INTEGRATED PROJECT DELIVERY WITH BIM: AN AUTOMATED EVM-BASED APPROACH

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ABSTRACT

The Integrated Project Delivery (IPD) in integration with Building Information Modelling/Management (BIM) is an optimal approach for delivering construction projects. This is, however fraught with complications, due to the inability of current cost management practices to determine fair risk/reward ratio in IPD arrangements. Previous research has established the advantages of Earned Value Management-based (EVM) method for risk/reward sharing, as well as, how Activity Based Costing (ABC) method can facilitate automating the sharing process. This study proposes an innovative approach to exploit the capabilities of these techniques coupled with BIM in automating/optimising the process of IPD risk/reward sharing. This includes providing mathematical equations for risk/reward sharing and developing a model that strengthens IPD parties' relationships. The process is enhanced through developing an EVM-Web grid that enables the participants to easily track their costs on computers and mobile devices. To demonstrate the applicability and validity of the proposed model, it is applied on a real-life case and displays promising results in terms of flexibility in allocating risk/reward for varying scenarios.

Keywords: Building Information Modelling; BIM-IPD; 5D; IPD cost; Construction procurement.

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1. INTRODUCTION

Traditional project delivery systems have proven inefficient in improving overall performance [48]. In response to this, Integrated Project Delivery (IPD) has been proposed and used in projects across the construction industry [85]. IPD provides a new contractual, behavioural and organisational context for delivering construction projects, through enhancing integrated and collaborative practices [62]. It is an innovative project delivery method, characterised by early, collaborative, and collective engagement of key stakeholders across all phases of delivering a project [3,4].

Evidence, however, shows that the percentage of real-life projects using IPD is small [25,61], mainly due to the negative influence of barriers that hinder widespread use of IPD [23,73,75]. Successful delivery of a project through IPD is not easy, and IPD requires fulfilling a wide range of requirements and establishing various support systems [21]. Failure in establishing these support systems creates barriers. Examples are flawed IPD compensation model, resistance to information sharing, ineffective decision-making regimes, and disagreement on liability waivers among stakeholders [32,72]. Of these, the IPD compensation model, also called risk/reward compensation, is of cardinal importance [46]. It is described as a key principle of IPD [83], that plays a pivotal role in stimulating creativity, motivating collaboration, and sustaining performance [42,85]. Lack of a proper IPD compensation model is seen as a formidable barrier to the use of IPD on construction projects [84].

The risk and reward must be shared and allocated to all participants in core project teams, necessitating joint project control [10,21]. For designing the risk and reward model (hereafter referred to as the compensation approach), economic models provide a sound foundation based on the cost of projects [4,84]. The compensation approach typically depends on achievements throughout the project, as well as two cost lines; target cost that defines the cost baseline, and agreed percentage for profit-at-risk [32]. If a project achieves below its target cost, it means the cost saving percentage should be shared between key participants, and when a project performance indicates the level of achievement is located between the two lines, it implies that the surplus should be shared as well. Finally, if the performance indicates this level exceeds the profit-at-risk line, the client is solely required to pay the direct costs [4,10].

As such, the cost management system under IPD must be one of dynamically integrated, and capable of avoiding any waste of cost information throughout all project stages [46,85]. The cost structure applied for IPD must ensure that there is no hidden profit in the estimated cost [7], and achieve the purpose of fostering trust among project parties [4,46,62-64,75]. Any inaccuracy in data handling and usage – influencing determining the individual trade package – will affect the value of the proportions of profit-at-risk percentage of each member in IPD team. All members must be continuously involved and attend all meetings, even when their tasks are completed [70]. As such, using web-based platforms is important to effectively share the needed information among parties, regardless of their geographical locations and disparity.

With the above in mind, IPD as a delivery method, is largely promoted for its potential in integration with Building Information Modelling/Management (BIM) on construction projects [21]. Coupling BIM with IPD is proven to improve efficiency, reduce errors, enable exploring alternative approaches, as well as expanding market opportunities on projects [32]. In fact, "the full potential benefits of IPD and BIM are achieved only when they are used together" [8]. Therefore, control of construction on IPD projects can rely on data-rich BIM models, with a focus on exploiting BIM in integrating information flows [45,77]. Such combined use of IPD and BIM makes sense from a theoretical perspective, but in reality, it faces substantial roadblocks [28].

To date, however, BIM-based project control activities have largely relied on automated site data collection tools that use various methods, like spatial sensing technologies, linking between 3D BIM model and performed works, etc. [29,31]. Despite the undeniable advantages, these methods almost entirely measure physical items and components on construction sites, overlooking the value of activities [77,78]. There are also problems with sharing of acquired control information across the entire project, given that project team members are still dominated by silo thinking [49,50], and information systems loosely coupled [29,71]. An automated process that integrates information of physical components with managerial attributes (such as allocated resources and values), to facilitate controlling cost-time integrated progress can, therefore, provide a solution [38,63].

Such automated cost structure must be capable of differentiating overhead costs from profit, ensuring that no profit items remain hidden in overhead costs and labour rates [7,75]. Besides, all parties in IPD are equally held responsible for the entire project performance [4,7], and as such, the automated cost structure must provide a financial tracking system that: (1) aggregates all cost data, (2) presents data in a clear format, (3) is readily accessible by all parties, (4) shows saved costs, and by whom [7].

With the above in mind, the present study aims to provide a solution to enhance the cost structure of compensation mechanism, develop an automated cost structure for risk/reward sharing, and enhance collaborative interactions among project participants through introducing a web-based platform for instant sharing of risk/reward mechanism outcomes. Sharing risk/rewards rely upon completing all project activities [70]. And there exist several issues with managing the financial data: keeping all parties informed of all achieved profit/risks data during the entire construction stages, and displaying the financial metrics in a readable/understandable manner – to make sure all core team members can understand [7]. Therefore, using methods to share the real-time data is increasingly needed, for which embedding information technology in the form of web-based applications has received priority [3,46]. Moreover, face-to-face collaborations for IPD arrangements are considered expensive, disruptive and inefficient [57]. Consequently, the work is more often executed by geographically dispersed, digitally mediated teams of knowledge specialists, coming from various firms, yet organised into an IPD team [49,50]. The above facts reinforce the urgency of using web-based platforms.

To this end, the paper outlines the design of an automated model of the cost control system of IPD projects. The capabilities of Earned Value Management (EVM) in effectively tracking, analysing, and controlling project costs make it a recommended tool for cost management on projects [65]. Besides, EVM can provide performance metrics for both cost and schedule alike in an integrated pool [17]. The model, therefore, is designed to draw upon EVM. Moreover, the proposed risk/rewards system is supported by a web grid to enable visualising the project status, for the reason that the IPD core team members come from different backgrounds/disciplines. Therefore, the EVM-web grid will enable synchronous/asynchronous collaboration as well as helping members to understand the project situation graphically.

In accordance with the introductory information provided above, in section 2, the theoretical background on the key concepts discussed in the paper are introduced, culminating in establishing the research gap in section 3. Research methods, approach and requirements are described in section 4, and developing the framework is presented in section 5, followed by results and analysis that are presented in section 6. The paper concludes by describing the broad ideas presented by the study, limitations, and eventually futures research, areas offered in view of the findings of the study in section 7 and 8.

2. THEORETICAL BACKGROUND

The theoretical background is divided into several sections, each section covering one major area associated with the aims and objectives of the study, a description of each follows.

2.1. BIM and cost management

In moving towards efficient project delivery, the ultimate goal is having a database of information that is available to all project participants, with confidence in its accuracy, universal utility, and clarity [11,57]. The main drive for adopting BIM, is managing all project documents and stages (i.e. design, planning, and costing) in a single/dynamic context, to secure the proper exploitation of available information [1,49,67]. BIM design elements must contain the required information in various natures, including design or management [13], to acquire smartly-designed elements, rather than traditional 3D components [22,60]. BIM users should be capable of acquiring all the required information from a single BIM elements, to make informed decisions [2,53,71]. Four-dimensional modelling (4D BIM) can embed progress data in 3D model objects by adjusting the task-object relationship [24]. Application of 4D BIM leads to easily operate workflows, efficient on-site management, and assessing constructability [26]. As for the cost management, BIM is one of the most efficient Architectural, Engineering, and Construction (AEC) tools in increasing productivity on construction projects [6,39,79]. Colloquially termed as 5D BIM [6], this capability of BIM offers the preferred technique for extracting quantities from 3D models, allowing cost consultants to incorporate productivity allowances and pricing values [19,39]. The cost estimating process starts with exporting data from 3D models to BIM-based cost estimating software (e.g. CostX®) to prepare quantity take-off. Afterwards, the Bills of Quantities (BoQ) are generated and exported to an external database [6]. Prices and productivity allowances can also be added to project schedule preparation [19,39]. Such automated quantification will shorten the quantity take-off processing time, and will automatically consider any changes in design – which is likely in fast-track projects [66,79].

2.2. IPD-based cost estimation

IPD is a project delivery system for delivering value, where value might include considerations other than pure cost [64]. That said, even where the value has qualitative dimensions, the projection and tracking of costs will be critical to IPD success [9,44]. Cost estimation hence has a vital role in applying IPD [4,84], and therefore, must be tracked through a scrutinising method by core team members to determine their profit, and shared benefits/risks, according to the deviation between the actual and target costs [4,85]. The compensation approach structure must be capable of drawing upon effective methods, to determine cost overrun proportions, cost underrun, and any saving in total budget under the agreed cost [76]. That is because, risk/reward proportion rely on the degree of achievement during the entire project stages [44]. The compensation approach has two limits (as shown in Figure 1); firstly, the direct, indirect, and overhead costs, which can be nominated as agreed cost, and secondly the profit-at-risk percentage after estimating the agreed cost [4,85].

