



**UNIVERSITY OF
PORTSMOUTH**

**AN AUTOMATED IPD COST MANAGEMENT
SYSTEM: BIM AND BLOCKCHAIN BASED
SOLUTION**

By

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The thesis is submitted in partial fulfilment of the requirements for the award of the
degree of Doctor of Philosophy of the University of Portsmouth

January, 2020

School of Civil Engineering and Surveying

University of Portsmouth

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ACKNOWLEDGEMENT

Praise Allah the Almighty God from whom I come and belong. The One, who I always depend on and look to for help in leading me to this path of self-discovery and humbling experience. Many people have directly and indirectly contributed to the successful completion of this research study.

My appreciation and love also go to my country **Egypt**, which, has inspired me throughout accomplishing this work.

I am deeply grateful to my supervisor, **Dr Sepehr Abrishami** for his exceptional support, constructive criticisms and invaluable advice throughout this research. It has been a privilege to have had the chance to work with them and share their valuable knowledge and expertise. I would also like to thank my co-supervisor Mr Richard Wise and **Prof. Mark Gaterell** for their generous advice and support. I am very happy with the opportunity to have worked with all of you. Your thoughts and valuable insight are highly appreciated. This research would not have been possible without your support.

I am deeply indebted to all individuals who took part in this research by offering their valuable time for the interviews. It has been a meaningful and wonderful experience to conduct the research and to learn from them.

My appreciation and thanks go to **Dr M.Reza Hosseini** for his valuable helping throughout my PhD journey.

Lastly but most importantly, my never ending thanks and loves goes to my beloved parents, **Ali Elghaish** and **Zainab Shehab**; my siblings, **Elsayed, Reem** and **Hanan** for their support and encouragement. All of you are the greatest gift that Allah has given to me in this world.

DECLARATION

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

Faris Elghaish

PUBLICATIONS

- **Elghaish, F.**, Abrishami, S., Abu Samra, S., Gaterell, M., Hosseini, M., & Wise, R. (2019). Cash flow system development framework within integrated project delivery (IPD) using BIM tools. *International Journal Of Construction Management*, 1-16. <https://doi.org/10.1080/15623599.2019.1573477>
- **Elghaish, F.**, Abrishami, S., Hosseini, M., Abu-Samra, S., & Gaterell, M. (2019). Integrated project delivery with BIM: An automated EVM-based approach. *Automation in Construction*, 106, 102907. <https://doi.org/10.1016/j.autcon.2019.102907>
- **Elghaish, F.**, & Abrishami, S. (2020). Developing a framework to revolutionise the 4D BIM process: IPD-based solution. *Construction Innovation*, ahead-of-print(ahead-of-print). <https://doi.org/10.1108/ci-11-2019-0127>
- **Elghaish, F.**, Abrishami, S., Hosseini, M., & Abu-Samra, S. (2019). Revolutionising Cost Structure within the Integrated Project Delivery: A BIM-Based Solution. *Engineering, Construction And Architectural Management*. <https://doi.org/10.1108/ECAM-04-2019-0222>
- **Elghaish, F.**, & Abrishami, S. (2019). Integrated Project Delivery With Blockchain: An Automated Financial System. *Automation In Construction*. <https://doi.org/10.1016/j.autcon.2020.103182>
- **Elghaish, F.**, & Abrishami, S. (2020). A Centralised Cost Management System: Exploiting EVM And ABC Within IPD. *Engineering, Construction And Architectural Management*, <https://doi.org/10.1108/ECAM-11-2019-0623>
- **Elghaish, f.**, Abrishami, S., Hosseini, M., & Dehkordi, B. (2019). Integrating EVM and ABC for developing risk/rewards sharing metrics of IPD: A web-based management system. In *36th CIB W78 2019 Conference*. Northumbria University at Newcastle, United Kingdom: 36th CIB W78 2019 Conference.
- Abrishami, S., & **Elghaish, f.** (2019). Revolutionising AEC financial system within project delivery stages: A permissioned blockchain digitalised framework. In *36th CIB W78 2019 Conference*. Northumbria University at Newcastle, United Kingdom: 36th CIB W78 2019 Conference.

LIST OF ABBREVIATIONS

IPD: Integrated Project Delivery

AEC: Architecture, Engineering and Construction

BIM: Building Information Modelling

4D: Fourth Dimensional

5D: Fifth Dimensional

EVM: Earned Value Management

ABC: Activity Based Costing

TVD: Target Value Design

DLT: Distributed Ledger Technology

ICT: Information Communication Technology

CCMS: Centralised Cost Management System

CCMS4IPD: Centralised Cost Management System for IPD

DCMS: Decentralised Cost Management System

EVO: Earned Value Outcome

EVO4Profit: Earned Value Outcome for Profit

MV: Monetary Value

CSooC for NO: Cost Saving of Overhead Cost for Non-Owner parties

CSooOA: Cost Saving of Overhead Organisation Activities

CSooPA: Cost Saving of Overhead Project Activities

PoNO or PoO : The Proportion of sharing cost-saving for Non-Owner Parties/ Owner

NoARP/ OARP: Non-Owner/Owner Agreed Reward Percentage

TR4O/TR4NO: Total Reward for Owner/Non-Owner parties

TCS: Total Compensation Structure

PLIMB-1: Planned LIMB-1

PLIMB-2: Planned LIMB-2

ABSTRACT

Integrated Project Delivery (IPD) in the Architecture, Engineering and Construction (AEC) is characterised by risk/reward sharing, deferring paying the parties' profits until all project activities are completed, and replacing the tender stage by buyout stage without traditional bidding. 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 lack of practical methods to direct this integration, and the inability of current cost management practices in developing accurate compensation structures, providing detailed cost information during the buyout stage (to enable parties to make the right decision), and determining fair risk/reward ratio in IPD arrangements.

This research presents a comprehensive cost management system/solution for cost estimation, budgeting, and risk/reward sharing, by presenting; (1) an innovative approach to utilise 5D BIM capabilities with Monte Carlo simulation, hence providing reliable cost estimation during the conceptual Target Value Design (TVD) stage, (2) mathematical models that are developed through integrating Activity Based Costing (ABC) into 5D BIM to determine the three IPD's cost structure limbs, (3) a novel mechanism of managing overhead costs through distinguishing between saved resources from the organisation level to the daily task level, to increase the trust amongst parties, (4) development of a framework to generate a cash flow approach using BIM tools (considering that IPD does not include tender stage), (5) development of a model (based on the framework) that displays all estimated cost data of each package as minimum/maximum estimated cash inflow during the buyout stage, for informed decision making. Regarding the risk/reward sharing solution, extant literature has highlighted the advantages of Earned Value Management-based (EVM) method for risk/reward sharing, and how 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.

Diverse Information and Communication Technologies (ICT) were adopted to develop the cost management system that comprises of two sub-systems; a Centralised Cost

Management System (CCMS) and a Decentralised Cost Management System (DCMS). CCMS enables implementing the developed framework, and includes an integrated database for cost estimation, budget, and sharing risk/reward calculations. It is also linked with an interactive web-based management system to enable IPD core team members to check their package costs, making the decision during the buyout stage according to the displayed cash flows, access to a comprehensive financial report that includes the three main transaction in every payment milestone, and tracking the project status graphically using the developed EVM-Web grid. This system has been validated using an illustrative case study. DCMS enables all parties to control and track financial transactions, secured with no unauthorised change allowed using blockchain technology. As the first of its kind, this technology is adopted in the present study, in developing a framework to propose utilising the blockchain technology in delivering IPD-based projects. The outcome enables IPD's core team members to execute all financial transactions automatically, through coding IPD's three main transactions – reimbursed costs, profit and cost saving – as functions of the IPD's smart contract. To demonstrate the applicability of the proposed framework, a proof of concept prototype is developed and validated through an IPD case project; the practicality of the built-up hyperledger network (IBM blockchain cloud beta 2) and the advantages of the proposed smart contract functions are examined. Findings demonstrate that the proposed financial system is user-friendly and very efficient in automating all transactions. No deficiency in the blockchain network components is observed. This research will foster the adoption of IPD across the AEC industry by providing a workable solution to existing financial barriers. It also opens a new horizon for researchers and practitioner to exploit blockchain in solving comparable deficiencies affecting the AEC industry.

The research findings have been validated by interviewing BIM and IPD experts. The interviewees confirmed the applicability, practicability and validity of the developed framework and tools to deal with the revealed challenges of the IPD. The findings of this research are recommended by IPD experts to be presented to the industry as a set of steps to globalise its adoption.

Table of Contents

CHAPTER ONE: RESEARCH OVERVIEW	1
1.1. INTRODUCTION	1
1.2. BACKGROUND	1
1.3. RESEARCH AIM AND OBJECTIVES	10
1.4. RESEARCH METHODOLOGY	11
1.4.1. The Adopted Methods.....	12
1.5. RESEARCH MOTIVATION AND GAP	15
1.6. CONTRIBUTION TO THE BODY OF KNOWLEDGE	17
1.7. THESIS STRUCTURE	20
1.8. CHAPTER SUMMARY.....	23
CHAPTER TWO: IMPLICATIONS OF COST MANAGEMENT FOR BIM AND IPD	24
2.1. INTRODUCTION	24
2.2. BACKGROUND OF COST MANAGEMENT PROCESS	24
2.3. THE TASKS OF THE COST MANAGEMENT PROCESS	26
2.3.1. Cost Estimation	26
2.3.2. Cost Budget and Control.....	27
2.4. THE TRADITIONAL COST MANAGEMENT PROCESS.....	28
2.5. CHALLENGES OF THE COST MANAGEMENT PROCESSES	30
2.5.1. Cost Estimation Challenges	30
2.5.2. Cost Budgeting and Controlling Implementation and Challenges	32
2.6. THE INTEGRATION CHALLENGES IN THE COST MANAGEMENT PROCESSES	34
2.7. ACTIVITY BASED COSTING (ABC)	38
2.8. COMPARISON OF ACTIVITY-BASED COSTING (ABC) AND TRADITIONAL COSTING METHODS	39
2.9. EARNED VALUE MANAGEMENT	41
2.10. CAPABILITIES OF MONTE CARLO SIMULATION	45
2.11. INTEGRATED PROJECT DELIVERY (IPD)	47
2.11.1. The Benefits of IPD in Construction Projects	49
2.11.2. IPD-Based Cost Estimation	50
2.11.3. TARGET VALUE DESIGN (TVD)	52
2.12. BUILDING INFORMATION MODELLING/MANAGEMENT	54
2.12.2. Overview of BIM Dimensions and Levels.....	54
2.12.3. 4D BIM Implementation and Challenges	57
2.12.4. BIM and Cost Management	59
2.12.5. BIM and cash flow	64

