VBA), based on allocating the cost of resources directly to objects, regardless of the cost structure—direct, indirect, and overhead costs (Holland and Jr, 1999). Cost distortion, however, occurs in using these traditional methods, due to conflating all indirect costs into one, which distorts the pricing of the company's' products (Miller, 1996). Activity Based Costing (ABC) is a solution to such distortion, through allocating costs to multi-pools and determining the overhead activities and the associated costs needed to transform the resources into activities that can deliver the final product (Kim and Ballard, 2001, Kim et al., 2011).

Related research regarding evolutionary schedule optimisation:

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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 resources levelling, cost and time. Another model has been developed by (Senouci and Eldin, 2004) in order to articulate a model which consider time cost trade-off in order 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 which considers the time–cost trade-off, resource-constrained allocation, and the unlimited resource-levelling models, however this model was implemented in two stages, and first stage is to reach the optimal cost regardless of the resource levelling constraints, however the second stages focus on levelling the resources, this can affect the final results of the model due to the levelling stage can affect the selected cost and vice versa could happen as well.

Ghoddousi et al. (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), even though, the results of this research presented a high level of multi-objective optimisation, however it seems not applicable in a complex project which usually includes plenty of activities with unlimited possible solutions to execute each activity.

Furthermore, Elbeltagi et al. (2016) developed a model to optimise the schedule based on multi-criteria, these criteria are the time, cost, resources, and cash flow. The used method was the particle swarm optimisation in order to determine the optimal path of activities based on several possible solutions to execute each activity (Elbeltagi et al., 2016). However, the proposed model relies on collecting data manually in order to enable implementing the optimisation model, Moreover, because of activities are linked manually in the presented model, the application for a complex project will not be attainable, especially in AEC industry.

Research gap

There are intensive research has discussed the multi-objective optimisation in construction planning and scheduling such as Hyari and El-Rayes (2006), Sriprasert and Dawood (2003), Leu et al. (2001), (Liu and Wang, 2007) and (Anvari et al., 2016), however, all mentioned attempts were before emerging 4D BIM, therefore, A BIM-based schedule optimisation has not been explored in mentioned studies. Earlier, Kymmell (2007) used the concept of 4D BIM as a tool in managing construction projects. The 4D BIM was utilised in other research to improve the planning and costing processes, particularly, research conducted by (Kim et al., 2013) to automate the cost control task. Additionally, Boton et al. (2015) explored the challenges that face the adoption of 4D BIM in the construction industry. Regarding the optimisation of 4D BIM, research conducted by (Jianping et al., 2011) to build a 4D construction resource informational model to optimise the project resources. Moreover, Hakkarainen et al. (2009) proposed the integration of 4D BIM with the Augmented Reality (AR) technologies for providing mobile users.

Later, Many research has explored the application of 4D BIM within the construction industry in different construction context (i.e. UK) such as Gledson and Greenwood (2016) conducted a survey within UK industry firms to measure the applicability of the 4D BIM in the UK and positive results were obtained regarding the level of awareness and experience. In addition, The 4D BIM was utilised in other research to improve the planning and costing processes, particularly, a research conducted by (Kim et al., 2013) to automate the cost control task.

As such, most of the research explored the application of 4D BIM and the improvement of its features and processes were ignored. Thereby, this research is needed, and it is an attempt 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.

Methodology

Research approach

The objective of the current study is to present a workable solution and explore its practical validity within a real-life setting. As argued by (Yin, 1981), exploratory case study and experiment methods are the most applicable methods in accomplishing this type of objective. To be specific, context is an essential part of case study research, in which too many variables can affect the outcome and produce inferences about the causes and effects of the methodologies and procedures under question (Yin, 1981). As a result, assessing the impacts of this type of workflow in a real-life case would be not only affected by many factors but also mediated through various procedures: consequently, running a case study and applying observational techniques were deemed irrelevant.

Experiments are effective in revealing whether the real data support or rebut the conceptualisations of researchers. According to Zellmer-Bruhn et al. (2016), "experiments isolate causal variables and enable a strong test of the robustness of theory: they provide convincing evidence for theories". The validity of an assumption about causes and effects, in which a match between data and theory is observed, is demonstrated through experiments (Shadish et al., 2002, Yin, 1981). The current study has therefore selected the use of an experiment as the principal method for testing the assumptions about the positive effects of the proposed cost estimation methodology. Accordingly, this research has been implemented and designed using a mixed research methods strategy since the literature review (qualitative approach) is utilised to develop the research hypothesises, subsequently, a framework is developed to provide a solution, finally, a comparative case study (quantitative case study) is applied to validate the proposed solution.

Logic

The gap has been highlighted within an intensive literature review to explore the existing research to integrate between 4D/5D BIM as well as the automation process. Thereafter, the framework will be articulated to manage the lack of integration/automation which has been determined from the literature review. In order to apply the developed framework, the proof of concept prototype will be developed as a plug-in inside the Navisworks. Thereafter, the case study will be conducted in order to measure the applicability, validity, and practicality of the developed prototype. Below figure (1) reveals all methods of conducting this research.