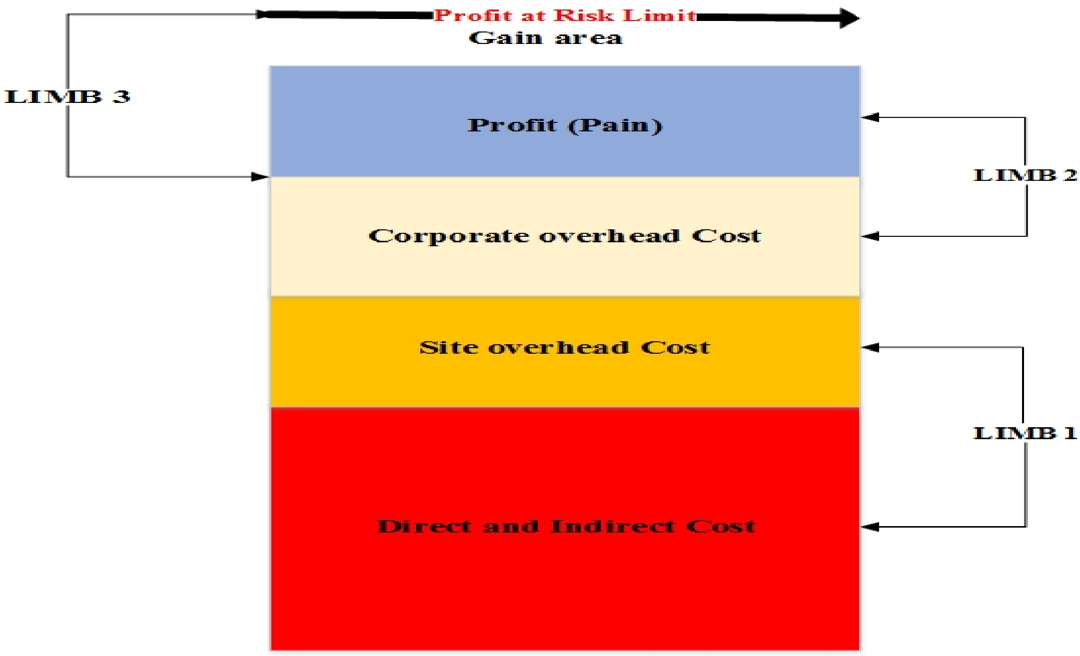

Figure 1. Compensation approach structure, adapted from Zhang and Li [85]

The precise determination of risk perception is critical to ensure the agreed compensation structure will be implemented correctly throughout the project, so that, the risk/reward ratio can be fairly allocated among project participants. Therefore, the participant who carries more uncertain works can be compensated with higher profit-at-risk percentage [16]. Alliancing agreements, however can reduce risk impacts through sharing information, given that the success in dealing with risks depends on data availability [18].

As illustrated in Figure 1, IPD limbs can be classified into three limbs; Limb-1 representing the reimbursement of project costs, Limb-2 indicates the overhead costs for all participants, and Limb-3 is the profit-at-risk ratio. Limb-3, that is represented through risk/reward sharing model, must be specified at the beginning of the project [68]. According to Ross [68], risk/reward ratio is measured by the Overall Performance Score (OPS), which is a scale between 0 and 100, where 0 to 50 represents the pain scope, and 50 to 100 represent the gain range (see Figure 2). After computing the risk/reward ration using OPS, the project participants should share this ratio in correspondence with the contract.

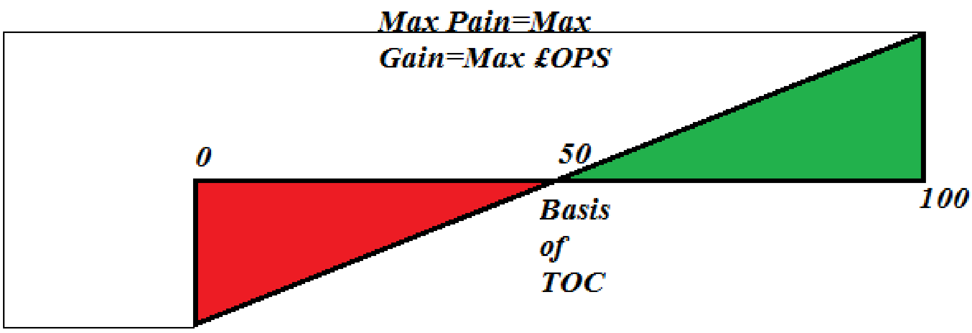

Figure 2. OPS ranges for Risk/Reward ratio, adapted from Ross [68]

2.3. Earned value management

Earned value management (EVM) is a quantitative project management technique for measuring project progress, and to provide project participants with early warnings where the project is running 'over the budget' or 'behind the schedule' [59,65]. Khamooshi and Abdi [33]provided evidence of EVM being successfully applied on several real-life projects to deliver accurate cost/schedule metrics. According to Naeni, et al. [54] "earned value technique is a crucial technique in analysing and controlling the performance of a project". EVM, as recommend by PMI [65], is an effective tool for supplying cost and schedule indicators, to measure performance through Cost Performance Ratio (CPR) and Schedule Performance Ratio (SPR) values, according to Equation 1 and Equation 2.

$$\mathrm{CPR} = \frac{\mathrm{ACWP}}{\mathrm{BCWP}} \quad (1)$$

$$\mathrm{SPR} = \frac{\mathrm{BCWS}}{\mathrm{BCWP}}$$

(2)

Where ACWP represents the actual cost of work performed, BCWP represents the budgeted cost of work performed, and BCWS represents the budgeted cost of work scheduled. The achievement values are determined in accordance with the following parameters; (1) CPI < 1 indicates that the cost performance is poor, CPI = 1 indicates that the cost performance is efficient, and CPI > 1 indicates that the cost performance is excellent. Using EVM, achievements can be measured as variance not performance, such as Cost Variance (CV) and Schedule Variance (SV), as highlighted in Equations 3 and 4. In that case, a CV<0 indicates a project over budget, a CV=0 indicates a project on budget, and a CV>0 indicates a project under budget [59].

$$\mathrm{CV} = \mathrm{BCWP} - \mathrm{ACWP} \tag{3}$$

$$\mathrm{SV} = \mathrm{BCEP} - \mathrm{BCWS} \tag{4}$$

The granularity between project scheduling, represented through WBS, and the actual way, represented through the expenditures, is a problem in accurate implementation of EVM [59]. The EVM system, therefore, needs to be smarter, provided with advanced capabilities, to enable a correlation between data from multiple sources, and also, automatically generating the cost control report [41]. The interoperability issue among various data sources, to build federated project cost control sheets, is best resolved through using advanced technologies and visualisation techniques [15].

2.4.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 [8,50]. There are several traditional cost accountant methods; Resource Based Costing (RBC) that relies on resources' cost, and Volume Based Allocation (VBA) that is based on allocating the cost of resources directly to the objects, regardless of the cost structure – direct, indirect, and overhead costs [27]. Cost distortion, however occurs in using these traditional methods, due to conflating all indirect costs into one, which distorts the pricing of company products [51]. Activity Based Costing (ABC) is a solution to such distortion, through allocating costs of multi-pools, and determining the overhead activities and the associated costs needed to transform the resources into activities that can deliver the final product [34,37].

2.5. BIM 4D/5D automation

Integrating BIM into daily construction activities will facilitate automatic updating of all site information, and as such, can result in enhancing productivity and strengthening relationships amongst stakeholders, and increasing trust in site-collected data [56]. As such, El-Omari and Moselhi [20] asserted that using unsystematic procedures in collecting site data can lead to a huge loss of information with unreliable results. BIM 4D automation will enhance the quality of collected data and reduce the human interference in the data collection process [24,26]. Similarly, 5D BIM provides an effective methodology for cost data collection and analysis of construction projects [6,39,66,79]. Furthermore, Lee, et al. [39] recommended that BIM cost systems should participate in decision making, rather than merely generating BoQ.

Automated data collection methods have intensively improved, through various kinds of technology like bar coding, radio frequency identification, 3D laser scanning, photogrammetry, multimedia, and pen-based computers [20,77,78]. Eastman, et al. [19], on the other hand, argues that there is no comprehensive BIM-based cost management platform that can perform all cost-related processes, namely; estimation, budgeting, and control. Collected data hence remains not ideally exploited across the construction industry, and research studies are shifting to explore the means towards analyse data in efficient ways [29,79].

3. RESEARCH GAP

A review of the literature shows several trends of research on the topic. Of these, a major part of the research has been allocated to exploring the potential of available tools and techniques (i.e. EVM and ABC within IPD) [28,29]. These studies, for the most part, stop at providing an outline of how these methods and techniques add value to the risk/reward sharing mechanism in IPD [30,63,64].

BIM in integration with IPD practices are also discussed in several research studies [7,9,21,30,55,69]. The challenges of such integrations are explored in another stream of studies [28,70,81]. Technological difficulties, including technical problems of linking BIM with IPD and immature web-based platforms to smooth data exchange are found to be well-known barriers to IPD use [47]. No workable methodology is however provided to demonstrate the interrelationship among BIM tools/dimensions and IPD stages in practical terms [70,81]. The issues with BIM interoperability, and lack of support systems to facilitate BIM use, remain formidable barriers [5,74]. This makes providing web-based solutions, acting as the links between BIM and IPD support systems, relevant [3,7]. There exist, however, no such IT systems for IPD users. As discussed, a preferable system must be capable of sharing risk and rewards data periodically on a web-based platform [58]. Particularly, utilising such a web-based system in cost management, based on the EVM method, is recommended and justified [14,40]. A review run on previous studies on this topic, reveals a gap, as discussed below.