2.12.6.	4D/5D BIM Automation	66
2.12.7.	The Applicability of Integrating IPD, BIM and TVD.....	67
2.13.	THE REQUIREMENTS OF THE COST MANAGEMENT PROCESS —THE HIGHLIGHTED RESEARCH GAP—OF THE IPD APPROACH.....	72
2.13.1.	Research Gap in Cost Estimation Operation within IPD	72
2.13.2.	Cash Flow-Cost Budgeting— Research Gap	73
2.13.3.	Research Gap Regarding Cost Control and Sharing Risk/Reward within IPD...	75
2.14.	CONCLUSION	78
CHAPTER THREE: OVERVIEW OF INFORMATION COMMUNICATION TECHNOLOGY (ICT) AND BLOCKCHAIN IN CONSTRUCTION MANAGEMENT		80
3.1.	INTRODUCTION	80
3.2.	OVERVIEW OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN CONSTRUCTION	80
3.3.	WEB APPLICATIONS IN DATA SHARING FOR CONSTRUCTION INDUSTRY	82
3.4.	BLOCKCHAIN/DISTRIBUTED LEDGER TECHNOLOGY (DLT) ..	83
3.4.1.	Smart Contracts.....	84
3.4.2.	The Blockchain Platforms and Consensus Mechanisms.....	85
3.4.3.	Hyperledger-Fabric and Chaincode	86
3.5.	BLOCKCHAIN/SMART CONTRACTS IN CONSTRUCTION.....	88
3.5.1.	Previous Works	91
3.6.	BIM, IPD AND SMART CONTRACTS INTEGRATION	93
3.6.1.	Decision Criteria for Selecting a Suitable Blockchain Platform for IPD.....	95
3.7.	BARRIERS TO IMPLEMENT BLOCKCHAIN/SMART CONTRACTS FOR CONSTRUCTION PROJECT DELIVERY	100
3.8.	JUSTIFICATION OF USING BLOCKCHAIN IN THE CONSTRUCTION PROJECT DELIVERY	102
3.9.	CONCLUSION	103
CHAPTER FOUR: RESEARCH DESIGN AND METHODOLOGY		105
4.1.	INTRODUCTION	105
4.2.	RESEARCH PHILOSOPHY	105
4.2.1.	Ontology	106
4.2.2.	Epistemology	107
4.2.3.	Axiology	109
4.3.	RESEARCH APPROACH.....	110
4.3.1.	Deductive Approach	110
4.3.2.	Inductive Approach.....	111
4.3.3.	Abduction Approach.....	112

4.4.	RESEARCH CHOICE	113
4.4.1.	Quantitative Research	114
4.4.2.	Qualitative Research	115
4.4.3.	Mixed Research Methods.....	116
4.5.	Time Horizon.....	117
4.6.	RESEARCH METHODS.....	117
4.6.1.	Experiments	118
4.6.2.	Case study	118
4.6.3.	Ethnographic Research	120
4.6.4.	Action Research	121
4.6.5.	Grounded Theory	121
4.6.6.	Surveys.....	122
4.6.7.	Questionnaire	122
4.6.8.	Literature Review and Document Analysis	124
4.6.9.	Interview	127
4.7.	ADOPTED RESEARCH METHODS AND TECHNIQUES.....	131
4.8.	DATA VALIDITY AND RELIABILITY.....	134
4.8.1.	Validity	134
4.8.2.	Reliability.....	135
4.9.	ETHICAL CONSIDERATIONS OF THE RESEARCH	136
4.10.	SUMMARY	136
CHAPTER FIVE: POINT OF DEPARTURE		138
5.1.	INTRODUCTION	138
5.2.	RELIABILITY OF DATA.....	138
5.3.	THE DESCRIPTIVE FINDINGS OF PRIMARY DATA.....	140
4.10.1.	THE CHARACTERISTICS OF THE PARTICIPANTS.....	140
5.4.	THE BIM-BASED COST MANAGEMENT PROCESS.....	143
5.4.1.	Cost Management Tools	143
5.4.2.	Overhead Costs in Construction Projects.....	144
5.4.3.	Cost Control Practices in Construction Projects	146
5.5.	Evaluation of the Current 4D/5D BIM Integration.....	148
5.5.1.	PROPOSING ADDITIONAL FEATURES TO IMPROVE THE PERFORMANCE OF THE IMPLEMENTATION.....	148
5.6.	BIM-BASED INTEGRATED PROJECT DELIVERY (IPD) APPROACH	149
5.6.1.	The Participants' Experiences with IPD	150
5.6.2.	Main IPD Barriers Based Cost Management	151

5.6.3.	Adding Features to Foster IPD Implementation	152
5.7.	SUMMARY	156
CHAPTER SIX: FRAMEWORK DEVELOPMENT		158
6.1.	INTRODUCTION	158
6.2.	COST ESTIMATION BASED IPD STAGES	159
6.2.1.	Conceptualisation and Outline Design Stages	159
6.3.	DETAILED DESIGN STAGE.....	164
6.4.	DOCUMENTATION AND BUYOUT STAGES.....	164
6.4.1.	Activity-based costing (ABC) estimation sheet	166
6.4.2.	Formulation of the IPD-based ABC model.....	167
6.5.	CASH FLOW BASED IPD CHARACTERISTICS.....	172
6.5.1.	Data Integration (4d/5d BIM) Within IPD Approach	172
6.5.2.	Formulation of Cash-Flow Model.....	174
6.5.3.	Different IPD cash flow scenarios	177
6.5.4.	BIM-Based Cash Flow	178
6.6.	COST CONTROL AND RISK/REWARD SHARING SYSTEM	179
6.6.1.	Implementation Process	180
6.7.	THE FRAMEWORK TASKS OVER IPD STAGES.....	189
6.8.	USING DLT TO SHARE AND VALIDATE THE RISK/REWARD SHARING DATA	191
6.8.1.	Conceptualisation to Buyout	192
6.8.2.	Construction Stage (Processing and Reflection).....	196
6.8.3.	The Close-Out Stage	198
6.8.4.	Interoperability among BIM, IPD and Blockchain	200
6.9.	SUMMARY	202
CHAPTER SEVEN: PROTOTYPE DEVELOPMENT AND VALIDATION		204
7.1.	INTRODUCTION	204
7.2.	PROTOTYPE DEVELOPMENT	204
7.2.1.	Centralised Cost Management System (CCMS) for IPD	204
7.2.2.	Developing an Interactive Web Interface to Display the Project Data — CCMS4IPD.	214
7.2.3.	Model Integration and Flow of Data through the CCMS and IPD Stages	223
7.2.4.	The Decentralised Cost Management System (DCMS) of IPD using the Blockchain Technology	225
7.3.	A PRACTICAL CASE—AN ILLUSTRATIVE CASE STUDY.....	234
7.3.1.	Cost Estimation	236
7.3.2.	Buyout Stage (Cash Flow)	246
7.3.3.	Construction Stage (Cost Control and Sharing Risk/Reward)	260

CHAPTER EIGHT: THE RESEARCH FINDINGS VALIDATION	270
8.1. INTRODUCTION	270
8.2. THE CHARACTERISTICS OF INTERVIEWEES	270
8.3. ENGAGING WITH PARTICIPANTS	272
8.4. INTERVIEW ANALYSIS AND FINDINGS	274
8.4.1. The Evaluation of the Framework Processes and Tasks	275
8.4.2. The Applicability of the CCMS Tools (The Database and CCMS4IPD Web System)	276
8.4.3. The Practical Implications of the Proposed Tools (CCMS4IPD and Blockchain/Smart Contract Tools).....	277
8.4.4. The Interviewees Recommendations for Additional Features	278
8.4.5. The Implications of Blockchain and Smart Contracts	279
8.4.6. The Degree of Satisfaction of the Framework and Prototype	281
8.5. SUMMARY	282
CHAPTER NINE: CONCLUSION, RECOMMENDATION AND FUTURE WORKS	283
9.1. INTRODUCTION	283
9.2. ACHIEVEMENT OF RESEARCH OBJECTIVES	283
9.3. RESEARCH PRACTICAL IMPLICATIONS	292
9.3.1. The Practical Implications of CCMS	292
9.3.2. The Practical Implications of DCMS—Blockchain based IPD.	293
9.4. RESEARCH LIMITATION AND FUTURE RESEARCH	296
9.4.1. Cost Estimation	296
9.4.2. Cost Budget.....	297
9.4.3. Cost Control and Developed Sharing Risk/Reward Model	297
9.5. SUMMARY	299
10. References	301
11. Appendixes	328
11.1. Appendix A (Ethical approval)	328
11.2. Appendix B (questionnaire form)	331
11.3. Appendix C (interview form)	338
11.4. Appendix D (Sample of interview script)	341
11.5. Appendix E (3D BIM documents for the case study)	342
11.5.1. 3D BIM model	342
11.5.2. List of Schedules.....	344
11.6. Appendix F (CCMS Outcome for the Case Study)	345
11.6.1. CCMS (ABC sheet)	345
11.6.2. CCMS (LIMB-1 sheets).....	346

11.6.3.	CCMS (Compensation structure).....	346
11.6.4.	CCMS (Developing calculation fields for sharing/reward model)	346
11.7.	Case study cost estimation sheets	348
11.7.1.	Direct and indirect cost estimation based BIM data	348
11.7.2.	Monte Carlo Simulation based BIM Data Sample.....	349

LIST OF FIGURES

Figure 1. Research's aspects interrelationships	10
Figure 2. The research logic of proposed methods	14
Figure 3. The interrelationships between thesis' chapters	23
Figure 4. Cost management through the project lifecycle (Kujala et al., 2014)	28
Figure 5. The architectural system of EVM data collection and analysis (Wilson et al., 2013).44	
Figure 6. The IPD stages and the involved parties during each stage (AIA, 2010).	48
Figure 7. Design effect/effort for traditional and integrated methods (AIA, 2010).	49
Figure 8. Compensation approach structure, adapted from Zhang and Li (2014)	51
Figure 9. OPS ranges for Risk/Reward ratio, adapted from Ross (2003)	52
Figure 10. Illustrates the differences between the different levels of adopting BIM (Porwal and Hewage, 2013).	55
Figure 11. The research onion (adapted from (Saunders et al., 2007))	106
Figure 12. A snapshot of the creation of themes using “Nvivo”	131
Figure 13. the entire research design.....	133
Figure 14. The profession of participants.	140
Figure 15. Shows the experience ranges of the survey participants.....	141
Figure 16. The BIM disciplines for participants	142
Figure 17. The BIM implementation level of the participants' organisations	143
Figure 18. The performance of 5D BIM for cost estimation process.....	144
Figure 19. The proportion of overhead costs for participants' organisations/projects	145
Figure 20. The Method of determining the overhead cost	145
Figure 21. The applicability of Activity Based Costing (ABC).....	146
Figure 22. The participants' experiences with IPD	150
Figure 23. Measuring the understanding of participants in relation to IPD	151
Figure 24. Cost estimation within conceptualisation and outline design stages	163
Figure 25. ABC Hierarchy levels: Comparison between traditional delivery operational levels (left) and IPD approach (right).....	165
Figure 26. ABC structure sheet with correlation between 4D/5D BIM.....	167
Figure 27. Compensation under the IPD approach using ABC estimation.....	169
Figure 28. Structure of IPD cost estimation for each party.....	169
Figure 29. Cost estimation data flow within IPD pre-construction stages.....	171
Figure 30. Data Flow within IPD Approach	174
Figure 31. Proposed cash flow of IPD approach.....	176
Figure 32. IPD Cash Flow Scenarios	177
Figure 33. BIM and IPD Cash Flow Correlation	178
Figure 34. Compensation under the IPD approach using ABC estimation.....	180
Figure 35. Function to assess the overall project situation and the limb location.....	181
Figure 36. EVM-Based IPD with considering ABC estimating approach.....	186
Figure 37. EVM-based IPD approach implementation flowchart.....	188
Figure 38. The summary of the framework tasks over the IPD stages	190
Figure 39. The framework: IPD-based hyperledger fabric	196
Figure 40. The architecture of the IPD-based smart contract transaction	198
Figure 41. The interoperability among BIM, IPD and the chaincode system.....	201
Figure 42. The Database structure of the CCMS	207
Figure 43. The structure of the database tables of the CCMS.....	209
Figure 44. The entry form of the CCMS.....	212