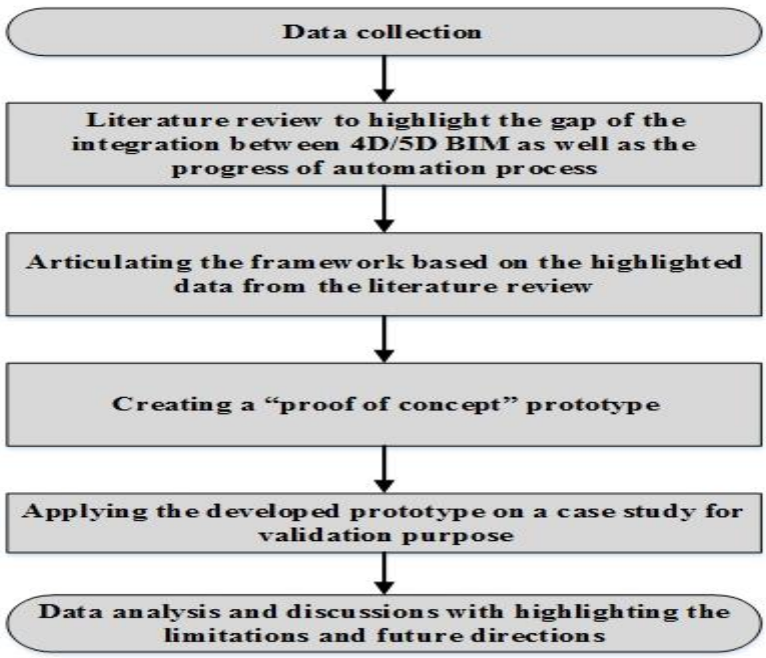

Figure 1. Research methodology

Development of the framework with proposing tools

The proposed framework works from the detailed design stage when the 3D BIM model becomes ready. The 4D/5D BIM manager begins to import the 3D design model to Navisworks as 4D/5D BIM platform in order to emerge the schedule/costing process simultaneously. Because of ABC interests by the level of consuming project resources (Hierarchy of project's organisation), Navisworks platform will be configured by distinguished colours to identify each type of task (i.e. package level, daily task level). After that, starting to select the most suitable Work Breakdown Structure (WBS) from the proposed library. The 4D BIM planner will start to create the list of activities by using adverse direction against the traditional path in 4D BIM, the traditional path begins by writing the list of activities manually or import it from any traditional scheduling software (i.e. Microsoft Project, Primavera), then the planner estimates the durations based on the available resources and project quantities and in order to simulate the project, the planner attach the corresponding design elements to every activity in the model. However in this framework, the 4D planner will start by attaching the design element firstly and after that, the corresponding activity will be selected from the proposed library in order to support the automation and make the entire process completed automatically with minimum human contribution to minimising the possibility of errors, particularly for the complex project schedule.

Regarding supporting the automation of selecting the optimal construction method to perform the activity, the library includes all possible methods to perform the activity, therefore the planner will be able to select the suitable methods to each activity and the criteria of selection can be selected from a wide range will be offered from the proposed library. The 4D planner can just tick in correspondence with each criterion (ie, degree of complexity, duration). Genetic Algorithm model will work here in order to select the best construction method of each activity

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based on the given criteria, with respect to the sequence of activities which represents the sequence of model designs as attached.

$$OM = \min_{MV} \sum AC(Ie, \quad complexity\ degree, duration\ factor, ..) \times CoA \qquad (1)$$

Where,

MV: Method Value; AC: Activity Criteria; CoA: Cost of Activity.

Steps for implementing the proposed constructability optimisation method:

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.

The figure (2) shows the differences between the traditional path of formulating the project schedule as well as the proposed path.

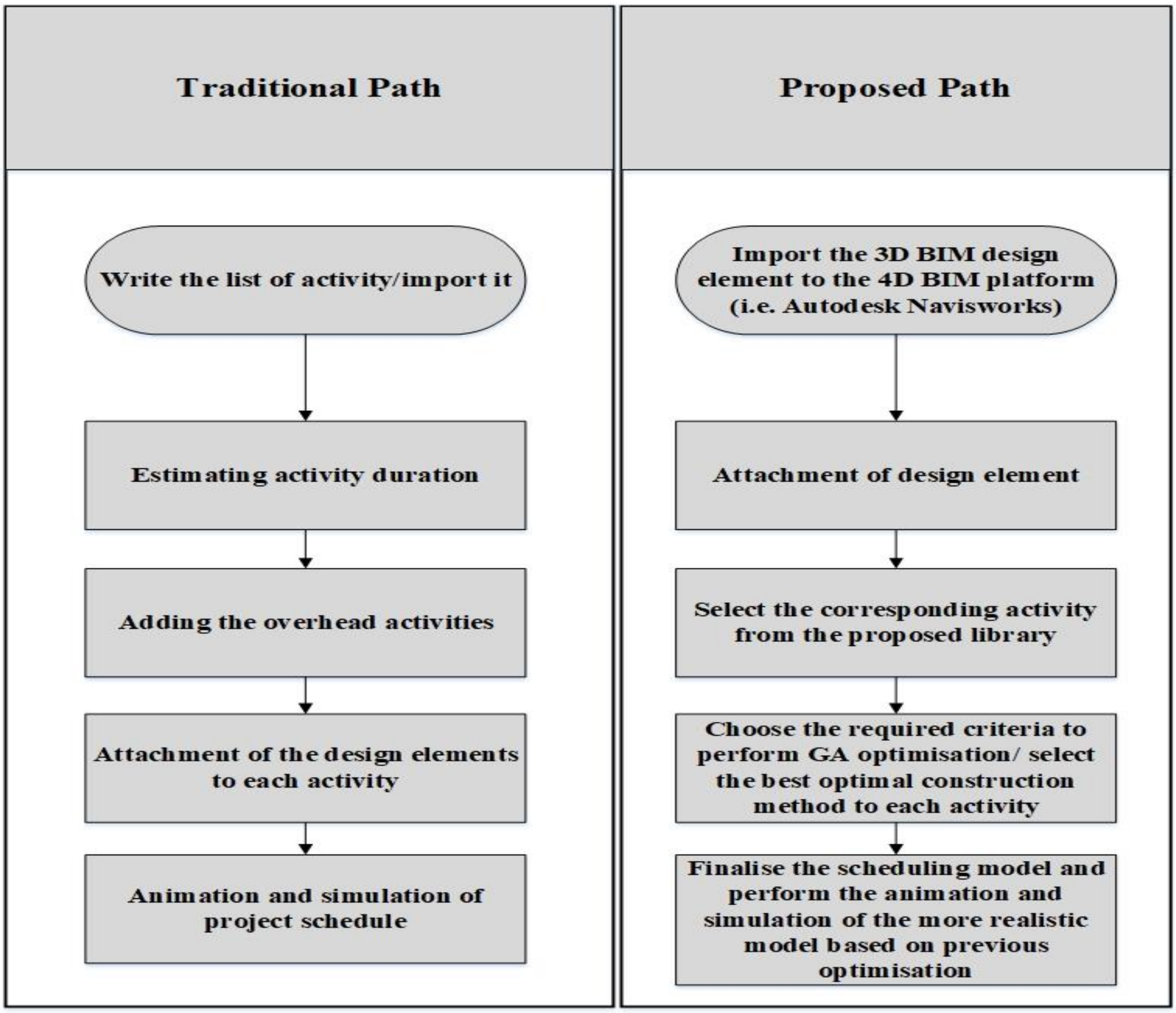

Figure 2. Comparison of traditional/proposed scheduling paths

Figure (1A) 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. Moreover, the contribution of each party in the core team members by following the summation of durations of their colours which appear in the animation feature. The below equations shows how this can be calculated:

$$CL = \sum \frac{DoCA}{TD} \% \qquad (2)$$

Where:

CL: Contribution Level for each party; DoCA: Durations of Colours Appearing; TD: Total duration of the project animation scale.