Some researchers have directly attempted to provide effective IPD compensation structures and frameworks. As an example, Zhang and Li [85] developed a risk/reward compensation mechanism by combining risk perception and Nash Bargaining Solution (NBS) techniques. However, this model does not consider the method of sharing actual risk/reward amongst participants, and overlooked the impact of IPD compensation structure in successful profit/cost saving sharing. Liu and Bates [43] also articulated a probabilistic contingency calculation model to predict proper contingency to minimise cost overrun, nevertheless, a mechanism to share pain/gain percentages remain unexplored.

With the above in mind, the review of the literature on previous studies reveals that there is much potential for integrating BIM, ABC and EVM into IPD cost structure practices. A workable and theoretically-based solution that presents such integration is still missing [7,12]. This gap supports the necessity of conducting the present study.

4. METHODS

4.1. Research approach

This research aims to propose a practical and feasible solution to the problems with current practices, in the form of a workable procedure. Therefore, this research endeavours to examine the applicability and validity of assumptions, derived from the literature (qualitative evidence) within a real-life setting, as illustrated in Figure 3. An amalgamation of *exploratory case study* and *experiment* is deemed a suitable method for accomplishing such an objective, following the arguments by Banihashemi, et al. [13]. That is, the real-life context is an essential part of case study research, where too many variables affect the outcome and put inferences about causes and effects complicated [80]. As a result, assessing the impacts of any proposed workflow in a real-life case would be affected by many factors, and mediated through various procedures, consequently, running a case study and applying observational techniques can offer reliable outcomes for research purposes [82]. Experiments are particularly effective in revealing whether the real data can support or refute any proposed procedure, as according to Zellmer-Bruhn, et al. [82]experiments can demonstrate the match, if any, between data and a proposed theory.

4.2. Requirements and techniques

The study commences with a critical review of IPD-based cost management practices to identify the gaps associated with: sharing risk and rewards techniques among project parties; needed technology to display cost data (profits, risks and cost-saving); the interrelationship between BIM and IPD. This study relies on integrating several methods and processes like EVM, ABC, and BIM in order to develop a framework to enhance the cost structure of IPD, as well as, the mechanism of determining risk and rewards values for project parties. The exploratory case study and experiment are afterwards conducted to check the validity, namely, practicality of the developed mathematical models for different scenarios of project costs, and showcasing how the movement of data must be handled through BIM, IPD and the proposed EVM-web system.

Figure 3 shows the logic of the research in terms of developing a framework in response to the identified deficiencies with the available practices, as well as, the validation process.

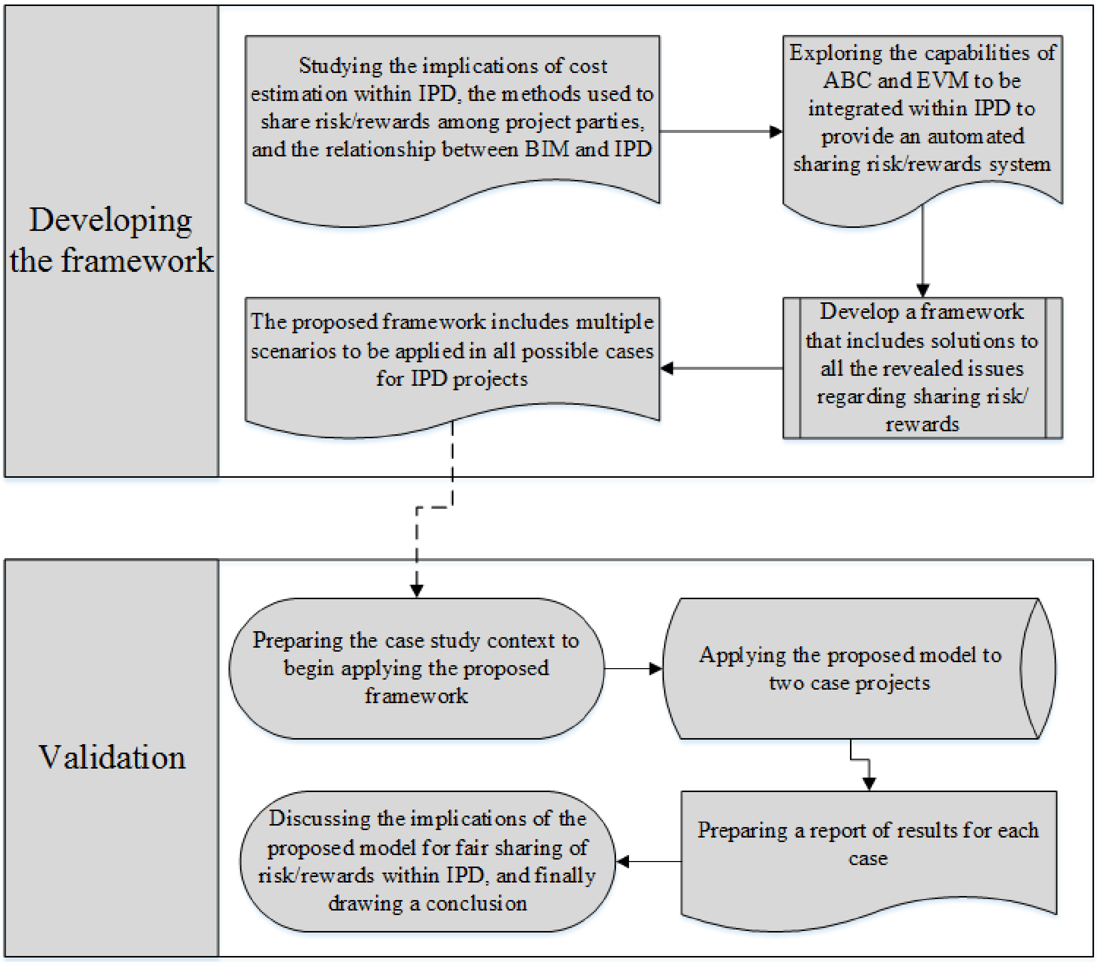

Figure 3. Research methodology

5. Developing the framework

The proposed framework relies on estimating the costs within the IPD approach, based on ABC, given the proven capability of ABC in assigning different costs—direct, indirect, and overhead. Moreover, the cost estimator will be able to distinguish between direct cost of activities and others, through cost controlling tasks, which is vital to ensure an appropriate IPD application. EVM is also used to measure project progress. Therefore, this framework will adopt EVM in integration with IPD approach, using an ABC-based estimation method (see Figure 3).

The compensation structure in IPD depends on distinguishing direct and overhead cost such that owners and non-owner parties can manage their activities in accordance with achievements in each Limb (as illustrated in Figure 4). Hence, the proposed framework involves an innovative risk/reward sharing method through integrating the ABC estimation method into EVM controlling technique. Figure 4 demonstrates the compensation structure formulation of the proposed framework. The direct and indirect costs are determined as a summation of costs of direct activities, and similarly, the overhead costs are estimated as a summation of costs of overheard activities for each trade package, all from the ABC estimation sheet. The reason behind using ABC for articulating the compensation approach is its capability to measure the degree of savings for each participant, which accordingly leads to effective and precise computation of the risk/reward sharing ratio. Furthermore, the cost saving share for owner differs from the non-owner participants given the difference between the cost overhead saving in the organisation sustaining level and project level. Thus, the goal of determining the participants sharing risk/reward ratio using this approach is to ensure equitable and a more applicable approach.

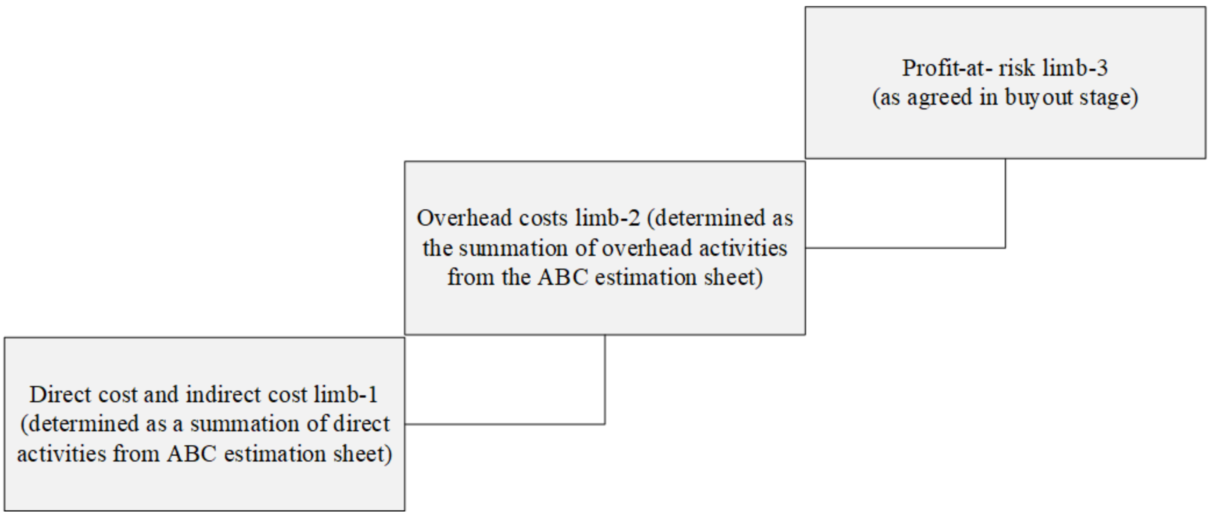

Figure 4 Compensation under the IPD approach using ABC estimation

The EVM-grid output is used to measure the project progress (since it represents the cost and schedule progress in a single index). The proposed framework will integrate EVM and ABC, to articulate three models in dealing with all possible scenarios (see Figure 3). Moreover, the cost savings' sharing will adopt a different scheme to distinguish between the overhead costs for each participant, through analysing the overhead cost levels, as illustrated in Figure 5.