Figure 45. The user interface of the CCMS	213
Figure 46. Snapshot of the Macro and a sample of added message to direct the users.....	213
Figure 47. The CCMS4IPD non-data pages	215
Figure 48. The structure of the CCMS4IPD based web system.....	216
Figure 49. The database tables and web-pages	217
Figure 50. The cost management contents of CCMS4IPD	219
Figure 51. The financial report pages	222
Figure 52. The path of creating data within the CCMS	223
Figure 53. The logic of the proposed “Proof of Concept” blockchain based IPD framework.	226
Figure 54. The developed blockchain network based on IPD.....	228
Figure 55. The MSP for the organisation members	229
Figure 56. Creating a channel to assign the data to the network participants	230
Figure 57. Snapshot of the developed chaincode based on IPD financial transactions	231
Figure 58. Snapshot of installing and instantiating smart contracts on blockchain-IPD network	232
Figure 59. Total material and labour costs prepared by Monte Carlo simulation.....	237
Figure 60. Organisation overhead costs (ABC estimation).....	237
Figure 61. Cost drivers of overhead operations	238
Figure 62. The ABC cost structure of the case study.....	239
Figure 63. IPD cost structure using two costing methods.....	243
Figure 64. Deviations between ABC estimation and traditional estimation for each package .	243
Figure 65. The overhead contribution level between all participants	245
Figure 66. Snapshots of the cost estimation data from the CCMS4IPD web system	246
Figure 67. 4D BIM - Navisworks Platform	248
Figure 68. 5D BIM model - Navisworks Platform	248
Figure 69. Estimated overdraft of each Package.....	256
Figure 70. Packages cash in deviations’ percentage	257
Figure 71. Cost budget data based CCMS4IPD web system	259
Figure 72. The IPD cost structure	260
Figure 73. The risk/reward report for scenario 1	262
Figure 74. The risk/reward report for scenario 2 and 3.....	265
Figure 75. Result analysis of displaying risk/reward values on EVM-web system	268
Figure 76. The respondents’ level of understanding IPD approach.....	272
Figure 77. The generated codes according to interviewee’s responses.....	274
Figure 78. The mind map of the interview codes.....	274
Figure 79. The outcome of words relationships search for words (Trust, collaboration, transparency).....	276
Figure 80. The outcome of words relationships search for words (Information).....	278
Figure 81. The outcome of words relationships search for words (framework)	279
Figure 82. The outcome of words relationships search for words (blockchain).	280
Figure 83. The outcome of words relationships search for words (Yes)	281

LIST OF TABLES

Table 1. Cost management challenges of IPD approach.....	76
Table 2. The related works of blockchain.....	91
Table 3.The permissioned blockchain platforms and the IPD financial characteristics	97
Table 4.the Cronbach alpha coefficient (CA) test for the questionnaire results	139
Table 5.The descriptive statistics of the EVM performance and the generic BIM-based cost management	147
Table 6.The descriptive statistics of the evaluation of the current 4D/5D BIM integration	148
Table 7.Adding features to BIM-based cost management	149
Table 8.The IPD main barriers.....	152
Table 9.The proposed solutions to improve cost management practices of the IPD	153
Table 10.Cases summary and required models.....	182
Table 11.The evaluation of financial parameters during the IPD close-out stage	199
Table 12.Compensation structure components	240
Table 13.ABC hierarchy contribution.....	244
Table 14.Cost Packages	250
Table 15.Estimated Cash Flow Distribution	250
Table 16.Monthly cost data – Scenario 1	260
Table 17.Monthly cost data - Scenario 2 and 3.....	263
Table 18.The characteristic of interviewees	271

CHAPTER ONE: RESEARCH OVERVIEW

1.1.INTRODUCTION

This chapter presented the research background and how the proposed cost management system is important for the IPD approach. The research gap to show the motivation beyond this research is introduced, as well as, presenting the justified reasons beyond each tool and techniques that are used to develop the proposed framework. Research aim and objectives are introduced by highlighting the proposed research methods to fulfil the mentioned objectives. To show the significance of the research, the function of each tool in the framework (i.e. EVM-Grid and blockchain) is presented with highlighting how each tool can contribute to the body of the knowledge, as well as, industry practitioners.

1.2.BACKGROUND

Integrated Project Delivery (IPD) is characterised by the early, collaborative and collective engagement of key stakeholders through all phases of delivering a project (Ashcraft, 2014a, Ahmad et al., 2019). Compared to common methods of project delivery, such as design-bid-build, construction management at-risk and design-build, IPD is proving distinctly superior in performance (Asmar et al., 2016, Manata et al., 2018). Evidence shows that IPD can result in improving 14 metrics of project performance with these including quality, scheduling, communication management and cost performance, among others (Asmar et al., 2016, Ahmad et al., 2019).

IPD relies on open pricing techniques and fiscal transparency among participants (Ahmad et al., 2019). In addition, project stakeholders, such as designers and contractors, typically assess and determine their profit and shared risks, according to the deviation between actual and target costs (AIA, 2007).

Evidence, however, shows that the percentage of real-life projects using IPD is small (Pishdad-Bozorgi, 2017, Hamzeh et al., 2019), mainly due to the negative influence of

barriers that hinder widespread use of IPD (Ghassemi and Becerik-Gerber, 2011b, Sun et al., 2015, Teng et al., 2017). Successful delivery of a project through IPD is not easy, and IPD requires fulfilling a wide range of requirements and establishing various support systems (Fischer et al., 2017b). 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 (Kent and Becerik-Gerber, 2010, Smith et al., 2011). Of these, the IPD compensation model, also called risk/reward compensation, is of cardinal importance (Ma et al., 2018) and described as a key principle of IPD (Ma et al., 2018) that plays a pivotal role in stimulating creativity, motivating collaboration, and sustaining performance (Liu and Bates, 2013, Zhang and Li, 2014). Lack of a proper IPD compensation model is seen as a formidable barrier to the use of IPD on construction projects (Zhang and Chen, 2010).

As aforementioned, IPD is characterised by; (1) early involvement of project participants (AIA, 2007, Allison et al., 2018), (2) sharing risk/reward (Allison et al., 2018, Ballard et al., 2015a), (3) replacing the tender stage by buyout stage without traditional bidding (AIA, 2007), (4) deferring paying profits until all project works are completed (Roy et al., 2018). Therefore, IPD requires a distinguished financial management approach, as well as, a collaboration platform (Roy et al., 2018, Allison et al., 2018). A review of the literature indicates that the required financial system and the collaboration platform for IPD project must satisfy several requirements, these are; (1) readable/consistent accounting system is needed (Roy et al., 2018), (2) all project participants can check all cost records for each other (Allison et al., 2018), (3) all recorded data should be immutable to achieve the desired trust environment (Allison et al., 2018, Roy et al., 2018), (4) the collaboration platform should be inaccessible for any third party (Ma et al., 2018).

Cost management practices in IPD are not yet well established (Chen et al., 2012). This warrants expansion of the capacity of BIM in the form of an innovative cost estimation solution to support the TVD process (Pishdad-Bozorgi et al., 2013, Hall et al., 2018, Alves et al., 2017), with this being the primary objective of the current study. 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 (Ma et al., 2018, Zhang and Li, 2014). The cost structure applied for IPD must ensure that there is no hidden profit in the estimated cost (Allison et al., 2018), and achieve the purpose of fostering trust among project parties (Ma et al., 2018, Pishdad-Bozorgi and Beliveau, 2016, AIA, 2007, Pishdad-Bozorgi and Srivastava, 2018, Pishdad-Bozorgi et al., 2013, Teng et al., 2017). Any inaccuracy in data handling and usage – influencing determining the individual trade package – will affect the value of the proportions of the profit-at-risk percentage of each member in the IPD team. All members must be continuously involved and attend all meetings, even when their tasks are completed (Roy et al., 2018). As such, using web-based platforms is important to effectively share the needed information among parties, regardless of their geographical locations and disparity.

Cost estimation is essential for the compensation arrangement, which defines accurate risk/reward proportions (Love et al., 2011). Therefore, accurate cost estimation is vital for the successful delivery of the IPD-based projects (Allison et al., 2017, AIA, 2007, Ebrahimi and Dowlatabadi, 2018). Target value design (TVD) is treated as part of the IPD approach, with TVD requiring rapid cycles of suggestions and analyses of costs (Alves et al., 2017). Therefore, continuous estimation feedback is essential for accomplishing the pre-construction IPD stages and making informed decisions (Allison et al., 2017, Zimina et al., 2012). With these facts in mind, a precise semi-automated,

agile estimation technique that is interoperable with BIM data is deemed an ideal solution (Pishdad-Bozorgi et al., 2013).

This study contributes to the field by addressing the need for a TVD-based solution for IPD, based on BIM's capabilities. In broader terms, the study provides a background for addressing the need for accurate cost estimations at planning stages of IPD projects, in which, little research currently exists (Andersen et al., 2016, Welde and Odeck, 2017). The practicality and potential advantages of the proposed solution are tested in a case study project, by comparing its performance against that of common traditional methods. 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 (Teng et al., 2017, Allison et al., 2018). Besides, all parties in IPD are equally held responsible for the entire project performance (AIA, 2007, Allison et al., 2018), 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 (Allison et al., 2018).

This research adopts Activity Based Costing (ABC) for its ability to distinguish between cost structure's elements. ABC prevents this distortion by allocating the costs through multi-pools and determines the overhead activities and costs needed to transform the resources into activities that can deliver the final product (Kim and Ballard, 2001, Kim and Kim, 2016). The traditional integration of cost and schedule is time-consuming and causes a significant waste of information (Kaka, 1996). Kim and Grobler (2013) state that utilising Building Information Modelling (BIM) can improve the traditional cost/scheduling processes. Lu et al. (2016) state that there have been several studies for analysing cash flow processes, however, most of the research does not consider the differences between project delivery approaches. Since each delivery approach has the

distinguished relationship between project parties, therefore, the management of cash out should be compatible with the delivery approach. Regarding the cost budget, which is formulated by assigning cost estimation to project timeline, this research adopts 4D/5D BIM to generate the project budget, subsequently, the project's cash-out (S curve) will be structured using proposed ABC cost sheets after integrating into automated 4D BIM. Since IPD relies on profit-at-risk percentage for payment, therefore the proposed cash-in will be formulated as proportional cash-in during IPD buyout stage for an informed decision.

In the IPD approach, the risk and reward must be shared and allocated to all participants in core project teams, necessitating joint project control (Ashcraft, 2011, Fischer et al., 2017b). 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 (Zhang and Chen, 2010, AIA, 2007). 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 (Kent and Becerik-Gerber, 2010). 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 (Ashcraft, 2011, AIA, 2007).

Traditional forms of IPD, such as alliancing, can be implemented without BIM. However, new forms of the IPD are defined in relation to their integration with BIM (Fischer et al., 2017a, Rowlinson, 2017), which facilitates smooth data exchange between a project's packages and parties, in line with IPD's aims and objectives (Niemann, 2017, AIA, 2007).

The integration of BIM and IPD improves all likely outcomes of the design and construction process, including cost/profit, the schedule, return on investment (RoI), safety, productivity and relationships (Ilozor and Kelly, 2012, Azhar et al., 2015).

With the above in mind, IPD as a delivery method is largely promoted for its potential for integration with BIM in construction projects (Fischer et al., 2017b). Coupling BIM with IPD is proven to improve efficiency, reduce errors, enable exploring alternative approaches, as well as expanding market opportunities on projects (Kent and Becerik-Gerber, 2010). In fact, “the full potential benefits of IPD and BIM are achieved only when they are used together” (Ashcraft, 2008). Therefore, control of construction on IPD projects can rely on data-rich BIM models, with a focus on exploiting BIM in integrating information flows (Turkan et al., 2012, Ma et al., 2017). Such combined use of IPD and BIM makes sense from a theoretical perspective, but in reality, it faces substantial roadblocks (Holzer, 2011). 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. (Jaselskis et al., 2005, Hosseini et al., 2018). Despite the undeniable advantages, these methods almost entirely measure physical items and components on construction sites, overlooking the value of activities (Turkan et al., 2012, Turkan et al., 2013). 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 (Merschbrock et al., 2018, Mignone et al., 2016), and information systems loosely coupled (Shen et al., 2012, Hosseini et al., 2018). 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 (Lee et al., 2017, Pishdad-Bozorgi et al., 2013).