The proposed library has been 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.

2. Comparison of traditional/proposed scheduling paths

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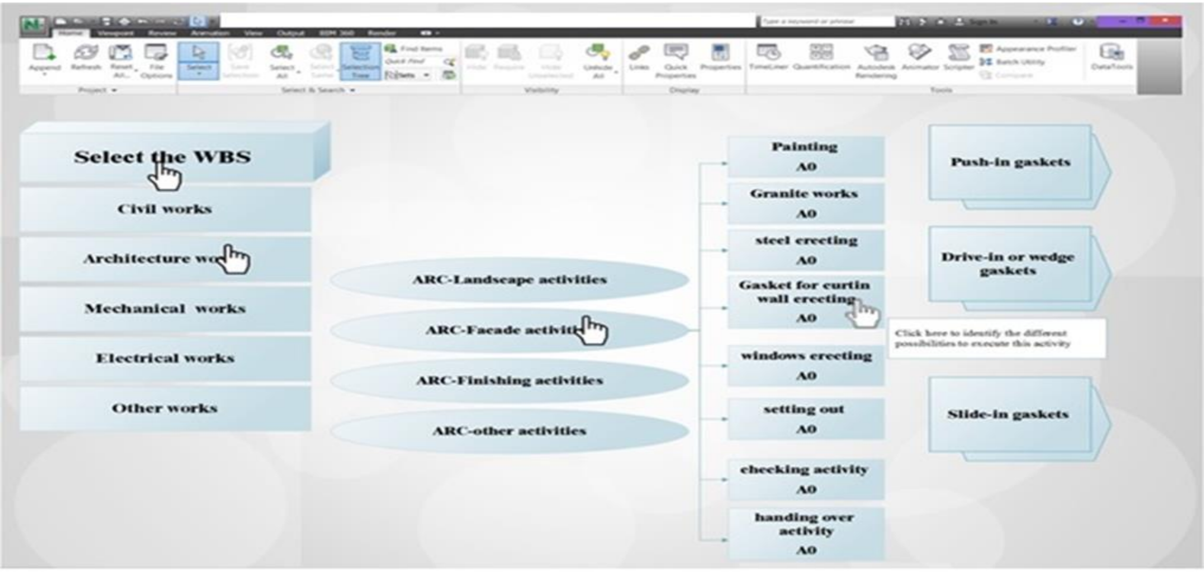

Figure 3. The proposed BIM activity library

After the creation of a list of activities by using the proposed library, there is a correlation between the embedded Bills of Quantities (BoQ) and the embedded constructability methods as well. Therefore, the duration will be determined automatically by using the following formula:

$$D = \frac{Q\ for\ each\ type\ of\ material}{P\ for\ each\ process} \quad (3)$$

Where:

D: Duration of each activity/method; Q: quantity which will be derived automatically from the 3D BIM model; P: Productivity which updated to the proposed library.

Thereafter, the price of materials, equipment, and labour are updated to the library. The criteria to enable GA to work can be selected from the proposed browser as it can be seen from the below figure 5, section 3.

The figure 5, 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 (1-4).

Genetic algorithm population will be the project activities with their corresponding potential methods, the fitness generation will be the method will achieve the minimum Method Value (MV), which represent the initial cost after multiplying it by all different criteria which has been selected previously, see figure 5, section 3. Therefore, the mathematical model should be as follows:

$$Min(MV) = IC \times F(1,2,3, \dots., n) \quad (4)$$

Where:

IC means Initial Cost; F means that factors

Thereafter, the optimal path of activities should be as follows:

$$OPA = Min(MV) for\ Activity\ A + \cdots + Min(MV) for\ Activity\ n \quad (5)$$

Where:

OPA means that Optimal Path of Activities

Integration of data through the developed framework:

The below figure 4 shows the integration of data through the most three critical stages of the IPD project, which are the detailed design stage, documentation and buyout stage. In these three stages, the project information becomes completely shaped. Since IPD approach supports the Risk/Rewards sharing as well as open pricing technique, therefore this enables to determine the project costs fairly as well as exploiting all available resources which offer from all core team members (client, main constructor, trade constructors and architect).Regarding the integration between all tasks which included in this framework, figure 5 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 the optimisation process for the different construction methods. All the mentioned tasks will be implemented in a single platform (Navisworks).