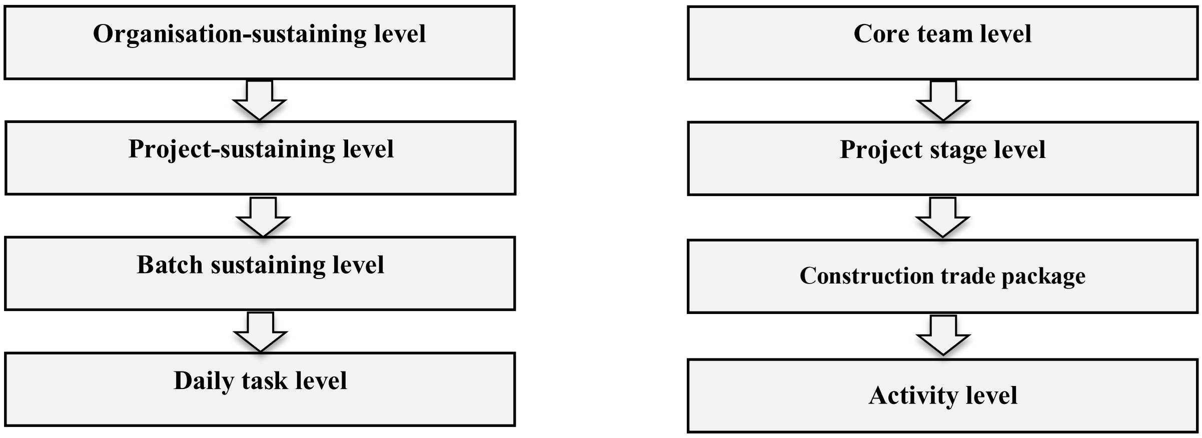

Figure 5 ABC functional level: comparison between the traditional delivery approach (left) and the IPD approach (right)

5.1. Framework implementation process

After determining the BCWS, ACWP, and BCWP for controlling milestones, quantity surveyors determine the values of CPR and SPR, and enter these values into the grid, as positive or negative percentages, to determine the project situation. The EVM-grid divides the project into four areas, where each area represents the project situation and is distinguished by a specific colour. Through allocating potential project cases on the grid, whilst considering X-axis as the schedule and the Y-axis as the cost, each area is then divided into small squares around the planned point. The user should determine the value of the CPR and SPR and enter them into the grid as positive or negative percentage to determine the project situation at each milestone or for each package. Furthermore, the quantity surveyor should mark the square in accordance with CPR and

SPR percentages, to determine the cumulative progress throughout the project execution stages. Thereafter, the ‘Profit-at-Risk’ percentage will be shared in accordance with the output of the developed EVM-Based IPD grid. For instance, if the output is 63%, it means that a project is running over the cost and behind the schedule. Thus, the profit-at-risk percentage is used to determine if the project is still within Limb-2 or exceeds it. To determine the overall project situation as well as the limb location, the function illustrated in Figure 6 is used.

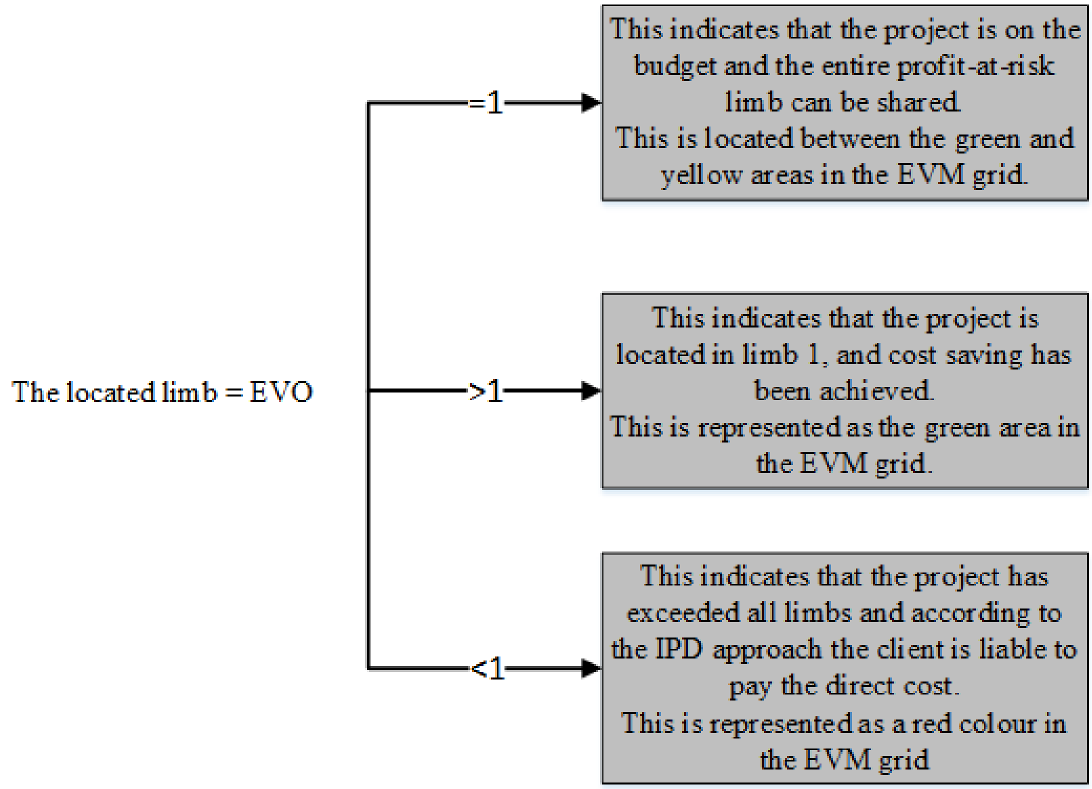

Figure 6. Function to assess the overall project situation and the limb location

Hence, the proportion for each participant is determined based on the limb location. After determining the project progress in accordance with the IPD compensation approach, the appropriate model will be applied to share the risk/reward between the core team members, as tabulated in Table 1, where EVO represents the EVM grid output.

Table 1. Cases summary and required models

No of cases	Case	EVM output values	Equation(s)
1	On cost/schedule	EVO =1	Equations 5 and 6 (Case 1)
2	Ahead of schedule and/or cost underrun	EVO >1	Equations 7 and 8 (Case 2)
3	Behind schedule and/or cost overrun	EVO<1	Equations 9 and 10 (Case 3)

5.1.1. Case 1

The first case occurs when a project is progressing on the schedule and within the budget. Equations 5 and 6 should be used to determine the risk/reward sharing among the project participants.

$$\text{Rewards value} = \big((\text{EVO}) \times \text{P@R Per}\big) \times \text{MVoLIMB2} \tag{5}$$

$$\text{MV for R or RD for each party} = \text{Rewards value} \times \text{PoO or PoNO} \tag{6}$$

Where: P or G Per represents the risk/reward (Pain/Gain) percentage of all project participants (%); P@R Per represents the profit@Risk percentage (%); MVoLIMB2 represents the monetary value of LIMB-2 (summation of LIMB-1 and overhead costs) (£); MV for R/RD for each party represents the monetary value for Risk or Rewards for each participant (£); and PoO/PoNO represents the proportion of owner or non-owner party (%).

5.1.2. Case 2

The second case is the case when the project is progressing ahead of the schedule and below the budget. Equations 7 and 8 should be used to determine the cost savings' sharing among the project participants.

$$\text{CSoOC for NO} = \sum \text{CSoOOA from ABC estimation sheet} + \sum \text{CSoOPA from ABC estimation sheet} + \text{NOARP} \quad (7)$$

$$\text{CSoOC for O} = \sum \text{CSoOPA from ABC estimation sheet} \times \text{OARP} \quad (8)$$

Where; CSoOC for NO represents the overhead cost saving for non-owner participants (£); CSoOOA from ABC estimation sheet represents the overhead organisation activities costs' saving from the ABC estimation sheet (£); CSoOPA from ABC estimation sheet represents the overhead project activities costs' saving from the ABC estimation sheet (£); NOARP represents the Non-Owner Agreed Rewards Proportion (%); CSoOC for O represents the overhead cost saving of for owner participants (£); and OARP represents the owner agreed rewards proportion (%).

5.1.3. Case 3

The third is the case of the projects progressing behind the schedule and over the budget. It implies that a project is in the crisis area (red zone). In that case, the owner will be liable to pay the direct costs only to the non-owner (i.e. constructor and trade contractors), as shown in Equation 9. In case the P@R< EVO<1, the project progress is at risk/crisis area. However, the profit-at-risk percentage will cover the determined deviation.

$$\text{DC} = \sum \text{DAC from ABC estimation sheets} \quad (9)$$

In case the deviation is less than the profit-at-risk percentage, there will be a remaining rewards value which can be determined as Equation 10.

$$\text{Rewards value} = \left((\text{OoEVMG} - 1) + \text{P@R Per}\right) \times \text{MVoP@Rper} \tag{10}$$

Where: DC represents the direct cost (£); DAC from ABC estimation sheets represents the direct activities' costs from the ABC sheet as BCWS (£); RV represents the Rewards Value (£); MVoP@Rper represents the monetary value of Profit@Risk percentage (£).