As another advanced methodology in the AEC industry, BIM is designed to enhance project delivery (Azhar et al., 2012). That said, some deficiencies appear, like the lack of traditional delivery approaches to foster the adoption of BIM (Nawi et al., 2014). The most advanced form of BIM implementation, termed as BIM level-3, relies on a delivery approach that facilitates collaboration and sharing risk/reward among project parties (Wickersham, 2009). With that in mind, the interrelationship between BIM and IPD is highly recommended by many researchers (Mathews et al., 2017, Nawi et al., 2014, Allison et al., 2018). Moreover, integrating BIM with blockchain is also highly recommended ((ICE), 2018, Mason and Escott, 2018, Lamb, 2018). The recent wave of research in the AEC industry presents the feasibility of integrating blockchain into construction processes to accelerate collaboration, maximise trust, and cut cost by minimising third party involvement in legal/financial tasks (Li et al., 2019b, Tozzi, 2018).

IPD requires high levels of information and communication technology adoption, to enable parties to interact and share sensitive data (Ahmad et al., 2019). Blockchain can, therefore, be an ideal solution, the reasons being: it is defined as a distributed ledger that is advantaged by decentralising the operation across the network through a specific consensus mechanism (i.e. peer to peer) (Li et al., 2019a), all data are presented as a block, which, will be immutable once joined the chain, and the self-authentication for all new recorded data (Turk and Klinc, 2017, Kinnaird et al., 2018). Recently, both researchers and practitioners have paid significant attention to exploring various forms of applying blockchain across the AEC industry. One particular area of interest in construction management has been the use of smart contracts to automate payments without appointing a third party and sharing data through a decentralised platform ((ICE), 2018, Li et al., 2019a, Turk and Klinc, 2017). As such, the AEC industry begins to explore blockchain opportunities in creating immutable financial systems (Lamb, 2018, Turk and Klinc,

2017), sharing information in a highly secured platform ((ICE), 2018, Lamb, 2018) and using smart contracts to automate payments (Lamb, 2018, Turk and Kline, 2017).

Various researchers have acknowledged the capabilities of blockchain in offering solutions for the deficiencies of existing financial systems. Among these, Li et al. (2019a) presented some generic cases about the application of blockchain in the AEC industry, and Wang et al. (2017), Turk and Kline (2017) discussed the potentials of blockchain to enhance construction management processes and tools. Other studies have investigated the integration of blockchain and BIM, like the work by Mathews et al. (2017), in which the authors argued how blockchain can enhance collaboration in using BIM.

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/reward rely upon completing all project activities (Roy et al., 2018), and there exist several issues with managing the financial data, such as; 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 (Allison et al., 2018). 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 (Ahmad et al., 2019, Ma et al., 2018). Moreover, face-to-face collaborations for IPD arrangements are considered expensive, disruptive and inefficient (Oraee et al., 2017). 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

(Mignone et al., 2016, Merschbrock et al., 2018). The above facts reinforce the urgency of using web-based platforms.

This research 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 (PMI, 2013). Besides, EVM can provide performance metrics for both cost and schedule alike in an integrated pool (de Andrade et al., 2019). The model, therefore, is designed to draw upon EVM, and the proposed risk/reward system is supported by a web grid to enable visualising the project status, since 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 visually. None of the available studies, however, go beyond the theoretical realm of integrating blockchain to manage the financial transactions in the construction projects, namely, their contribution remains confined to proposing conceptual frameworks or theoretical models. The present study provides a background in responding to the widespread consensus on the capabilities of blockchain in construction management. It extends existing research studies by moving beyond theoretical models and developing a workable solution. Particularly, to develop an automated distributed financial system of the IPD approach.

To sum up, a Centralised Cost Management System (CCMS) to implement the proposed tools and methods in the framework, and a Decentralised Cost Management System (DCMS) using blockchain technologies is developed in this research. Both CCMS and DCMS systems are interoperable, even though each system has a distinct role. Figure 1 illustrates the interrelationship between the highlighted research components.

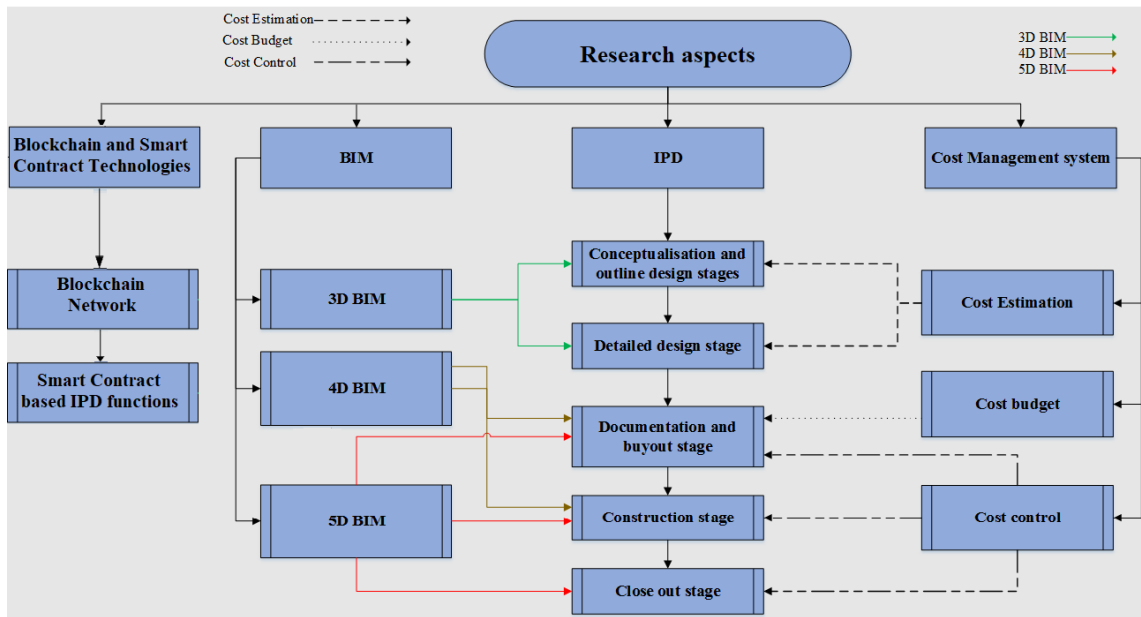


Figure 1. Research's aspects interrelationships

1.3.RESEARCH AIM AND OBJECTIVES

The research aim is to develop an automated cost management system for the IPD approach based on BIM and blockchain. This aim will be accomplished as follows:

1. To explore the existing cost management practices for the IPD approach, as well as, identifying the deficiencies in the existing practices.
2. To explore and verify the capabilities of the existing tools that can enhance the cost management process for the IPD approach.
3. To develop a framework that deals with identified challenges of cost management practices with implementing the IPD approach. Given, the cost management process comprises of three main processes, therefore, the framework will be divided as follows:

3.1.To revolutionise the cost structure of IPD through integrating Activity Based Costing into BIM.

- 3.2.To develop a budgeting methodology that enables project participants making the right decisions, this methodology depends on the integration of 4D and 5D BIM and ABC.
- 3.3.To develop statistical models to control project cost/schedules with enabling determine risk/ reward monetary values for each party at each payment milestone.
- 3.4.To exploit the revolutionary blockchain technology to automate the main three transactions (reimbursed costs, cost saving and profit). There are two main reasons beyond the adoption of blockchain:
- 3.4.1. To enhance the transparency among project parties by keeping all done transactions away from any amendments since this is the main feature of the blockchain Distributed Ledgers (DL).
- 3.4.2. To assess the performance of project parties during the project execution, this could be done in buyout stage through inquiring the value of the three transactions (reimbursed costs, cost saving and profit).
4. To develop and verify a “proof of Concept” that demonstrate all proposed tools of the developed framework using BIM and Blockchain technologies.
5. To evaluate the research outcome and measure the potential user's satisfaction for the developed tools, as well as, making recommendations for future research.

1.4.RESEARCH METHODOLOGY

Myers (2019) states that research methodology is the strategy to collect the required research data to move from the research hypothesis to research design and data collecting. There are two types of the methodology; quantitative and qualitative methods. Quantitative methods are usually used to collect data for the natural science to explore

the natural phenomenon, and the qualitative methods are developed to study the phenomenon which pertains to social effects. The mixed research method is implying a multi-research method to investigate a wide range of complicated data and complex research design to understand and analyse the research contents (Brannen, 2005). D. Holt and S. Goulding (2014) state most research in Building Construction Research (BCR) are usually conducted using mixed research method, entailing pragmatic view of expected findings. Therefore, the mixed research method selected in this research, therefore, this research requires to conduct both quantitative methods, such as case studies and questionnaire, and qualitative methods such as literature review and interview.

1.4.1. The Adopted Methods

The proposed mixed research methods to fulfil objectives are presented as follows:

- The literature review is adopted to highlight the research gap through studying and analysing the extant research in the research scope (i.e. IPD, BIM, cost management and blockchain). It is also used also to direct researcher regarding the abilities of some existing tools and techniques, which, can be integrated to fill revealed gaps.
- The questionnaire is used to explore the gaps from the expert's perspectives to confirm the literature review findings, and exploring a solution to fill these gaps and rate the validity of proposed solutions.
- Develop a framework to deal with key identified gaps in the IPD cost management process including estimation, budgeting and control through using different tools such as Monte Carlo Simulation, ABC, EVM, as well as, ICT technologies, such as BIM, web-based management systems and blockchain.

- Prototype development to enable implementing the proposed framework and test its applicability.
- An illustrative case study is used to validate the applicability and practicability of the developed tools such as CCMS, CCMS4IPD web system and blockchain network.
- The interview is adopted to appraise the research findings for both framework and prototype tools. To ensure the reliability of the data collection, the interviewees have been selected with a high level of BIM and IPD experience.

Figure 2 shows the role of each method to conduct specific tasks. It can be seen that the research process is divided into two main processes, which are solution development and the validation process.