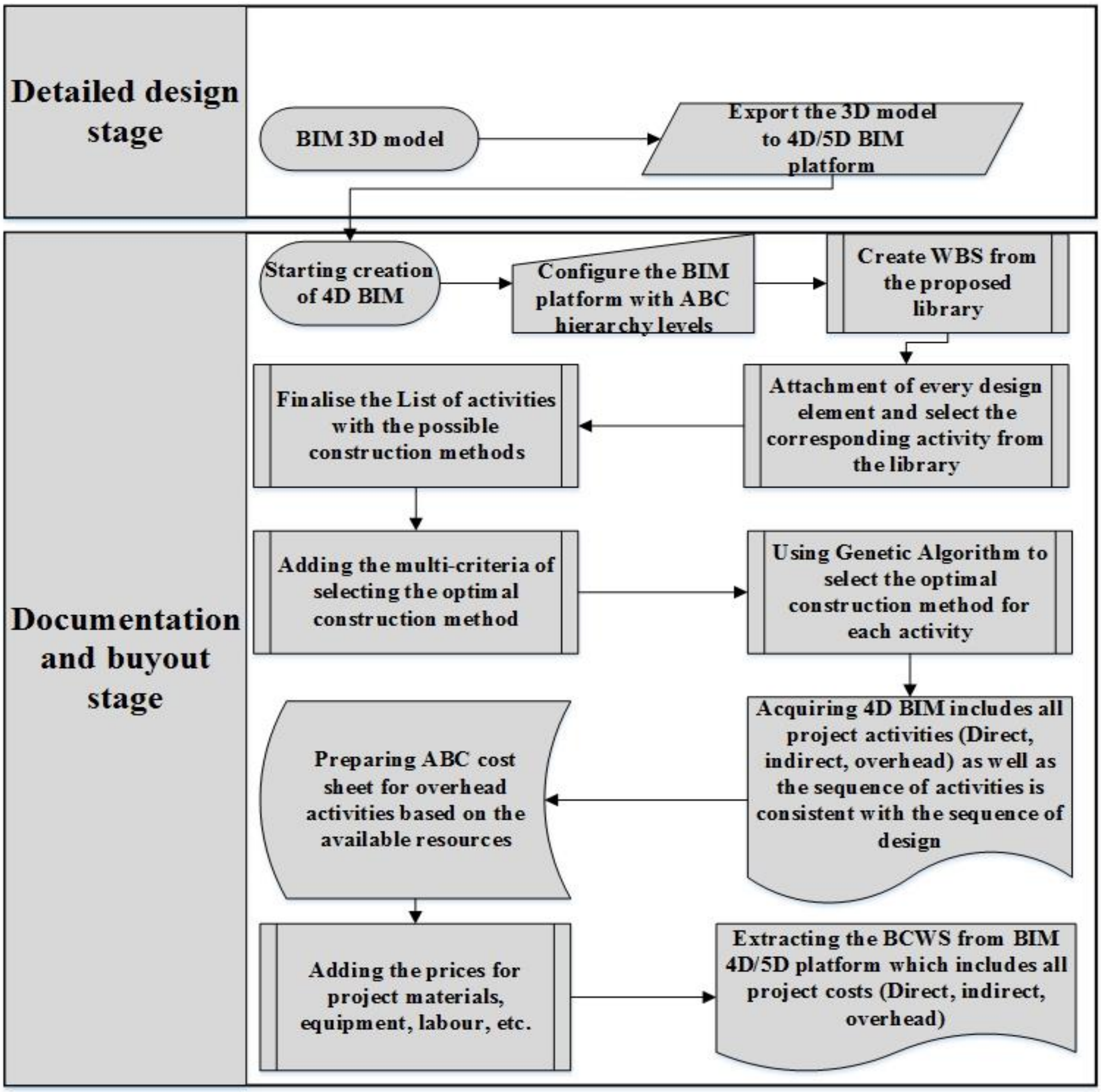

Figure 4. The Integration of data through the developed framework

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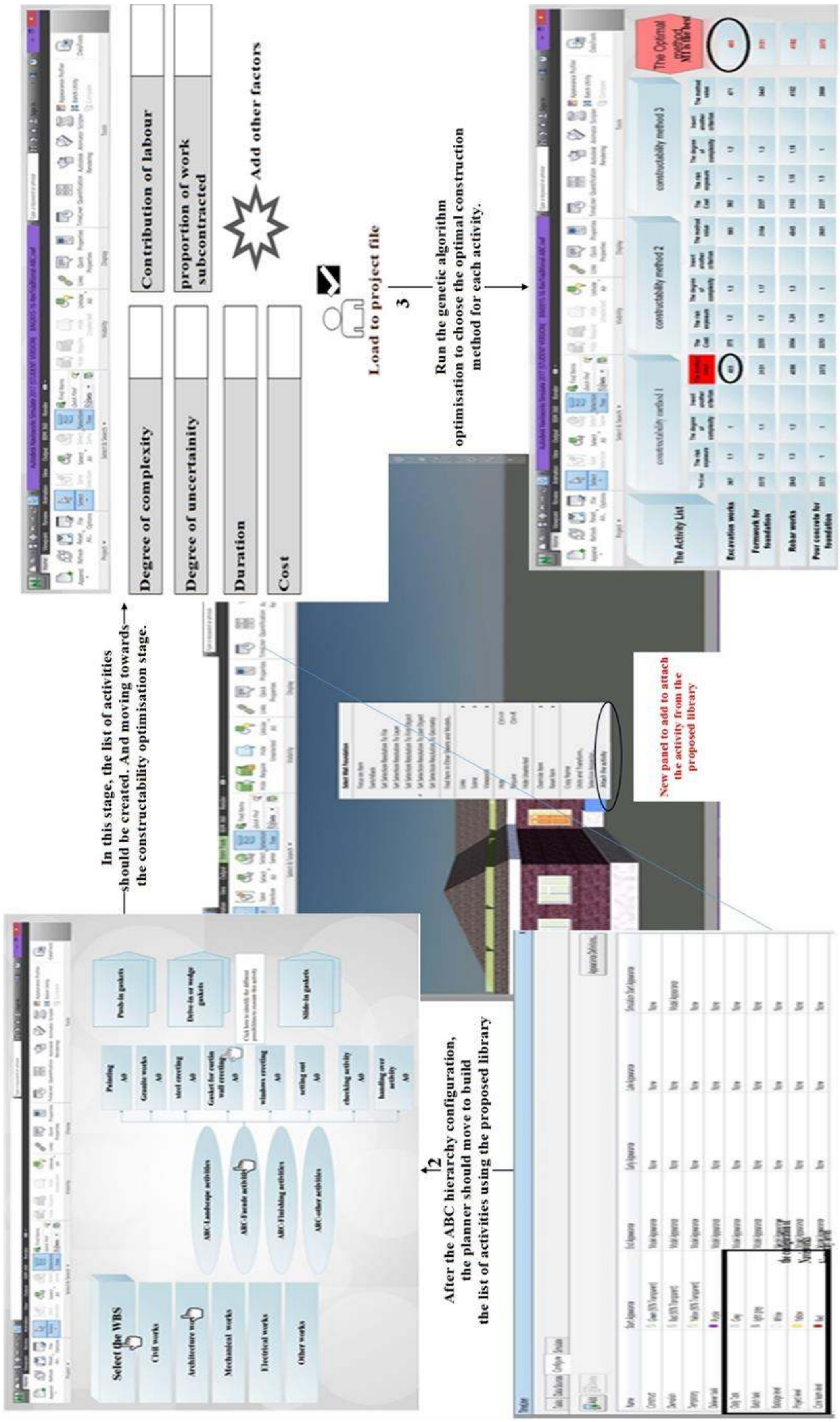