Figure 7 displays an example of the EVM-IPD grid, while considering a range of positive and negative CPR and SPR values, which depend on the project's degree of complexity and other factors including potential risks and mitigation plans. ON implies that the project is on the schedule and budget; OC implies that the project is on the budget; OS implies that the project is on the schedule; AS represents ahead of the schedule; BS represents behind the schedule; VS represents cost overrun; and UC represents cost underrun.

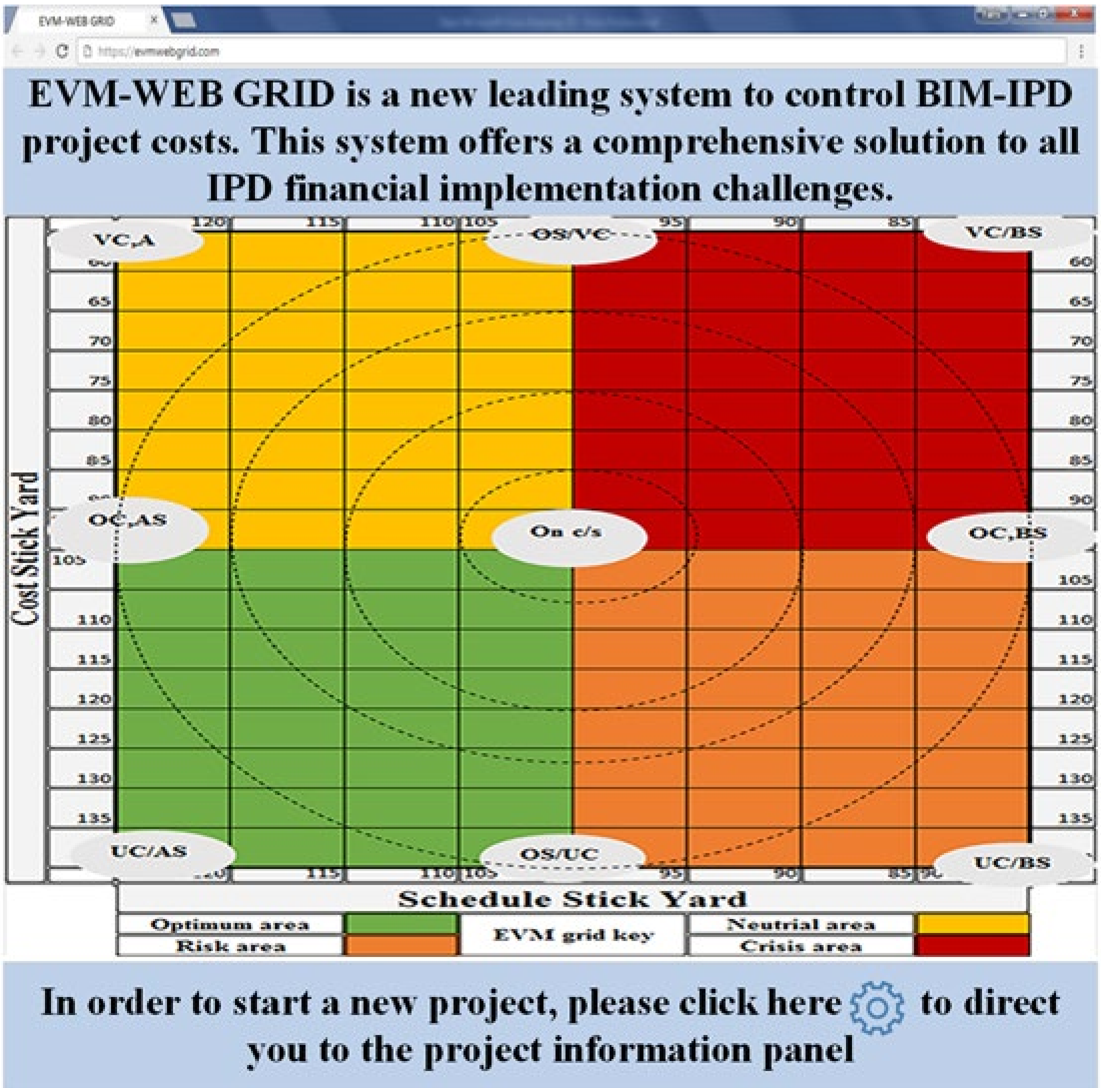

Figure 7. EVM-Based IPD with considering ABC estimating approach

Figure 8 summarises the framework in the form of a flowchart and provides a comprehensive solution for structuring IPD's compensation approach. Furthermore, it offers an easy method to manage the IPD compensation structure under different circumstances, while considering different participants organisational needs in terms of risk or reward sharing. This has been achieved by integrating ABC into IPD while using EVM technique.

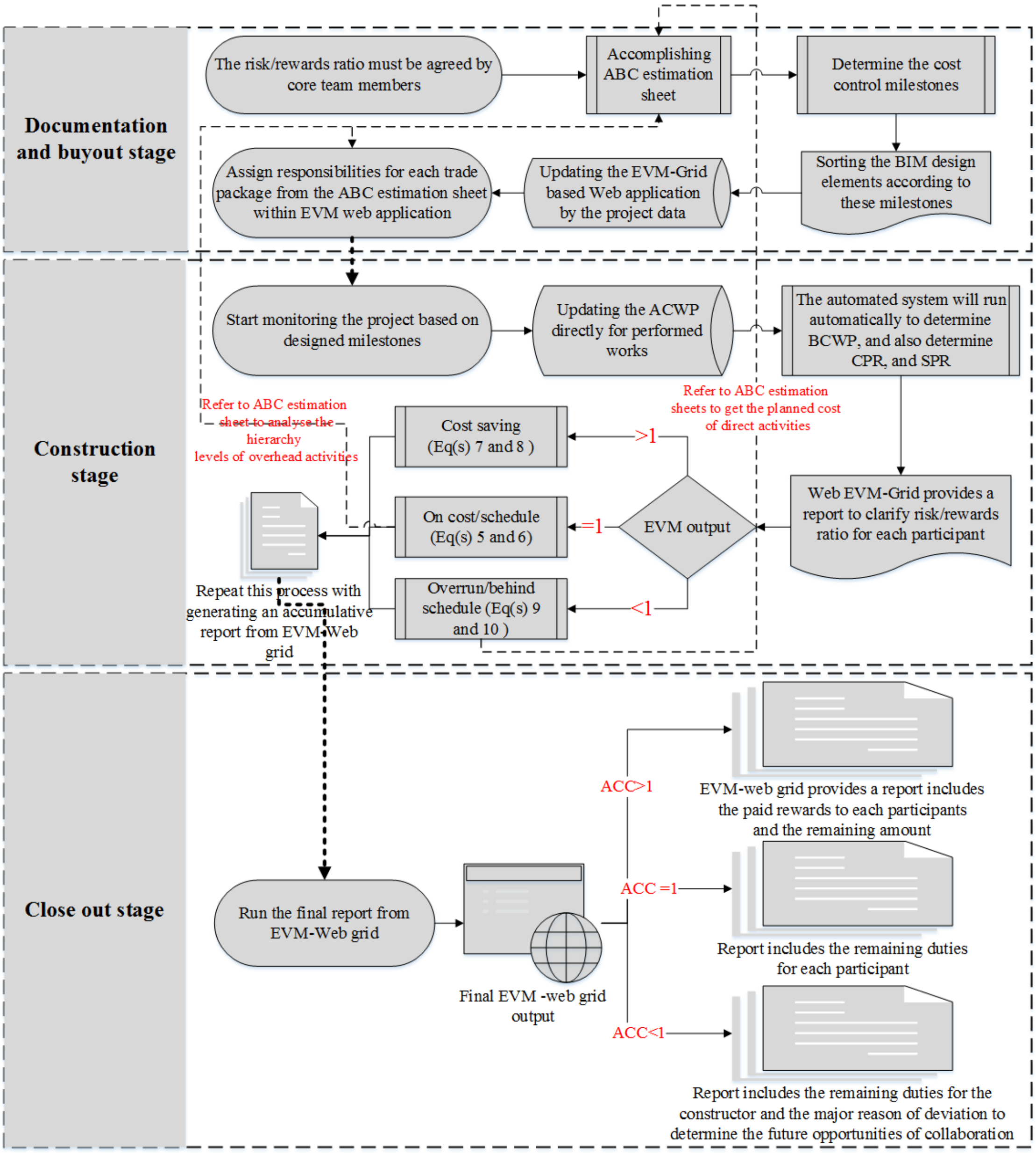

Figure 8. EVM-based IPD approach implementation flowchart

5.2. Model integration and flow of data

The flow of data in the proposed model will be from the documentation and the buyout stage to the close out stage, with highlighting BIM integration at each stage, as described below.