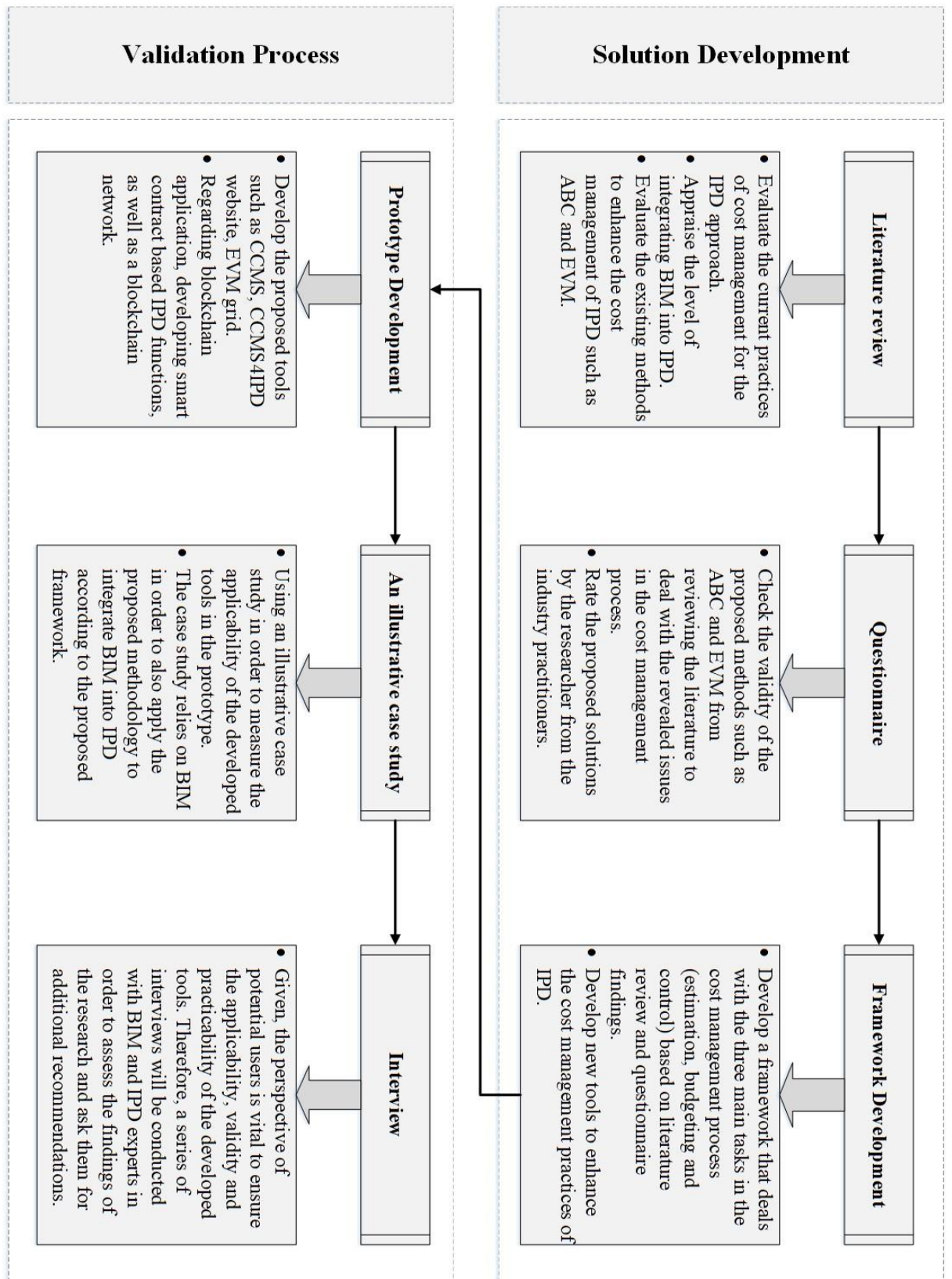


Figure 2.The research logic of proposed methods

1.5.RESEARCH MOTIVATION AND GAP

Given that the Cost Management Process (CMP) comprises of three main stages, namely; estimation, budgeting and control, this study should departure from the point of critique existing practices for each task. In order to justify the reason for undertaking this research, the challenges that face each stage in the CMP with IPD and BIM share presented. Before discussing the lack in each stage in CMP, the motivation of developing the proposed automated system is highlighted.

Given that IPD relies on sharing risk/reward as a financial system (AIA, 2007, Allison et al., 2018), as well as requiring a continuous estimation feedback during the pre-detailed design stage (Allison et al., 2018), particularly, Target Value Design (TVD) is recommended to be adopted with IPD design stages. Therefore, the efficiency of the cost management is vital to ensure the success of implementing IPD. Financial challenges within IPD implementation becomes a trend in several research, such as Roy et al. (2018), Ballard et al. (2015a), Tillmann et al. (2017), Azhar et al. (2015), Teng et al. (2017), Teng et al. (2019). From extant literature review, the most common challenges were developing a fair compensation structure (Ghassemi and Becerik-Gerber, 2011c, Kent and Becerik-Gerber, 2010), fair risk/reward sharing among all parties (Ashcraft, 2012, Teng et al., 2019), the accounting system is unclear and unreadable (Lichtig, 2006), controlling the achieved profits in case that the project has long duration(Ashcraft, 2012). Hereby, this leads to the necessity of developing an integrated cost management system that should be characterised by (1) providing a reliable and continuous estimation feedback to achieve TVD parameters; (2) optimising the cost structure profile through splitting the overhead costs from the profit; (3) providing a detailed budgeted plan during the IPD buyout stage that helps project participants to take the right decision before commencing construction stage; (4) determining risk/reward automatically; (5) displaying the risk/reward values for

each participants on a smart system to enable detecting all profit/risk that achieved by all core team members; (6) Ensuring that all data regarding, reimbursed costs, cost saving and profit pools.

There are several reasons for utilising BIM tools in the cost management process, firstly, BIM is integrated into each IPD stages as presented by (AIA, 2007, Allison et al., 2018), as well as, it is recommended by many researchers as a way to accelerate both BIM and IPD adoption (Mathews et al., 2017, Nawi et al., 2014, Pishdad-Bozorgi et al., 2013, Rowlinson, 2017). Secondly, the technical capabilities of BIM to provide an automated BoQ during different stages in the design (Aibinu and Venkatesh, 2013), simulating project planning and scheduling with defining task types (Hartmann et al., 2008, Turkan et al., 2012). Even though, there is not a workable methodology to demonstrate the correlations between BIM dimensions and IPD stages (Allison et al., 2018, Roy et al., 2018), there are several attempts to develop an integrated cost management system, such as Theodorakopoulos (2017) developed an integrated cost management system for construction delivery project, however, the developed system does not consider the different characteristics for each construction stage such as the mechanism of cost management tasks during the pre-detailed design stage. Moreover, the cost control process is not enough developed as the researcher used EVM system without linking it with the budgeting stage. Although BIM level 2 becomes mandatory in many countries (Ganah and John, 2014, Davies et al., 2015), BIM has not been exploited in this system.

With all above in mind, this research develops an integrated cost management system that comprises of two sub-systems as follows:

- Centralised Cost Management System (CCMS): In this system, adoption and adaption of such methods and tools such as ABC, EVM, BIM and web-based management systems in order to develop a system that manages all revealed

deficiencies. On other words, this research explores two sides of a method, first, to exploit the method to perform a specific task in the proposed system, second, to enhance the function of a method whether by integrating it into another (i.e. ABC into EVM to enable controlling all project costs) or extending a method such as EVM method (i.e. EVM grid to avoid the common EVM shortcoming regarding visualising cost control data).

- Decentralised Cost Management System (DCMS): developing a smart contract-based IPD approach in order to enable sharing and auditing risk/reward data automatically, in which, this can enhance the trust and collaboration among IPD core team members.

1.6.CONTRIBUTION TO THE BODY OF KNOWLEDGE

Recognising that the traditional cost management process cannot be used in implementing BIM within IPD, due to the new IPD requirements, such as risk/reward sharing approach. Moreover, the project development stages are completely different from traditional procurement approach, hence, the need to develop an automated and integrated cost management system for the IPD becomes a necessity to successful project delivery as aforementioned in the research gap section. With all above in mind, this research contributes to the theoretical knowledge as follows:

- Dealing with all elements which pertain to cost management system: first, develop a method for an early cost estimation using Monte Carlo simulation by exploiting data availability from early involvement of participants, which enable participants to make the right decision before commencing detailed design stage; second, integrating ABC into cost estimation, budget and control for fair risk/reward sharing due to its ability to distinguish between different cost elements which enables implementing IPD; third, adapting EVM for

integrated cost control with providing a comprehensive report that includes the fair ratio in terms of risk/reward for each party. The adapted EVM will be connected with the web system to enable easy tracking for all participants.

- The proposed EVM-Grid (a new visualisation tool for EVM output) will enable to locate the party's performance regarding cost and schedule by a visualised way. 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 the potential nine project cases on the grid, whilst considering the 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 a positive or negative percentage to determine the project situation at each milestone or for each package. The quantity surveyor should mark the square in accordance with the CPR and SPR percentages to determine the cumulative progress throughout the project execution stages. This research will give an accumulative indicator to all parties' performance during the closeout stage.
- As blockchain is widely recommended by many research institutes and industry companies to be integrated into the construction industry, therefore the blockchain is exploited to automate the payment as well as keeping all data regarding achieved cost saving, profits and reimbursed costs without any amendments from any party. A framework is developed to essence the concepts of consensus mechanism for the IPD approach based on BIM. As well as, showing how the endorsement policy should be formulated based on IPD characteristics. Moreover, proposing a way of integrating IPD, BIM and blockchain in an integrated context.

In addition to the mentioned theoretical contribution, this research has invaluable practical contribution as follows:

- Developing an integrated platform for the CCMS that includes a user-friendly database that enables potential users implementing the developed cost estimation methodology in the framework. The developed database includes a set of forms to enable entering the data. This database is linked with an online database to enable creating them as web pages and then sharing them as an interactive web-based management system to enable parties to interact with the cost data throughout the different stage of the IPD. The system is also operated automatically with enabling the Macros features as the database is designed using MS Access, therefore, this enables the users to finish all tasks efficiently. Additionally, the EVM-Grid is developed using MS Excel with enabling Macros feature to automate the process, therefore, this enables automating the process once the user enters the CPI and SPI data. The web-based management system is developed under the name of CCMS4IPD, this website works as an interactive environment that includes all cost data (Estimation, budgeting, control and sharing risk/reward). This website enables the parties to get a comprehensive financial report that includes the three main transactions—Reimbursed costs, profit and cost saving—for each milestone. As well as, the data that has been used in the calculations are also included in this report.
- Regarding using the Distributed Ledger Technologies (Blockchain) to develop a decentralised platform to share risk/reward among IPD core team members, this research presents practical solutions based on Blockchain with utilising the hyperledger fabric platform. A real smart contract functions were developed using IBM VS extension to develop a smart contract, as well as, a real blockchain

network is developed for a case study, therefore, the user in the future can use the presented methodology to develop their networks. This could increase the transparency, collaboration and security in using IPD as a delivery approach. As aforementioned, the proposed cost management system deal with all project's tasks from conceptualisation to close out stage and all its tools and methods are developed, specifically, for IPD approach using all BIM capabilities.

1.7.THESIS STRUCTURE

The thesis is structured from nine chapters (see figure 3), a summary of the content of each chapter is stated as follows.

Chapter 1: Introduction

This chapter provides a background about the research elements, research gap and motivation, research aim and objectives, research methodology and the correlation with the stated objectives and research significance and contribution. The structure of the thesis is also presented to direct the reader.

Chapter 2: Implications of cost management for BIM and IPD

This chapter presents a critical analysis of the traditional cost management process, exploring the requirements of the integrated cost management process, investigating different methods to enhance the cost management of the IPD. In addition, providing a theoretical background for the IPD approach, as well as, BIM.

Chapter 3: Overview of Information Communication Technology (ICT) and Blockchain in Construction Management

The theoretical background of ICT in the construction industry is presented in this chapter. Two applications of ICT such as web-based management system and blockchain

were explored. The previous research about the blockchain technology and its platforms such as hyperledger fabric are well-explained to enable the researcher to make a decision which platform is fit for the IPD approach.

Chapter 4: Research design and methodology

This chapter presented the research philosophy, approach and methods that were adopted to deliver the research's aim and objectives. Justifications for each adopted method is presented, as well as, explaining how the data will be collected and analysed for each method.

Chapter 5: Point of departure

After highlighting the deficiencies in the cost management practices for the IPD using literature review, as well as, the proposed methods to solve the revealed issues. A questionnaire is conducted to double-check the revealed problems from the industry perspectives, as well as, rating the validity of the proposed solutions. As such, the research can start developing integrated solutions.

Chapter 6: Framework development

This chapter includes the solution of the revealed gap. A comprehensive framework is developed including solutions of (1) cost estimation solution, (2) new cost budget methodology based on BIM, (3) new risk/reward calculation models, (4) integrating ICT applications such as web-based management system and blockchain to enhance sharing data among IPD core team members.

Chapter 7: Prototype Validation and Testing

Given that the framework proposes a set of tools to implement the developed solutions (ideas), therefore, this chapter includes the development process of these tools such as the

CCMS and the web-based management system (CCMS4IPD). Moreover, the blockchain based IPD smart contract and network. In order to validate the applicability of the developed tools, an illustrative case study was used and findings are stated in this chapter.