Figure 5. The integration/flow of data within the framework

Results and analysis

The description of the case study

The case study is a small house in order to be able to include and analyse all its data in this paper, the chosen house is a part of a group of 100 identical house which the property development firm (X) has decided to build this compound. The specification of each house is as follows: (1) the gross floor area is about 192 m^2; (2) the house has a single floor; (3) from reviewing the Revit architectural plan, the spaces are a master bedroom with its own facilities of a bathroom and a robing room, three bedrooms, large living room, kitchen, dining room, another bathroom, family room and utility room.

The company chose the IPD to be the delivery approach of this large size project due to its ability to share risk/rewards between all parties which enhance/sustain the relationship between all traditional parties in the project and this was the main objective of implementing this kind of delivery approach. The X Company intends to build a series of compounds based on the same designs and using the same contractors, sub-contractors and architect. Therefore, this case study focuses on one of these identical houses in order to apply the developed framework once the 3D BIM model becomes available. To ensure the sustaining relationship between all parties, the cost estimation must be more accurate and explicit throughout all different stages in the IPD approach.

The configuration of ABC hierarchy level inside Navisworks

As aforementioned in the context of the framework, the main purpose of this configuration is to follow the level of consumption of resources by each participant as well as measuring the contribution of each participant by the duration of appearing their configured colour in the animation video. Figure 6 shows the applied configuration using ABC hierarchy levels into Autodesk Navisworks platform.

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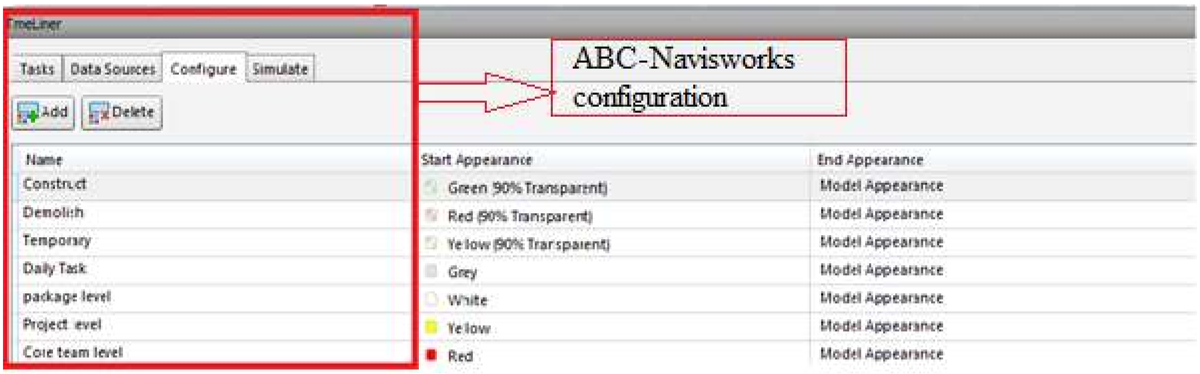

Figure 6. The ABC-hierarchy configuration

Building List of Activities from the proposed library

By referring to figure (5-2) the list of activities can be designed by attaching the corresponding activity to each design element from the model, therefore, figure (7) describes these steps in details.

Active	Name	Planned Start	Planned En	Task Type	Attached
☑	Setting out	12/02/2017	12/02/2017	Temporary	Sets->foundation
☑	Excavation works	13/02/2017	14/02/2017	Temporary	Sets->foundation
☑	Formwork for foundation	15/02/2017	16/02/2017	Temporary	Sets->foundation
☑	Inspection	16/02/2017	16/02/2017	Daily Task	Sets->foundation
☑	Rebar works	17/02/2017	18/02/2017	Demolish	Sets->foundation
☑	Inspection	18/02/2017	18/02/2017	Daily Task	Sets->foundation
☑	Pour of foundation concrete	19/02/2017	19/02/2017	Construct	Sets->foundation
☑	Inspection Foundaton Batch	19/02/2017	19/02/2017	package level	Sets->foundation
☑	Setting out walls	20/02/2017	20/02/2017	Daily Task	Sets->walls
☑	Masonary works	21/02/2017	26/02/2017	Construct	Sets->walls
☑	Inspection	26/02/2017	26/02/2017	package level	Sets->walls
☑	Setting out seperation rooms	27/02/2017	27/02/2017	Construct	Sets->room seperation
☑	Mobilizing material	28/02/2017	28/02/2017	package level	Sets->room seperation
☑	Erect the seperation plates	01/03/2017	01/03/2017	Construct	Sets->room seperation
☑	Inspection	01/03/2017	01/03/2017	Daily Task	Sets->room seperation
☑	Mobilizing roof material	02/03/2017	11/03/2017	package level	Sets->roof
☑	Setting out	03/03/2017	03/03/2017	Daily Task	Sets->roof
☑	Erect the roof	04/03/2017	16/03/2017	Construct	Sets->roof
☑	Inspection roof package	16/03/2017	16/03/2017	package level	Sets->Floors
☑	Setting out floors	17/03/2017	17/03/2017	Daily Task	Sets->Floors
☑	Erect floor	18/03/2017	28/03/2017	Construct	Sets->Floors
☑	Inspection	28/03/2017	28/03/2017	Project level	Sets->Floors
☑	Cost control report for General works	28/03/2017	28/03/2017	Core team level	Sets->Floors
☑	Mobilizing windows and doors	29/03/2017	29/03/2017	package level	Sets->Doors and Windows
☑	Erect doors and windows	30/03/2017	20/04/2017	Construct	Sets->Doors and Windows
☑	Inspection D&W package	20/04/2017	20/04/2017	Project level	Sets->Doors and Windows
☑	Cost control report for D&W works	20/04/2017	20/04/2017	Core team level	Sets->Doors and Windows
☑	Mobilizing ceiling material	29/03/2017	29/03/2017	package level	Sets->Ceiling
☑	Setting out for ceiling	30/03/2017	30/03/2017	Daily Task	Sets->Ceiling
☑	Erect ceiling grids	31/03/2017	05/04/2017	Construct	Sets->Ceiling
☑	Inspect the ceiling grids	05/04/2017	05/04/2017	Daily Task	Sets->Ceiling
☑	Mobilize lighting fixtures	29/03/2017	29/03/2017	package level	Sets->Lighting fixtures
☑	Set up lighting fixtures	30/03/2017	09/04/2017	Construct	Sets->Lighting fixtures
☑	Erect the ceiling plates	10/04/2017	10/04/2017	Construct	Sets->Ceiling
☑	Inspect the ceiling package	10/04/2017	10/04/2017	package level	Sets->Ceiling
☑	Cost control report for ceiling works	10/04/2017	10/04/2017	Core team level	Sets->Ceiling
☑	Inspection the lighting fixture package	10/04/2017	10/04/2017	package level	Sets->Lighting fixtures
☑	Cost control report for lighting and fixture works	10/04/2017	10/04/2017	Core team level	Sets->Lighting fixtures
☑	Mobilizing finishing works	10/04/2017	10/04/2017	package level	Sets->finishing works
☑	Installation the carprt floor	11/04/2017	15/04/2017	Construct	Sets->finishing works
☑	Inspection the carpet floor	15/04/2017	15/04/2017	Daily Task	Sets->finishing works
☑	Implementing the painting works	11/04/2017	13/04/2017	Construct	Sets->finishing works
☑	Inspection the painting works	14/04/2017	14/04/2017	Daily Task	Sets->finishing works
☑	Cost control report for finishing package	16/04/2017	16/04/2017	Core team level	Sets->finishing works
☑	The final cost control repport for whole works	17/04/2017	17/04/2017	Core team level	Sets->the whole project