During the documentation stage, core team members conduct cost estimation based on ABC and loading the costs to the corresponding activity – whether the activity is direct, indirect, or overhead. This can be implemented through estimating costs using a 5D BIM platform (i.e. Navisworks) after configuring its layers in accordance with ABC levels. Subsequently, BCWS values can be prepared through exporting data that are created through 4D/5D BIM platform to another software package like Microsoft Project. Hence, the buyout stage takes place to agree on the percentage of profit-at-risk (P@R%), as well as, risk/reward among owner/non-owner parties. Subsequently, the agreed upon P@R% is added to BCWS to develop project compensation approach, and all project data (BCWS for each package, P@R %, risk/reward sharing %) are recorded to enable determining the actual percentages within the construction stage. Once the construction stage begins, the project manager should start loading the project information (CPR and SPR) to the EVM-Web grid, as shown in Figure 9. The steps, shown in Figure 9, must be followed during the construction stage to generate the report at each milestone, that is, all the mentioned equations for three cases are coded to receive the input of equations terms and display the outcome automatically. The data will be centred in the project server and the project manager will attach the initial documents, including the budgeted cost of work schedule (BCWS). Afterward, the progress data will be updated on the server and lively used in generating the milestone report (See Figure 9, step 5). For the close out stage, the report should include accumulative monetary profit and risk values for each party and all participants, since all parties are completely responsible for profits and risks regardless of causes of profits/risks. The profit/risk outcome of each milestone should be kept in the profit/risk pool, to be shared during close out stage.

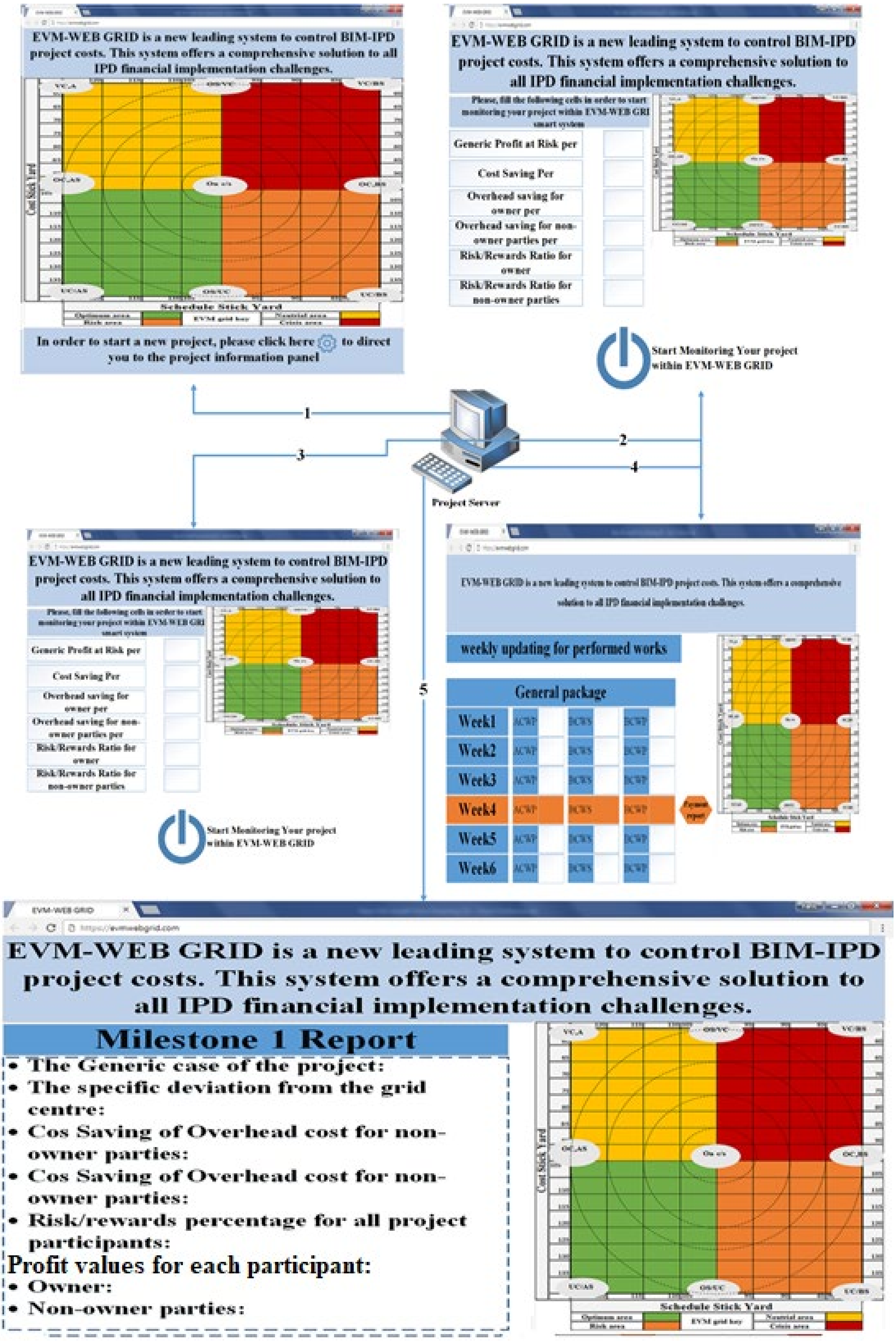

Figure 9. Data flow for the construction stages

The proposed web system facilitates all participants in interacting easily. As it can be seen from Figure 9, the proposed web page begins by providing a background to introduce the system. Subsequently, the web system provides empty cells to be filled by project parties (Figure 9, section 2). The compensation structure terms should be filled to automate the sharing process. Eventually, at each payment milestone, the web system is linked by an Excel sheet to upload the outcome of proposed equations to show risk/reward monetary values.

6. RESULTS AND ANALYSIS

To validate the proposed methodology, the model was applied to a case study; a property development company, whose managers decided to build a new house. The client decided to use IPD delivery approach for the project and commenced with appointing the architect and the main contractor from the conceptualisation stage, according to IPD principles. Therefore, the client formulated the core project team from the architectural firm (Company X) and the constructor (Company Y) to trade contractors to obtain the required information during start-up meetings. The project works were categorised into five trade packages; general works, ceiling, lighting fixture, finishing, and doors/windows packages. Since IPD depends on sharing the benefits and risks, it is necessary to assign the expenses and costs to specific activities. Through the ABC technique, after adapting it to be consistent with IPD levels, all parties gather in one unified cost pool under a joint venture cooperation arrangement [37]. Therefore, the costs of implementing IPD can be determined from the conceptualisation stage to buyout stages. The compensation structure was agreed upon as follows; (1) the agreed profit-at-risk percentage was 20%, (2) the saving cost allocation percentage for overhead project level cost was 70% for non-owner participants and 30% for owner, (3) the non-owner risk/reward ratio was 80%, and 20% for owner party. Although, within the existing IPD model, the owner does not get any proportion from P@R% [4,7], it is assumed that the owner gets a proportion from P@R% for two reasons: providing any service such as participating in managing project workflow, and showing capabilities of the presented framework to work on various scenarios. (4) the direct and indirect cost limit (Limb 1) was £118,484.9; (5) Limb 2, which involved direct, indirect, overhead costs was £190,484.9; and (6) Limb 3, which comprises from the total cost and the profit-at-risk percentage, which was £228,581.9. The project was packaged by trade, in accordance with the ABC method, and articulated the three limbs.

Furthermore, the detailed cost estimate was prepared by package for the three limbs, as shown in Table 2, where limb 1 represents the direct and indirect costs, limb 2 represents the summation of overhead activities, and limb 3 represents the profit-at-risk percentage after estimating the entire project cost.

Table 2. Compensation structure components

Construction packages	£ General	£ Ceiling	£ Lighting fixture	£ Finishing	£ Doors and windows
Total material costs	38,038.9	2,140.2	17,037.9	3,553.8	31,919.1
Total labour costs	21,318.9	1,715	296.5	1,334.4	763
Total equipment costs	366.8	0	0	0	0
Total direct and indirect costs (LIMB 1)	59,724.7	3,855.2	17,334.4	4,888.3	32,682.2
Overhead costs (LIMB 2)	27,557.6	11,519.2	7,134.6	15,403.8	7,134.6
Total costs (ABC) (Starting point of profit-at-risk percentage)	89,014.7	15,474.1	24,916.7	20,418.4	40,660.9
Profit-at-risk limit (LIMB 3)	106,817.6	18,568.9	29,900.1	24,502.1	48,793.1

The proposed framework was applied to manage the progress, whether positive or negative, and share the risk/reward in accordance with the agreed percentage of IPD. The case study considered two different scenarios to display the framework flexibility in capturing different circumstances, a description of which follows. Interested readers are referred to the Appendix for details on the ABC estimation sheet which was used to determine all overhead activities in this case study.

6.1. Scenario 1

Scenario 1 shows how the risk/reward can be shared among all project participants. The project payments were assumed monthly, with collected data from project cost centre tabulated in Table 3.

Table 3. Monthly cost data – Scenario 1

Activities	Feb W2	Feb W3	Feb W4	Mar W1
BCWS	1,867	49,985	4,385	12,073
Cumulative BCWS	1,867	51,852	56,236	68,309
ACWP	2,147	57,037	50,613	69,675
BCWP	2,362	62,740	40,490	75,946
CPR	0.91	0.91	1.25	0.92
SPR	0.79	0.83	1.39	0.90

The following steps are applied to determine the risk/reward sharing proportion for each participant. The project CPR and SPR are determined using the EVM grid (see Figure 8). The EVM output is 82.5%, which is located in the red area, implying a crisis situation due to the considerable deviation from the planned values. Since, the EVM output is 0.825, which is less than 1 with a 17.5% P@R deviation, less than 20% deviation, the third case (B) in the framework, model 11, should be applied. Through applying Equation 10, the total reward was valued at £341.5. Thereafter, in order to split the reward between the owner and non-owner, equation 6 was applied. The reward outcome displayed £68.3 and £273.2 for the owners and non-owners respectively.

6.2. Scenario 2

Scenario 2 shows how the cost saving is shared among all project participants without cost distortion. The project payments were assumed monthly and the collected data from the project cost centre, was displayed in Table 4.