Chapter 8: Validation of research findings

In order to measure the applicability, validity and reliability, an evaluation by experts is conducted using the interview method. This chapter includes details about the participants and the thematic analysis of the contents of the interviews.

Chapter 9: Conclusion

This chapter includes a summary of the findings in corresponding to each objective, as well as, the research contribution to knowledge and practice. Moreover, the research limitations. In addition, future research is also presented in this chapter.

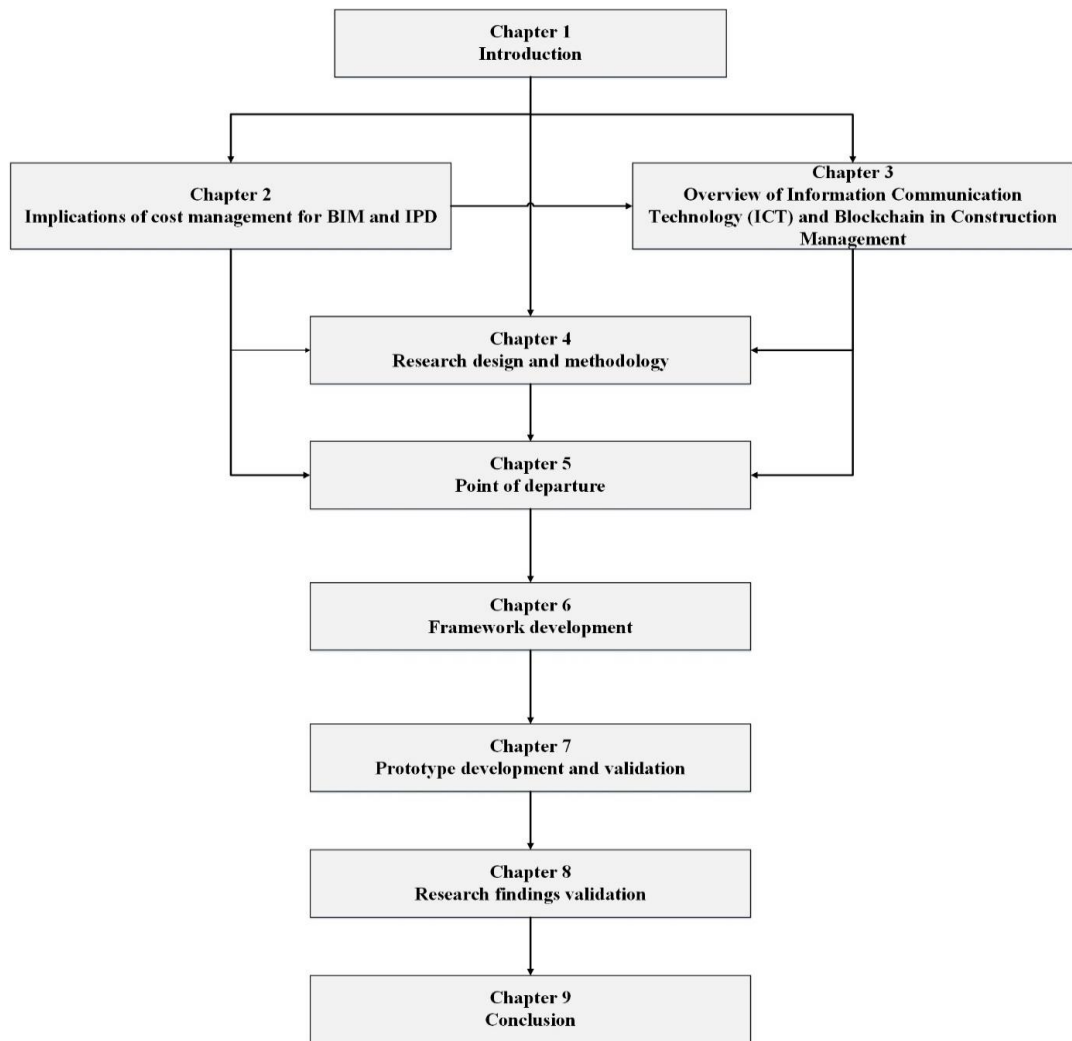


Figure 3.The interrelationships between thesis' chapters

1.8.CHAPTER SUMMARY

This chapter presented the research background and how the proposed cost management system is important for the IPD approach. The research gap to show the motivation beyond this research is introduced, as well as, presenting the justified reasons beyond each tool and techniques that are used to develop the proposed framework. Research aim and objectives are introduced by highlighting the proposed research methods to fulfil the mentioned objectives. To show the significance of the research, the function of each tool in the framework (i.e. EVM-Grid and blockchain) is presented with highlighting how each tool can contribute to the body of the knowledge, as well as, industry practitioners.

CHAPTER TWO: IMPLICATIONS OF COST MANAGEMENT FOR BIM AND IPD

2.1. INTRODUCTION

This chapter explores the cost management practices in the construction industry in general and specifically for the IPD approach. The existing challenges which face the cost management process and tasks such as estimation, budgeting, and control challenges will be discussed. The previous studies for each process of the cost management for the IPD approach will be critically analysed in order to highlight the current status and practices, consequently, the research gap will be clear. In addition, this chapter presents a critical evaluations of different methods to measure their validity to bridge the highlighted gap such as using EVM and ABC to enhance the efficiency of the cost management process for the IPD approach, particularly, the risk/reward sharing among IPD core team members. The capabilities/characteristics of the IPD is discussed in this chapter in order to highlight its cost management requirements. Moreover, a theoretical background about the BIM dimensions is developed to enable moving towards developing a solution., particularly, the 4D BIM (Planning and schedule) and 5D BIM (cost management) as these dimensions represent a significant part in this study.

2.2. BACKGROUND OF COST MANAGEMENT PROCESS

Ahmed (1995) states that the cost management process is a system of managing all cost tasks within the different stages in the construction project such as planning, construction, and closeout stages. The cost management system should include processes to manage each stage such as cost estimation, budget, and control (Horngren et al., 2002). Moreover, Oberlender and Oberlender (1993) mention that cost management plan is a “project money plan” and it represents the financial forecast action for the project and this requires to implement specific tasks to articulate this plan such as Estimation, budgeting, Control,

payment processing, and change management, etc. these tasks must be implemented in specific orders and stages in order to obtain a reliable cost management plan for the project (Kerzner, 2017).

Given that the cost plan is influenced by all decisions in the project, therefore, the cost plan should be flexible to deal with all changes as well as managing the data in a proper way (Potts and Ankrah, 2014). The cost management system has been defined by (Shank, 1989) as the framework of the project data and this system involves some tools and techniques to direct the project stakeholders during the entire project stages such as the estimation tools to support different managerial decision, as well as, providing a generic plan for the investment level, not only for the project level.

The most important activities in cost management process can be concluded as (1) the cost plan for preparing the needed data such as the price list, determining which estimation technique must be adopted in the project based on the availability of the data (Jorgensen and Shepperd, 2006), (2) cost estimation for the project design elements based on the completed design which can be extracted from tender documents (Niazi et al., 2006), (3) the cost control and accounting process throughout the construction stage such as preparing a payment invoices for the completed work (Leu and Lin, 2008), (4) Calculation of final accounts with considering the economic assessment. In addition to the cost management during the completion of the project, it also should consider the economic efficiency in its process such as measuring the life cost of the building to ensure that the whole Life Cost (WLC) is estimated (Szekeres, 2005).

2.3. THE TASKS OF THE COST MANAGEMENT PROCESS

2.3.1. Cost Estimation

Cost Estimation is the process of assembling and predicting the cost of the project (Schade, 2007), and this usually implements in specific stages as economic evaluation, project investment cost and cost forecasting (Doloi, 2011). Economic evaluation role is to determine which design alternative is technically, and financially feasible and this usually relies on the historical cost data records (Taal et al., 2003). When the project has its data as design drawings and tender documents, therefore, the project investment cost should be determined precisely by using specific techniques such as parametric estimation, reserve analysis, three points estimation, etc. (Lester, 2006, PMI, 2017). Ahiaga-Dagbui and Smith (2014) reported that the cost estimation task in the AEC industry is complicated due to the construction industry is risky and a considerable proportion of its process relies on the probability. Additionally, Shevchenko et al. (2008) state that each construction project is a unique due to it has a distinguished environment, as well as, different characteristics of participants affect the project cost since suppliers can provide a detailed price plan which is different from the main contractor one, accordingly, different cost estimation tools/techniques should be employed.

2.3.1.1. Cost Estimation on Construction Projects

Cost performance (meeting cost requirements), although frequently criticised, is still considered the gold standard for measuring project success (Berssaneti and Carvalho, 2015, Kim et al., 2004). Thus, cost estimation is an important element of project planning (Torp and Klakegg, 2016). According to the Project Management Institute (PMI (2017), cost estimation is the iterative process of estimating the project resources required for project activities; therefore, linking resources and activities is vital for successful cost

management. Major cost estimation activities must typically occur very early in a project at a time when minimal project information is available (Kim et al., 2004, Welde and Odeck, 2017); therefore, uncertainty remains a major cause of poor cost estimation across the construction industry (Johansen et al., 2014, Torp and Klakegg, 2016, Andersen et al., 2016). Uncertainty is identified as “controllable and non-controllable factors that may occur, and variation and foreseeable events that occur during project execution, and that have a significant impact on the project objective” (Johansen et al., 2014).

Many research studies have provided evidence that the greatest level of uncertainty for cost estimation purposes belongs to the feasibility study stages of projects, colloquially termed the ‘front-end’ of projects (Andersen et al., 2016, Welde and Odeck, 2017, Caffieri et al., 2018), where uncertainty levels ranging from -30% to +50% can be expected (Johansen et al., 2014). In IPD, the overall risk is equal to that of traditional methods, and the owner must guarantee the direct cost of projects (Ghassemi and Becerik-Gerber, 2011c). As a result, IPD relies heavily on cost estimation at the project feasibility study phase to develop a reliable business case for the client for decision-making purposes (Allison et al., 2017, Pishdad-Bozorgi et al., 2013).

2.3.2. Cost Budget and Control

Cost budgeting is the way of preparing the cost estimation as it will be spent/assigned and measured within the project phases, in other words, it is the outcome of allocating the cost estimation to the project timeline (Teicholz, 1993). It includes all required financial procedures in order to prepare the Budgeted Cost of Work Scheduled (BCWS) which will be used in the monitoring process (Caffieri et al., 2018).

Cost control can be defined as the process of gathering, accumulating, analysing, monitoring, reporting and managing the costs within the different stages in the

construction project (Al-Jibouri, 2003). Moreover, Georgas and Vallance, (1986) assert that the cost management functions must be interoperable with the other project management functions in order to ensure that the project will be accomplished under the triple constraints (Time, Cost, and Quality) (Heldman, 2018). Figure 4 shows that Cost

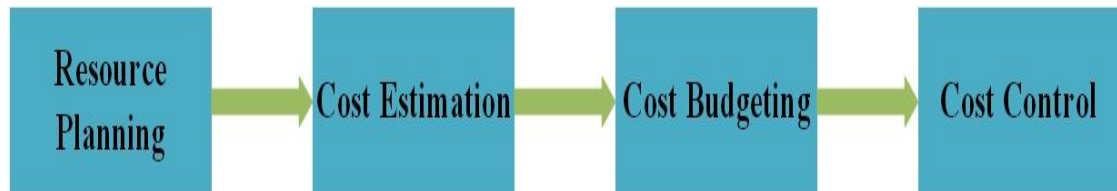


Figure 4. Cost management through the project lifecycle (Kujala et al., 2014)
management elements through the project lifecycle.