Figure 7. The List of activates

Figure 7 reveals that all activities have been articulated (Direct, indirect and overhead) activities, additionally, task type column shows that the overhead activities have been categorised as a core team level, batch level, package level, and daily task level. From another side, each type has a distinct colour to be shown during the animation process which will be used in this paper to evaluate the level of contribution to each party.

Optimisation of constructability methods for each activity

As aforementioned, this optimisation process will be carried out automatically by embedding GA into Navisworks as Plug-In, therefore the genetic algorithm model will be articulated based on selecting criteria from the proposed browser (see fig 5-3). After that, the GA model will be created automatically. The below figure (8) shows that the selected criteria in order to proceed with the genetic algorithm optimisation.

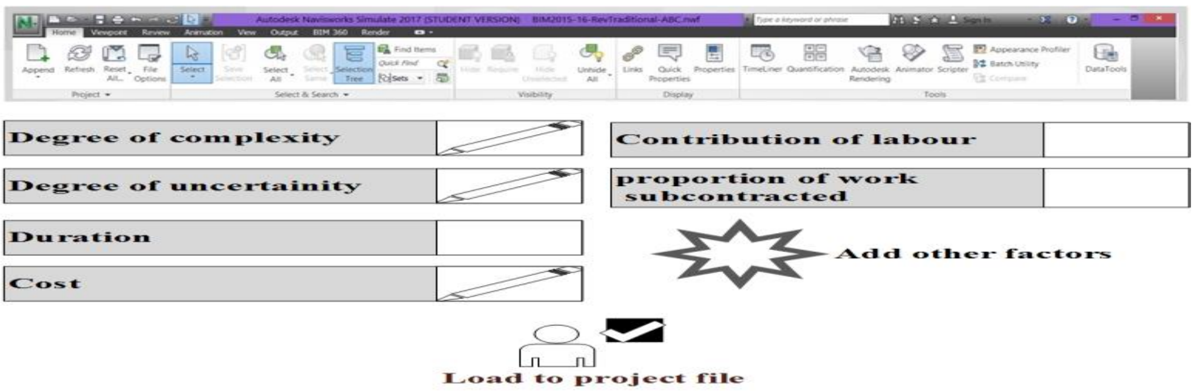

Figure 8. The optimisation criteria browser

Based on the above figure, three criteria have been selected to perform this optimisation (Degree of complexity, Risk, and Cost). Therefore, the Genetic algorithm model should be as follows (refer to equation 4 and 5):

$$Min\ (MV) for\ the\ entire\ project = \sum IC_{ij} \times DC_{ij} \times RF_{ij} \qquad (5)$$

The below figure 9 reveals the results of the optimisation process, therefore the thirteen direct activities have been optimised by reaching to the most fitness three methods based on the designed GA model. The below figure reveals that the optimal method in corresponding with each direct activity, the presented cost represents the labour, equipment to each activity. The total cost of performing direct activities is £32,524. However, the maximum cost to perform these activities is £42,165, therefore the saving cost represents 22.86%, this percentage for a single house is £9,641 and as mentioned in the context of a case study that the compound includes 100 identical houses, therefore the saving cost around £964,100.