Table 4. Monthly cost data - Scenario 2

Activities	Feb W2	Feb W3	Feb W4	Mar W1
BCWS	1,867	49,985	4,385	12,073
Cumulative BCWS	1,867	51,852	56,236	68,309
ACWP	1,680	51,852	50,613	68,309
BCWP	1,596	51,852	40,490	66,943
CPR	1.05	1.00	1.25	1.02
SPR	1.17	1.00	1.39	1.02

The project CPR and SPR values are determined using the EVM grid (illustrated in Figure 8). The EVM output was 104%, located in the green area, implying an optimum situation due to the considerable positive deviation from the planned values. Since, the EVM output was 1.04, which is greater than 1 with a 4% P@R deviation, Equation 7 should be applied to calculate the entire savings cost and then determine the proportion for each participant. The entire saving cost was valued at £2,732.4. Thereafter, through applying Equations 7 and 8, the cost savings for the owner and non-owner was computed. The cost savings for the owner and non-owner were estimated at £304 and £709.1 for the owners and non-owners respectively, noting that the savings from the overhead daily activities was estimated at £1,013 from the estimation sheet. Furthermore, the total planned overhead cost was valued at £17,038 for the first month and the actual project overheads was £16,025, showing £1,013 savings. Afterwards, the direct and indirect cost value for the owner and non-owner was estimated at £859.7. Finally, the profit-at-risk percentage was computed using equations 6 and 7 for the owner and non-owner respectively. The gain ratio was valued at £13,662, split into £2,732 and £10,929 for the owner and non-owner respectively.

Figure 10 summarises the above-mentioned scenario steps and results of implementing the framework for both owner and non-owner parties. The benefit of implementing EVM framework is allocating the risk/reward among the core team members within the IPD approach, as discussed earlier. The scenarios displayed two scenarios for an EVM output less and greater than 1. The sharing proportion was calculated accordingly, based on the developed framework.

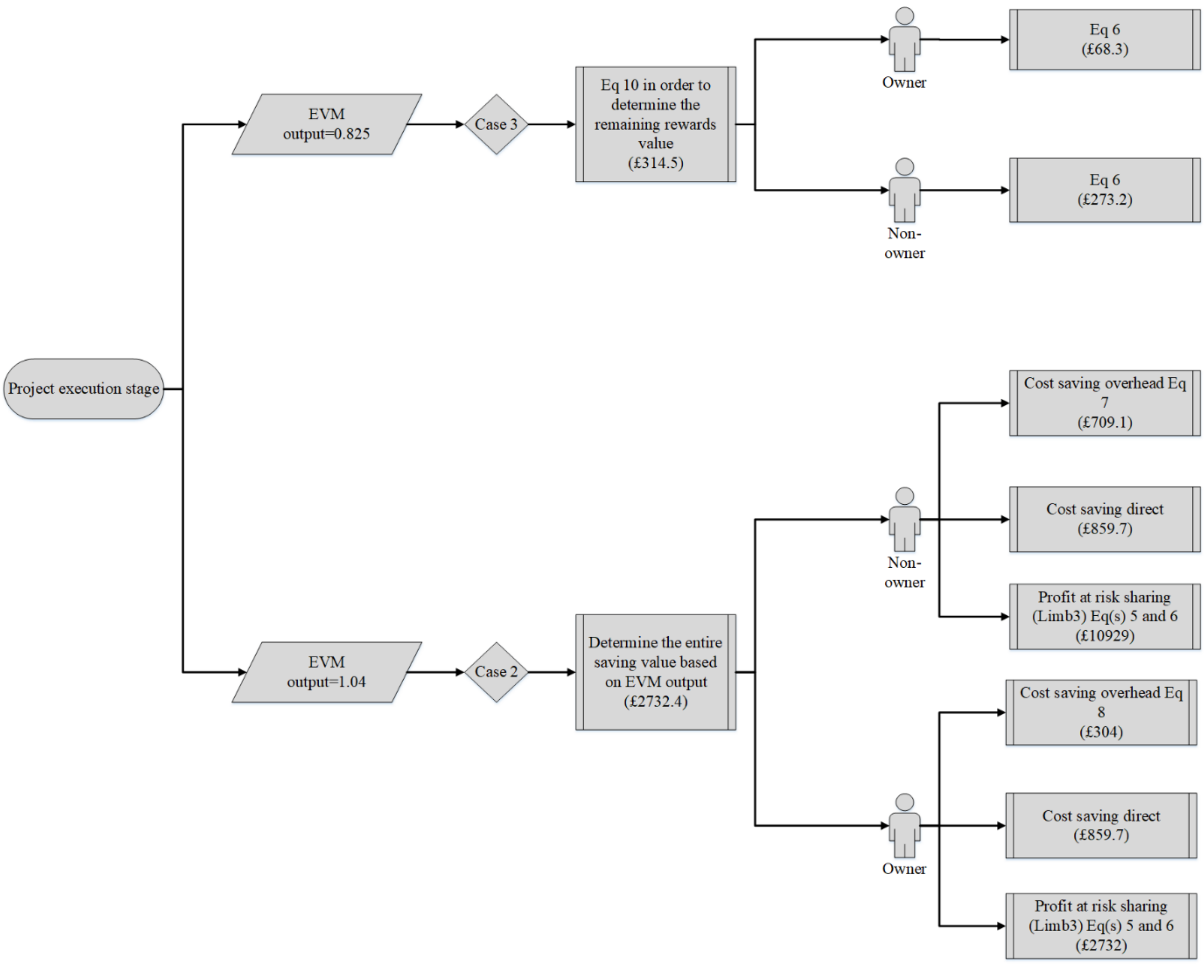

Figure 10. Results analysis flowchart

6.3. Utilising IPD With BIM and the Proposed EVM-Web Processes

In order to show how BIM and EVM-web can be utilised, the presented data in scenario 2, are illustrated in Figure 11.

Figure 11 shows the BIM dimensions (3D, 4D and 5D) that have been developed for this case study. The project data will be retrieved from these three models, as the case study supports the integration of IPD and BIM. With reference to the 4D model (see Figure 11) some works have been completed and milestone 1 is set by the end of week 1 in March. Subsequently, those parties responsible for the performed works should submit their invoices as three separate sections (reimbursed costs, profit and cost saving). Afterwards, the quantity surveyor (QS) proceeds all data and applies the proposed equations in the framework for determining risk and rewards for owner and all non-owner parties. Any party in the core team can easily gain access to the website, therefore, all the information on the achieved monetary value of profit and cost saving will be accessible remotely. Besides, each user can readily check the generic case of the designated package through EVM grid, while in the future payment milestone, a contour line between accumulative points – displayed as a white coloured star with the number of the milestone – will be drawn to show the historical performances. Moreover, the EVM-grid can be utilised as a graphical report of cost situation for the package and project (see Figure 11). All project parties, therefore, can easily understand and use the displayed information, regardless of their skills. This is seen as a remedial solution to one of endemic problems affecting IPD, as discussed: lack of skills and core team members coming from various different backgrounds [7,70].