2.4. THE TRADITIONAL COST MANAGEMENT PROCESS

Hansen et al. (2007) mentions that traditional cost management system such as traditional budgeting, cost volume profit (CVP) analysis, and standard costing with analysing the variances are not adequate to manage the existing construction environment so that the cost management process should be able to evaluate and enhance the construction tasks, rather than managing them (Smith, 2004). Therefore, the cost management system should be coherent to ensure that all data will move smoothly between the different cost functions—estimation, budgeting and control— within the project implementation stages (Membah and Asa, 2015). Kern and Formoso (2004) reported that the traditional cost management system does not offer a flexible mechanism to collect the information at the early design stage, as well as, there is a gap between the cost functions and other project management functions, for example, cost control process estimates the progress in cost and schedule regardless of the quality of performed works.

Kaplan (1984) states that the existing cost management process has been developed since last three decades and it is not able to deal with the existing changes in the construction

industry, therefore, Innovative cost management tools should be integrated in order to accept the rapid changes and manage them properly. Moreover, the researcher mentions some criteria for the required cost management system such as managing inventory, quality, productivity, and accepting any innovation in the construction methods. Furthermore, there is lack of transferring cost data between the project stages (Kim et al., 2004), which leads to reduce the value of maximising the benefit of the available data and increasing the accuracy of cost estimation. For example, the lack of integrating cost and time in a single context in order to enhance the quality of the collected data (Lu et al., 2016). Subsequently, the cost management system should be able to provide the required data to enable the decision-making process throughout the different stages in the construction process and providing proactive and reliable solutions for the cost issues (Kaplan, 1998).

According to (Vojinovic and Kecman, 2001), most of the construction problems are non-linear and the traditional cost management system is designed to deal with the linear problems, that's why it failed to manage the actual problems or introducing reliable solutions. Therefore, the need to develop a sustainable and integrated cost management process/system is vital for implementing the construction projects (Phaobunjong and Popescu, 2003). Kern and Formoso (2006) state that cost management process is an integration between cost estimation and control tasks in a single/integrated environment in order to provide a sustainable cost data which allows to exchange the data smoothly between the estimation and control tasks without losing any data as well as enabling using the historical data for new projects (Liu et al., 2012, Amos, 2004). Therefore, the purpose of any cost management system is to evaluate the cost of the sacrificed resources to acquire an asset and to provide the project stakeholders by the required data to make the right decision regarding the capital and operating costs. As such, the total cost

management process should consider both the cost of delivering the project and the cost of managing the asset (Westland, 2007).

2.5. CHALLENGES OF THE COST MANAGEMENT PROCESSES

2.5.1. Cost Estimation Challenges

Shane et al. (2009) state that bias in estimation is one of the most important reasons of underestimating the budget, it is called optimistic estimation and usually the estimator goes to this in order to show the agency is much smart more than others.

Procurement approach is playing a significant role in cost estimation escalating due to the lack of risk-sharing system (Harbuck, 2004). Allocating some risks to the party who cannot be able to manage them will lead to increase the project cost due to the contingency cost will not be enough to cover the consequences of risks (Love et al., 2011). Moreover, the lack of experience in dealing with the procurement approach in a proper way can lead to increase the cost such as misleading in schedule acceleration can cause a cost overrun more than expected (ECONorthwest, 2002, Weiss, 2000).

Callahan (1998) mentions that the unplanned changes in the schedule lead to changes in the project budget during the execution process. Therefore, some companies adopt a strategy to review their budgets in a specific period in order to ensure that their projects remain on the company budget and if there is any change, these companies apply a technique which is called expenditure timing adjustments (Touran and Lopez, 2006, Hufschmidt and Gerin, 1970).

The complexity is inherent in the construction industry due to the location of the project or implementing several design changes in project elements which adversely affect the

constructability method, this can cause a problem in determining the properly planned cost value due to the uncertainty is very high with repetitive changes in the project plans (Touran and Lopez, 2006, Callahan, 1998). Consequently, coordination problems will be existing between different disciplines and some information will be missing and this might affects the accuracy of cost estimation (Shane et al., 2009, Kaliba et al., 2009).

Scope changes such as changes in design components or modifying the proposed function of some parts in the project which leads to some changes in project cost and schedule (Hussain, 2012, Khan, 2006). In case of these changes are not managed properly by the owner, this can be a major change in the project scope and in many cases, projects are implemented with achieving cost overrun and behind schedule (Alinaitwe et al., 2013).

Akintoye and Fitzgerald (2000) state that Poor estimation procedures can cause misunderstanding case in terms of the used formats, which do not provide an easy way to check, verify, and correct the estimated elements. Therefore, the procedures, formats, and methods should be understandable, and clear to enable the user to determine the cost (Reilly, 2005). Moreover, Poor estimation can lead to miss some data and give unreliable results which cause an underestimation case (Azhar et al., 2008). This will affect other processes such as scheduling, and misleading inventory plan which definitely will cause cost overrun by considerable variance from the planned value (Shane et al., 2009).

The misunderstanding of the contractual agreement plays an important role in misleading cost estimation, specifically, the misallocation of the responsibilities between the different participants can cause cost estimation issues (Zaghloul and Hartman, 2003, Ali and Kamaruzzaman, 2010, Le-Hoai et al., 2008). Moreover, the ambiguous in contract provision can be a reason for allocating the responsibilities in a wrong way such as who is responsible for implementing reworks or change orders (Touran and Lopez, 2006). The lack in execution cannot be ignored as one

of the most important reasons of cost overrun, as well as, the bad site management and misleading in the collaboration can lead to cost overrun due to the inability for the participants' representatives to determine the decision properly (Shane et al., 2009, Enshassi et al., 2009).

The aforementioned challenges in cost estimation lead to misleading determining the proper contingency cost (Moselhi and Salah, 2012), hence, the overall agreed budget will be unreliable and the party who carries the most significant part of risks will not be able to manage them and the project will be affected whether by misusing the contingency cost or facing a shortage in the contingency costs to cover the carried risks (Schexnayder et al., 2011).

2.5.2. Cost Budgeting and Controlling Implementation and Challenges

Due to the interrelationship between project budget and control (Wang et al., 2016), this section will explore the current challenges which face establishing a reliable budget and having a proper cost control process within the construction industry.

The historical cost records (Cost Accounting) is considered as the main source of data to estimate the project cost in case that the project data (documents) is not enough to draw the cost baseline (Niazi et al., 2006), therefore, any problem in the used formats to record the cost data can reflect adversely on the cost control report. Furthermore, the forecasting and budgeting tasks for a project should be consistent for all project elements in order to ensure that all project activities are considered in the project budget (Hamledari et al., 2017). Moreover, the lack of integration of schedule and estimated cost which shapes the project budget causes a problem for the cost control process due to the mechanism of assign and allocate the schedule components is different from cost, since the project schedule usually breaks down as Work Breakdown Structure (WBS) (Wang et al., 2016),

while the cost usually breaks down by one of these methods cost codes, transactions, and fiscal periods. As such, there is no consistency in integration between cost and schedule which leads to a great waste in project data (Bergerud, 2012).

The interoperability between different data sources in order to build the own project cost control sheets is revealed as a problem in terms of the alignment process from different data sheets to the own project sheet (GCR, 2004). One of the most important obstacles is the time which is required to format the cost control report due to these reports remain to be articulated manually or by using excel smart sheets, as well as, the inconsistency between the used codes between the different organisation maximises this problem and leads to losing some data during implementing this process (Bergerud, 2012).

The conflict between what the contractor needs to know from the cost control reports and the client or other stakeholders want to see is an issue, therefore, the output of cost control reports should be readable, understandable, and representable to all questions, particularly, for the main performance indicators such as the cost and schedule ratios (Kaplan, 1988). The accuracy of cost control report cannot be ignored as one of the cost control concerns due to the report should include the main collected data to ensure that all data has been analysed and considered to provide the cost control metrics (AbouRizk et al., 2002).

Changes in project scope or agreed quantities are proven as one of the most severe issues in conducting a proper cost control process since any variation should consider different aspects such procurement approach, project organisation, and type of the contract, therefore, the outcome of the cost control report will be read in the same context of the mentioned aspects (Alnuaimi et al., 2009). Therefore, the mismanagement in change order could cause several problems such as insufficient budget to finish the project, wrong

updated estimated schedule which can lead to stopping the project progression and generates conflicts between stakeholders (Bergerud, 2012).s

2.6. THE INTEGRATION CHALLENGES IN THE COST MANAGEMENT PROCESSES

Given that the cost management process is related to all project tasks, therefore, it is affected by all issues which are generated by other processes/tasks such as design, constructability methods, and the entire project management tasks. The poor practices in the design process, determining the project duration, collaboration and design reviews can affect negatively the cost management process (Ashworth and Perera, 2015, Hastak, 1998, Kern and Formoso, 2004). Similarly, the limitation of understanding the cost management process itself can cause misleading in all project tasks (Potts and Ankrah, 2008).

According to (Akintoye and Fitzgerald, 2000), the lack of cost data and interoperability between the available software —cost estimation platforms— is a major reason for unreliable cost estimation. Moreover, Potts and Ankrah (2008) assert that the existing computer platforms increase the risk of cost estimation around 5% more than traditional estimation. As such, the incompatibility between the existing platforms cause waste in data within the exchanging process and this has a significant implication in the cost management process (Kaplan, 1998, Eastman et al., 2011a).

The experience of project manager plays a major role in managing costs within construction stages and the inability of the project manager to choose the right estimation technique can mislead the sequence of other tasks such as budgeting, and controlling issues (Akintoye and Fitzgerald, 2000, Eastman et al., 2011a, Hastak, 1998). Therefore, the lack of experience in terms of choosing the right techniques and methods back to the limitations of project managers knowledge (Niazi et al., 2006). Akintoye and Fitzgerald

(2000) noted that there is another reason which prevents project manager to avail available detailed cost estimation technique, this reason is the lack of delivered design data and this drives the estimator to assume some parameters in order to accomplish the estimation, this leads to having an inaccurate estimation (Smith and Mason, 1997).

The competition process in the traditional procurement can lead to underestimate the project cost intentionally to win the bid and the problem will be revealed during the project life cycle (Hanid et al., 2011). However, the highlighted reason is not derived only by the estimator because the client can play a vital role in the underestimation decision which is called "production of socially acceptable estimates" in order to get the client satisfaction in terms of the proposed budget (Skitmore and Wilcock, 1994). These reasons are mainly related to the employed bid and tendering approach and choosing proper approaches will positively affect the cost management process.

The traditional philosophy of using the pre-construction cost estimation to control the project budget cause a limitation in cost reduction and value engineering (Hanid et al., 2011). Therefore, the process should focus on the objective behind the cost estimation, which is the function of the product that can positively enhance the project value. Kashiwagi and Savicky (2003) state that modern clients pay more attention to the project value, however, the existing methods are not able to consider all variables in a single purpose. Moreover, the detailed estimations techniques are not employed due to lack of exploiting the technology and unfamiliarity from users (Akintoye and Fitzgerald, 2000). As such, The value engineering should implemented as a cost-cutting tool, therefore, the integration between cost process and value management is a vital to enhance the cost management process (Venkataraman and Pinto, 2008).

According to (Doloi et al., 2011, Doloi, 2011), The estimation relies on the historically recorded data from previous projects such as BCIS, therefore, the quality of these data is

mandatory to ensure the reliability of estimated cost and any missed data will be filled by assumptions which lead to miscalculation (Elfving et al., 2005, Hanid et al., 2011).

The mechanism of collecting the project progress data is important in order to enhance the existing estimation for the remaining parts in the project as well as having a reliable cost data for future projects (Froese, 2010). Moreover, the lack of standardisation can be considered as one of the reasons to lose the data during the transferring tasks, and according to (Eastman et al., 2011a), the quality of cost data is vital to successful cost management in the AEC industry.