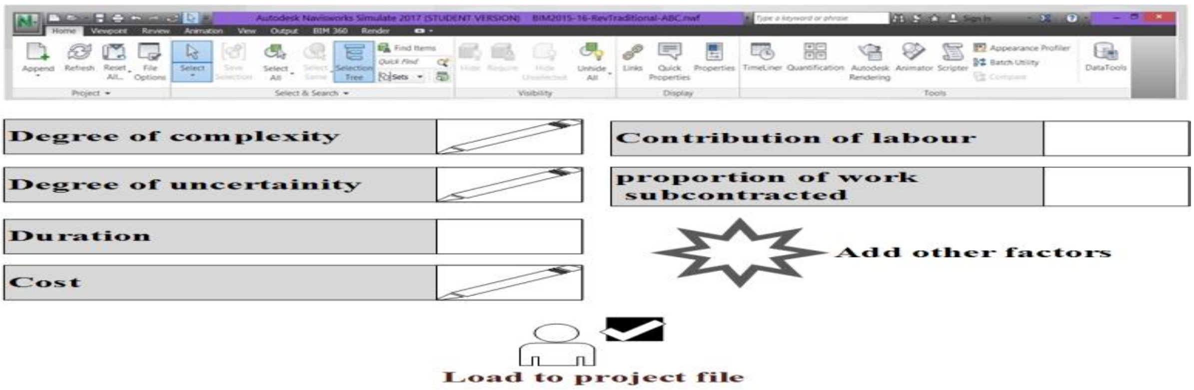

Figure 8. The optimisation criteria browser

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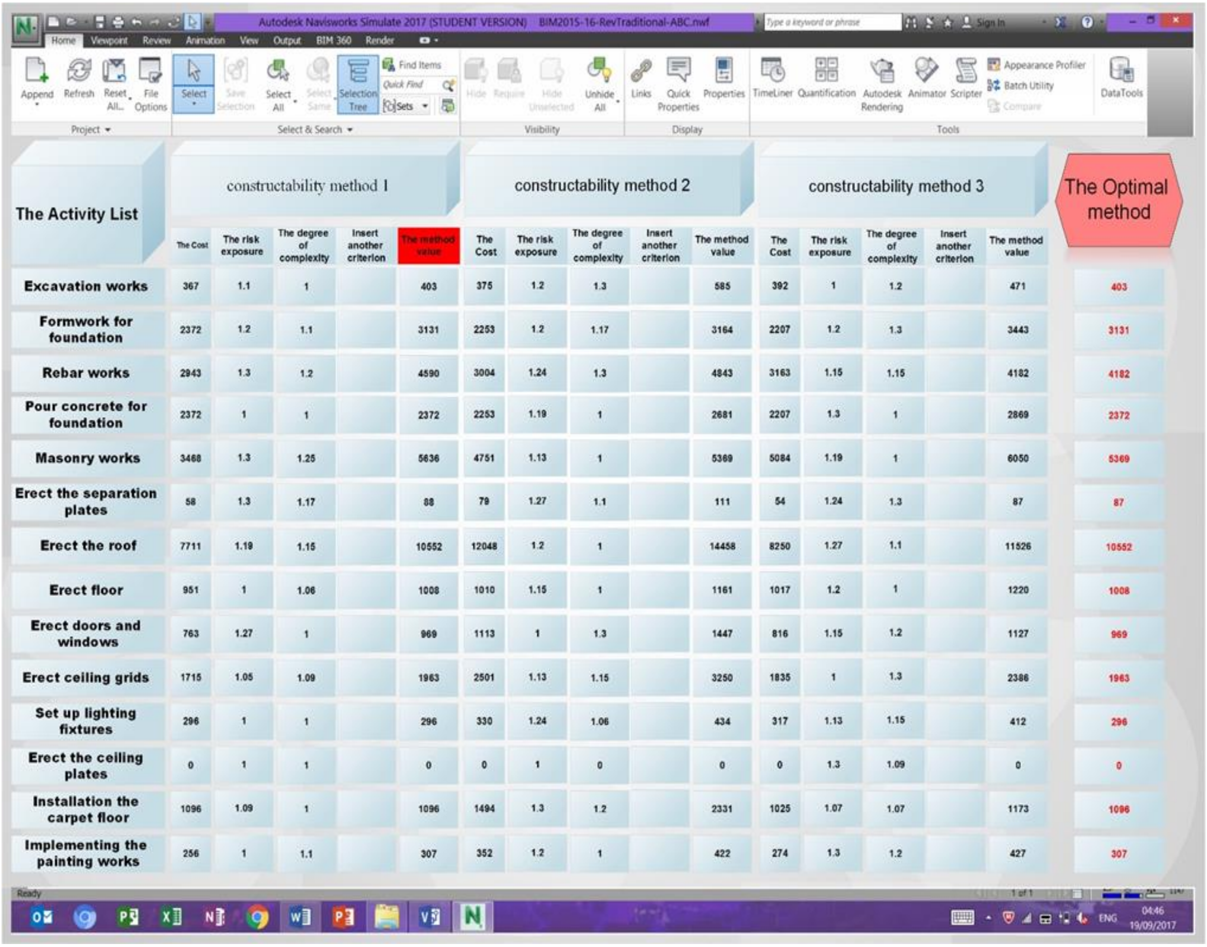

The Activity List	constructability method 1					constructability method 2					constructability method 3					The Optimal method
	The Cost	The risk exposure	The degree of complexity	Insert another criterion	The method value	The Cost	The risk exposure	The degree of complexity	Insert another criterion	The method value	The Cost	The risk exposure	The degree of complexity	Insert another criterion	The method value	
Excavation works	367	1.1	1		403	375	1.2	1.3		585	392	1	1.2		471	403
Formwork for foundation	2372	1.2	1.1		3131	2253	1.2	1.17		3164	2207	1.2	1.3		3443	3131
Rebar works	2943	1.3	1.2		4590	3004	1.24	1.3		4843	3163	1.15	1.15		4182	4182
Pour concrete for foundation	2372	1	1		2372	2253	1.19	1		2681	2207	1.3	1		2869	2372
Masonry works	3468	1.3	1.25		5636	4751	1.13	1		5369	5084	1.19	1		6050	5369
Erect the separation plates	58	1.3	1.17		88	79	1.27	1.1		111	54	1.24	1.3		87	87
Erect the roof	7711	1.19	1.15		10552	12048	1.2	1		14458	8250	1.27	1.1		11526	10552
Erect floor	951	1	1.06		1008	1010	1.15	1		1161	1017	1.2	1		1220	1008
Erect doors and windows	763	1.27	1		969	1113	1	1.3		1447	816	1.15	1.2		1127	969
Erect ceiling grids	1715	1.05	1.09		1963	2501	1.13	1.15		3250	1835	1	1.3		2386	1963
Set up lighting fixtures	296	1	1		296	330	1.24	1.06		434	317	1.13	1.15		412	296
Erect the ceiling plates	0	1	1		0	0	1	0		0	0	1.3	1.09		0	0
Installation the carpet floor	1096	1.09	1		1096	1494	1.3	1.2		2331	1025	1.07	1.07		1173	1096
Implementing the painting works	256	1	1.1		307	352	1.2	1		422	274	1.3	1.2		427	307

Figure 9. Optimisation browser

The level of contribution based on the ABC hierarchy level

After analysing the animation video and applying equation 2. The below table shows the percentage of contribution to each overhead hierarchy level from the core team member to the daily task level.