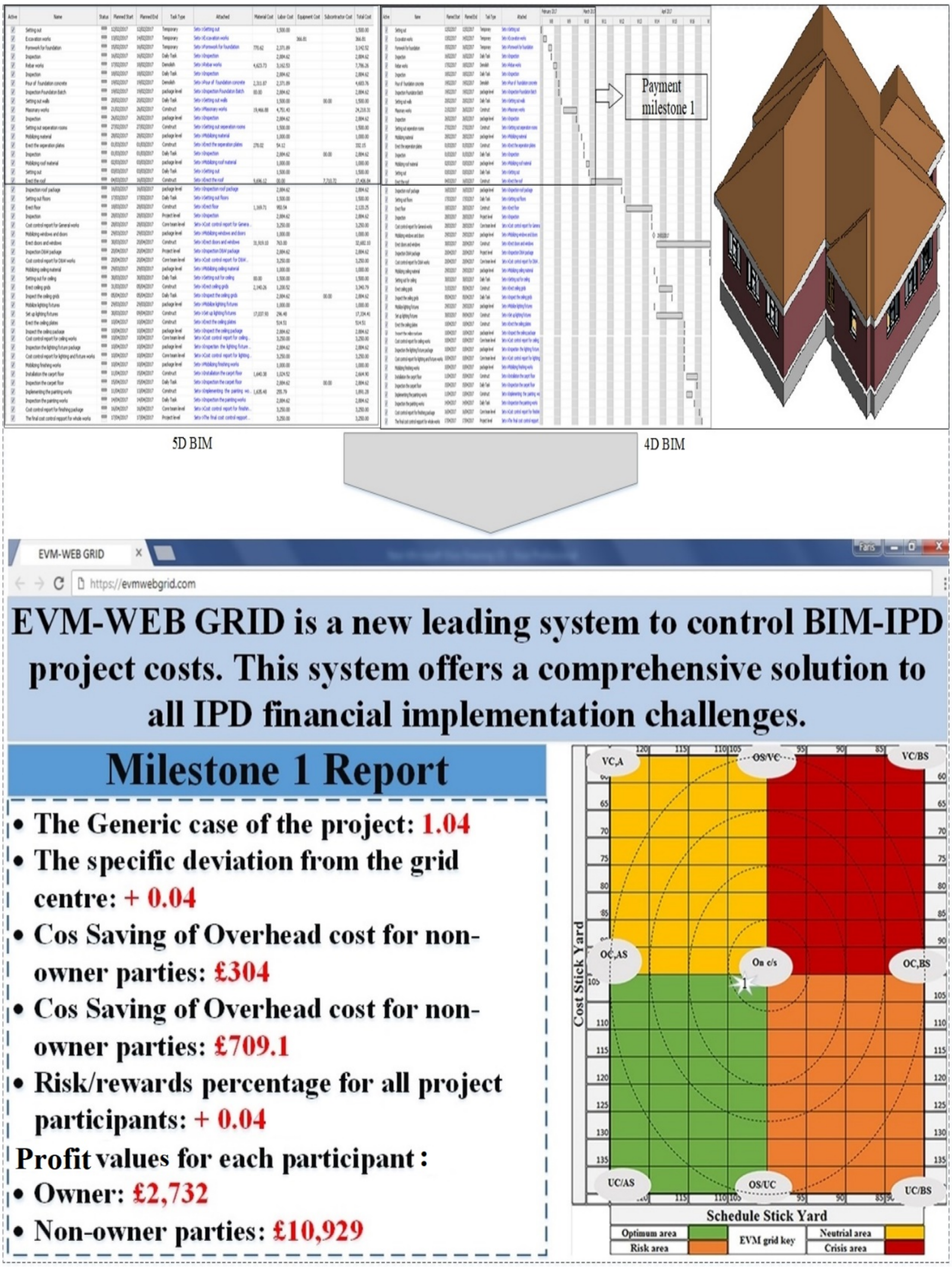

Figure 11. Result analysis of displaying risk/rewards values on EVM-web system

7. SIGNIFICANCE AND IMPLICATIONS

In view of the of case study's results, as discussed, the present study contributes to the field in several significant ways. That is, with reference to case 2, using ABC enables practitioners of identifying the source of cost saving accurately. This affects the monetary sharing value – whether for owner and non-owner parties – through distinguishing between the overhead cost sources, hence determining the proportion of sharing. In the case at hand, as an example, it becomes clear that non-owner parties received twice the percentage of owner. Previous studies like that of Zhang and Li [85] developed models capable of differentiating overhead cost levels such as corporate and project levels. These models are however not capable of identifying the accurate overhead cost and highlighting how the progress can be determined. The model proposed in the present study, therefore, is one step ahead in addressing this issue with the now-available models. As another novel feature, by using EVM with tailored mathematical equations for IPD's characteristics, the proposed model supports the automation of the sharing risk/reward process, as an extension of integrated models proposed in previous studies [63].

As another contribution of the present study, this research responds to calls for providing a workable solution for integration of BIM and IPD with cost-oriented tools that have proven their potential for cost estimation purposes like EVM and ABC [63]. Particularly, such integration will be a remedial solution to cost distortion problems that occur in applying existing methods [34,37,51]. Moreover, the model enhances the cost structure of BIM for IPD, as a recommended approach in the literature [4,7,69], through developing an integrated cost control system that determines the proportion of risk/reward automatically to respond to countermeasures that were recommended by Ballard, et al. [12] for sustainable risk/reward sharing.

The model presented here also addresses some chief deficiencies of EVM [35,36]. That is, EVM relies on Management by Results (MBR) thinking, a quantities method that overlooks the relationships among activities at the operational level and does not take into account the interdependences and the workflow of resources amid project packages, which results in unfair control results of project works. In response to this, the proposed solution integrates ABC into EVM. The outcome enhances the capability of analysing unit costs, either resources or activities, as well as enabling the tracking source of resources and needed activities to obtain the unit [52].

7. CONCLUSION

The study is an attempt to propose a model, to exploit EVM to structure the compensation approach in IPD, as well as, using ABC to optimise the cost structure for IPD projects. Due to the complexity of structuring a compensation system fairly, within the IPD approach for BIM projects, the proposed model was articulated to facilitate adopting BIM under the IPD approach. The model assists in sharing cost savings, which represents a significant barrier in implementing IPD, through managing this issue by adopting the ABC estimation method that enables distinguishing different types of activities within the project organisation hierarchy, and thus, differentiating between the overhead sustaining level and project level. In case of sharing overhead cost saving of overhead resources, the source of this saving will be determined, which will minimise the conflicts amongst all stakeholders. Furthermore, the research presented an EVM-Web grid that will enhance the collaboration among all stakeholders and increase the trust among project participants - since all the processes is implemented automatically, with minimal human interfering. The case study was applied to several scenarios and it showed the simplicity and accuracy of the model implementation.

With the above in mind, the study is novel in several ways. That is, the paper introduces an innovative grid that locates the Cost Performance Ratio (CPR), and Schedule Performance Ratio (SPR) to provide a picture of project position in terms of cost and schedule. Furthermore, it integrates the EVM-Grid with the ABC estimating method to optimise the cost structure, which is positively reflected in the compensation structure. In addition, the findings present models that deal with risk/reward sharing, through considering new directions, to ensure fair sharing using ABC sheets and distinguish between the direct and overhead cost saving. For the overhead cost, the framework distinguishes between the sustaining/organisation level and the project level. Additionally, the EVM-Grid has been developed as a web system to allow the participants to easily track their project.

In practical terms, the findings will be invaluable for novice BIM users, given the simplicity and user-friendliness of the proposed models. All the tasks are aligned with the implementation stages and easily expressed to allow novice users to collect the required data promptly.

The outcome of this research will also point to directions for further research on the topic. The findings here can be used to develop a prototype and thus, will be designed to be embedded, using Application Programming Interface (API) that is coded by C#.NET, on any BIM 4D and 5D platform, such as Navisworks. Focusing on the concept of open BIM, with developing a vendor-free IFC-based platform, compatible with various BIM packages, provides another fertile area for research into the topic. Moreover, the developed EVM-web grid will be working as a smart tool to provide recommendations for the optimal corrective actions that need to be taken to minimise the losses, and correctly assign the problem to the relevant person to ensure it being solved in a timely manner.

Despite the contributions as discussed, the findings of the study must be applied in view of some limitations. That is, the proposed sharing risk/reward equations rely on giving identical weights to cost/schedule in determining the participant's performance. Presenting the outcome of the discussed case study was also based on the same assumption. Though a limitation, the model is flexible, so that user can change the degree of importance, through multiplying CPR and SPR by any agreed decimal value, to give preference to one parameter over another. Other extensions are required, such as ranking the performance of the project's parties. This is required to enable sustaining relationships as a main target of using IPD in construction projects. Nevertheless, further research is in progress to maximise the advantage of presented model, moreover maximising the benefit of implementing IPD within the AEC industry.

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Appendix: Activity based costing overhead estimation sheet to all project overhead activities

No	Activities	Task type	Cost driver	Planned unit	Cost unit/ cost driver (£)	Total cost (£)	TPC/ package (£)
1	Setting out	daily task level	No. of days	1	1,500	1,500	
2	Inspection of formworks	daily task level	No. of inspections	1	2,884.615385	2,884.615385	
3	Inspection of rebar works	daily task level	No. of inspections	1	2,884.615385	2,884.615385	
4	Inspection of foundation batch	package level	No. of inspections	1	2,884.615385	2,884.615385	
5	Setting out walls	daily task level	No. of days	1	1,500	1,500	
6	Inspection of masonry works	package level	No. of inspections	1	2,884.615385	2,884.615385	
7	Setting out separation of rooms	daily task level	No. of days	1	1,500	1,500	
8	Mobilise material	package level	No. of receipts	1	1,000	1,000	
9	Inspection of separation of rooms	daily task level	No. of inspections	1	2,884.615385	2,884.615385	
10	Mobilise roof material	package level	No. of receipts	1	1,000	1,000	
11	Setting out	daily task level	No. of days	1	1,500	1,500	
12	Inspection roof package	package level	No. of inspections	1	2,884.615385	2,884.615385	
13	Setting out of floors	daily task level	No. of days	1	1,500	1,500	
14	Inspection of floors	daily task level	No. of inspections	1	2,884.615385	2,884.615385	
15	Cost control report for general works	package level	Proportion of the package	1	3,250	3,250	27,557.69
16	Mobilise windows and doors	package level	No. of receipts	1	1,000	1,000	
17	Inspection of D&W package	package level	No. of inspections	1	2,884.615385	2,884.615385	

18	Cost control report for D&W works	core team level	Proportion of the package	1	3,250	3,250	7,134.615385
19	Mobilise ceiling material	package level	No. of receipts	1	1,000	1,000	
20	Setting out of ceiling	daily task level	No. of days	1	1,500	1,500	
21	Inspection of the ceiling grids	daily task level	No. of inspections	1	2,884.615385	2,884.615385	
22	Mobilise lighting fixtures	package level	No. of receipts	1	1,000	1,000	
24	Inspection of the ceiling package	package level	No. of inspections	1	2,884.615385	2,884.615385	
25	Cost control report for ceiling works	core team level	Proportion of the package	1	3,250	3,250	11,519.23077
26	Inspection of the lighting fixture package	package level	No. of inspections	1	2,884.615385	2,884.615385	
27	Cost control report for lighting and fixture works	core team level	Proportion of the package	1	3,250	3,250	7,134.615385
28	Mobilise finishing works	package level	No. of receipts	1	1,000	1,000	
29	Inspection of the floor carpet	daily task level	No. of inspections	1	2,884.615385	2,884.615385	15,403.84616
30	Inspection of the paint work	daily task level	No. of inspections	1	2,884.615385	2,884.615385	
31	Cost control report for finishing package	core team level	Proportion of the package	1	3,250	3,250	
32	Final cost control report for the entire work	core team level	No. of reports	1	3,250	3,250	3,250

Legend: The Key of ABC estimation table

General Package	
Finishing package	
Windows and doors package	
Lighting fixture package	
Ceiling Package	