Table 1: ABC hierarchy contribution

Name	Start appearance	Percentage (%)
Core team member level		20.83
Project Level		8.33
Package level		33.33
Daily task level		37.5

As it can be seen from the below chart (1), daily task level represents the maximum contribution by 37.5%, this reflects the importance of the high level of consumption by the supervisors, site engineers. However, the core team level represents 20.83%, this reflects a high level of contribution of owner, constructor, architect to management of the project, and this also can be proved by checking the level of overhead per for the project level, which is 8.33%, and this is the minimum level of contribution due to the IPD approach reduce the dominant of the project contractor and sub-contractor management. Figure 10 shows all contribution proportions for each level in the IPD organisation.

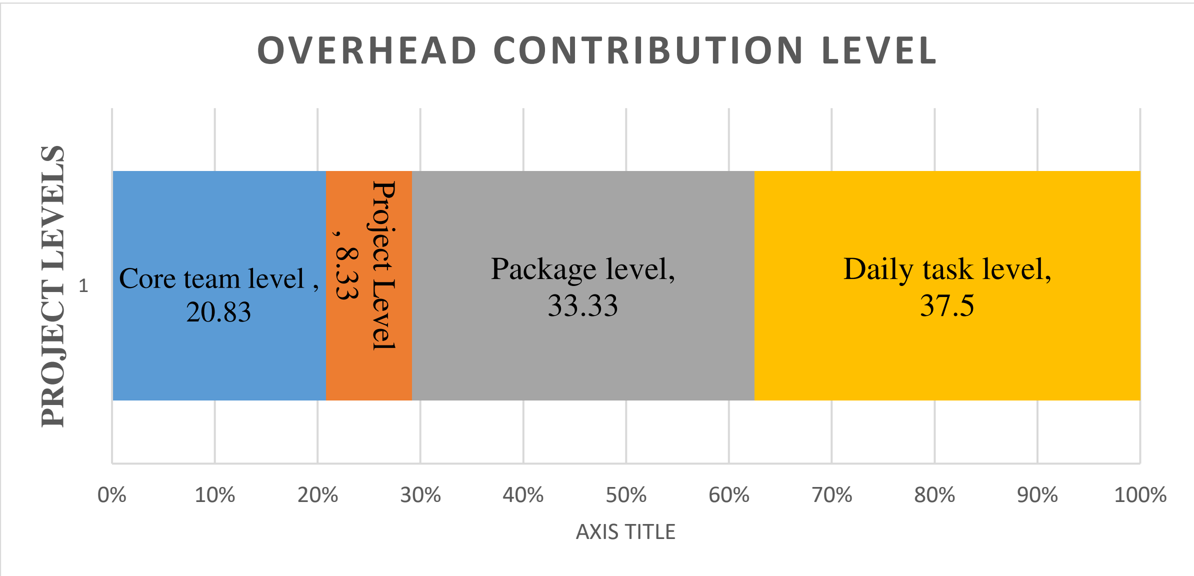

Figure 10. The overhead contribution level between all participants

Research implications

Below points summarise the implications of the developed framework:

1. The framework opens new horizons towards the automation of the project planning and scheduling since a new philosophy is presented to the link between the project design and systematised activities—The activities will be selected from a proposed library.

2. Given, the users target the user-friendly platforms and processes, therefore, the optimisation tasks using the genetic algorithm is proposed to be integrated into the 4D BIM platform to facilitate its implementation.
3. The multi-objective optimisation is usually presented as a sophisticated process that requires highly skilled users, particularly, researchers. However, in this research, the multi-objective optimisation is presented in practical steps that allow any potential users to carry out efficiently.
4. Given that the IPD approach is highly recommended in integration with BIM, therefore, this research presented a tool to maximise the automation that enhances the collaboration and trust among the core team members.
5. The developed framework enhances the integration of the 4D and 5D BIM models since the output of the constructability optimisation is linked with the activities costs.

Conclusion and future directions

This paper introduced a framework to support 4D BIM automation/optimisation within the IPD approach by integrating ABC in order to ensure that all activities will be considered, especially overhead activities. Adopting a new direction to exploit the simulation feature of 4D BIM by enabling analyse the level of contribution of each party in the IPD approach which facilitates fair sharing of risk/rewards. Indeed, minimising the dominant/traditional role of the contractor to manage the project in a separate environment and this has been proven by the case study which revealed that the percentage of core team contribution is 20.83%, meanwhile, the project contribution level is 8.33%. Regarding the multi-objective optimisation, this study adopts using a genetic algorithm in order to search for the optimal constructability method to perform each activity, the presented innovative method relies on enabling build the optimisation model automatically through the developed prototype by using Navisworks to link all proposed process in a single/dynamic platform. The proposed "proof of concept" prototype includes browsers to enable formulating the genetic algorithm model automatically by just selecting the potential selecting criteria as well as enabling creating new criterion and configure it.

Regarding the automation in creating the list of activity, this research has changed the philosophy of creating it whether manually or by importing it. Since the automation required libraries such as structural, architectural, etc. therefore, this research proposed a library for planning/scheduling which includes all needed activities in AEC industry as well as loaded each activity by all possible methods to execute it. By linking the proposed library and 3D model, the criteria for each method will be determined directly. Subsequently, it will be ready to be exploited in the multi-objective optimisation process.

Even though, this model deals with the entire planning/scheduling process, however, there are further sections will be added in order to link between 4D and 5D BIM to support the optimisation stage to conclude the real prices of all used resources. Moreover, this research is a part of a project to build an integrated cost management system within the IPD approach, therefore, further researches are in progress to enable the proposed model to generate an optimised cash flow which considers the availability of resources and showing the allocation of all resources in 4D BIM to check the space/area management factor.

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