Eastman et al. (2011a) state that poor coordination and communication which is caused by conventional competition, intrust environment, selfishness, short term relationship and use of separate systems by the companies can increase the entire project cost. Moreover, the unavailability of required data can adversely affect the decision-making process (Lyon et al., 2000). Therefore, Cartlidge (2011) asserts that Information and Communication Technology (ICT) helps the project stakeholders to share the information, however, it is required a high level of details in order to build an integrated collaboration system. According to (Hwee and Tiong, 2002), using a fragmented cost management system is a reason of many problems in construction cost management process such as delays, unreliable cash flow, inaccurate measurement of performed works, interruption of project payments and leads to several variations in the project time and cost.

Favato and Mills (2007) noted that cost management practise has been increasingly criticised due to lack of efficiency to deal with the rapid changes in the industry environment, therefore, research is highly needed in order to draw an innovative cost system which relies on decision-relevant information, as well as, the proposed innovative system should focus on the structure of the enterprise and project organisation (Bakar and

Rahim, 2014). As such, any attempt to develop a new system in the isolation environment will be inadequate and strengthen the existing miscommunication case (Kaplan, 1998, Hegazy et al., 2004).

Favato and Mills (2007) identified specific criteria and principles for an integrated cost management system in relation to information and decision making needs to be taken by the project manager. These criteria can be concluded as (1) it should be consistent with the mission and goals of the organisation which to ensure exploiting all available data (i.e. previous bids data, analogous projects data, etc.) (Zutshi and Sohal, 2005), (2) the system should be able to respond to all client needs within the business process or construction project, this can be implemented by providing a sustainable cost data channel (Adams and Frost, 2008), (3) considering the horizontal/vertical supply chain participants which means that the designed information channel should be able to deliver the information to each participant whether in the horizontal level (the same level) or in the vertical level between the several hierarchal levels in the project/organisation (Fox et al., 1993), (4) the estimator must focus on the most effective 20% of cost data which represents 80 to 90% of the decision (Vojinovic and Kecman, 2001), (5) an automated allocation of responsibilities to who should take the required decision and the consequences related to this decision, as well as, the needed data to make this decision (Favato and Mills, 2007).

Implementing cost management tasks manually leads to some bad practice in terms of the quantity surveyor usually keen to afford the needed fund to the project rather than having a reliable estimation (Flyvbjerg et al., 2018). Moreover, completing the cost management tasks in the construction phase based on the estimated cost during the pre-construction stage leads to stop improving it to minimise the cost and do not consider any ideas to lean the project due to just 70-80% of the project information can be predicted in pre-

construction stages and remaining information comes later during the construction stage (Rush and Roy, 2000). Therefore, Koskela and Tommelein (2009) reported that Target Value Design techniques enable to improve the cost along with the design changes, subsequently, the cost management system should be compatible with the delivery approach.

According to Zimina et al. (2012), the integrated cost management approach should consider both cost estimation and control as a single process since they work together towards maximising the project value and minimising its waste (Do et al., 2014).

The need of an integrated system is early discussed by Glad et al. (1996), identified the desired integrated cost management system as the system which provides multidimensional functions in terms of customers, products, services, functions, processes and activities. As well as, focusing on cost planning rather than recording and tracking cost data (Boussabaine, 2013). Moreover, providing the decision-making system by all required information in the right time and working as a platform to all other business functions (Jato-Espino et al., 2014).

2.7. ACTIVITY BASED COSTING (ABC)

Traditional costing methods, termed resource-based costing (RBC), rely on the cost of the required resources (Kim and Ballard, 2001) and are still frequently applied. Cost distortion occurs when using these traditional methods as the methods combine and allocate all indirect costs to a single pool of costs, based on the resources common to all products of an organisation (Miller, 1996, Kim et al., 2011, Wang et al., 2010). In other words, traditional methods fail to find the key decision variables that affect the total cost, particularly overhead costs (Kim et al., 2016). Activity-based costing (ABC) prevents this distortion by allocating the costs through multi-pools: this method determines the overhead activities and costs needed to transform the resources into activities that can

deliver the final product (Kim and Ballard, 2001, Wang et al., 2010). An ABC approach can measure costs based on activities and link the cost drivers to the impact measures of a certain product or service (Tsai and Hung, 2009). The ABC method, therefore, can improve the efficiency and accuracy of cost-related information and further monitor and control project costs (Tsai et al., 2014). This claim becomes more valid in a collaborative working environment, such as IPD, in which multiple stakeholders, extending beyond the control of a single company, can affect cost drivers (Kim et al., 2016).

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, 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 (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 company products (Miller, 1996). 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 (Kim and Ballard, 2001, Kim et al., 2011).

2.8. COMPARISON OF ACTIVITY-BASED COSTING (ABC) AND TRADITIONAL COSTING METHODS

According to (Akyol et al., 2005), ABC is a costing method which assigns the cost of resources to activities in order to accomplish the specific process as well as defining the position of the activity in the organisation such as unit-level, batch level, product level, and facility level. The level of resource-consuming is determined by the required units of

the cost driver. On the other hand, Resource-Based Costing (traditional method) focus on the cost which derives the process directly without considering the activities which are needed to perform this process, therefore, the overhead cost is determined based on the output, not the entered resources which cause cost distortion (Alsharari, 2016).

Oseifuah (2013) asserts that the RBC is based on linking the budget to the service directly with overriding the activities, therefore, the performance of the organisation/project is measured by comparing the value of sacrificed resources with the value of the product directly and this could reduce the productivity due to there is no scrutinising progress report with utilising the RBC method. The cost driver is defined as the factor that causes or control the level of resource consumptions, hereby it works as a channel to convey resources to accomplish the project elements by implementing specific activities (Kumar and Mahto, 2013). Moreover, DAMITIO (2000) reported that using ABC helps managers to balance between the demand and consumption of the resources to ensure that the resource management cycle will be executed smoothly within the operation/construction stage.

Kinsella (2002) noted that ABC helps to measure the project performance by analysing the relationships between project activities, therefore, the performance of activities and resources can be monitored properly. As such, the manager can measure the output of each set of activities in the project and measure whether the sacrificed resources have contributed to the project value or the introduced service (Chea, 2011).

Goddard and Ooi (1998) define the overhead cost as the value of needed resources for an ongoing business that contribute to the whole process rather than specific cost object. According to (Hastak, 2015), direct costs are those resources which are consumed to accomplish the activity and these resources will shape cost object by performing some activities. However, the indirect cost is defined as resources which are consumed to

support activities or services, and though these resources cannot be measured in the final product, however, the entire process cannot be performed without these resources (Hastak, 2015, Holland and Jr, 1999).

According to (Wang et al., 2010), traditional costing system which uses a single cost driver such as direct cost proportion of each package or its volume relative to the entire product in order to allocate the overhead cost can cause cost estimation distortion. Moreover, this leads to poor decision making due to the final price of the product will be unreliable and in many cases, this affects the organisation competition opportunities in the market. Hughes (2005) states that the indirect and overhead costs increase sharply during the last decades and it is predicted to be more increased in the future due to the skilled labour and technology are considered as an indirect cost. Therefore, the traditional costing method will not be able to deal with these rapid changes in terms of determining the actually consumed resources for each specific process (Tanaka et al., 1994, Van Der Merwe and Keys, 2002). As such, Grasso (2005) asserts that using ABC can minimise the waste of resources by optimising the cost structure with allocating the overhead resources as activities which can measure its efficiency in the organisation, as well as, ABC is a system which focuses on the cost of activities that are required to finish the project/product, rather than volume of resources (Kreuze and Newell, 1994, Kaplan and Anderson, 2003). Furthermore, Chiang (2013) noted that the linear assumption of allocating overhead cost to the direct cost is problematic due to some products derive more overhead resources than others regardless of the volume of these products (Ahsan and Khan, 1982).

2.9. 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’ (PMI, 2013, Pajares and López-Paredes, 2011). Khamooshi and Abdi (2016) provided evidence of EVM being successfully applied to several real-life projects to deliver accurate cost/schedule metrics. According to Naeni et al. (2011) “earned value technique is a crucial technique in analysing and controlling the performance of a project”. EVM, as recommended by PMI (2013), 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 11 and Equation 21.

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

$$SPR = \frac{BCWS}{BCWP} \quad (2L)$$

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 L-3 and L-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 (Pajares and López-Paredes, 2011).

$$CV = BCWP - ACWP \quad (3L)$$

$$SV = BCEP - BCWS \quad (4L)$$

The project scheduling output is represented using the Work Breakdown Structure (WBS) technique, meanwhile, the cost is structured using the Cost Breakdown Structure (CBS)

technique. Therefore, there is a problem to integrate cost into project timeline and this causes an inaccurate implementation of EVM (Pajares and López-Paredes, 2011). 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 (Lipke et al., 2009). The interoperability issue among various data sources, to build federated project cost control sheets, is best resolved through using advanced technologies and visualisation techniques (Chou et al., 2010).

In case of the EVM will be used to perform cost control tasks in construction projects (Howes, 2000), the following points will clarify the most revealed concerns in using it relating to the system itself or the accuracy of its output.

- There is no any quality indicator in Earned Value Management (EVM), The EVM indicators include indexes in regards to cost and schedule in order to measure the achievement ratios to determine the performance, as well as, predicting the Budget At Completion (BAC) indicator. However, the quality index cannot be ignored in order to have a comprehensive report and enhancing lean construction process (Cândido et al., 2014).
- The EVM system is not used properly at the early stage, Given, the construction project might start achieving progress less than the planned at early stages, therefore, the cost control process should be implemented at the early stage (Jrade and Lessard, 2015, Cândido et al., 2014). Moreover, Narbaev and De Marco (2014) reported that the improper cost estimation during the early design stage can cause a distortion of the EVM implementation process within the project execution stage.

- The indirect costs are not considered in the EVM calculations, Farok and Garcia (2015) state that the indirect cost is needed to perform specific activities in the project., and it represents about 20% of the total cost, and it is critical to finish the project activities. Therefore, it should be monitored within the entire project (Huang et al., 2014).
- The data collection system in the EVM technique is considered as a barrier of the wide applicability of this technique, due to the data collection and analysis of the actual cost is different from the earned value (Vargas, 2003). As such, the granularity between the project scheduling technique as WBS and the actual way which the cost has been spent is the problem in implementing EVM properly (Wilson et al., 2013). On the other hand, the EVM system has been developed originally by US federal government to perform cost controlling tasks in large scale projects, however, since this time, it has been adapted to be exploited in medium, and small scales (Kwak and Anbari, 2012). Therefore, on such contemporary use, the EVM system needs to be smarter to retrieve data from multi-sources as well as generating the cost control report automatically (Wilson et al., 2013). The below figure 5 Shows the architectural system of EVM.

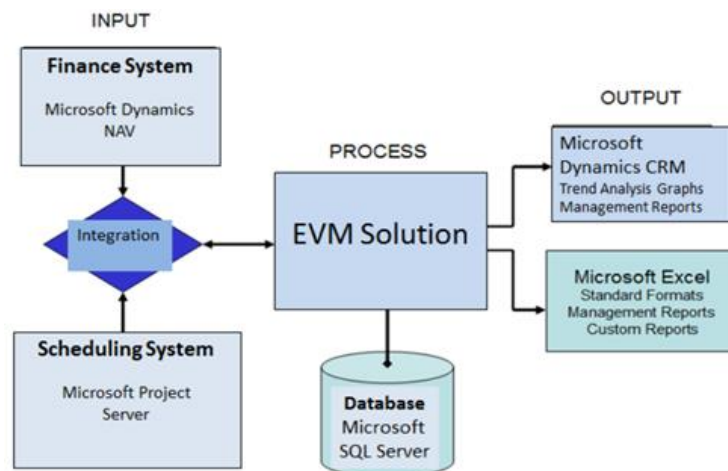


Figure 5. The architectural system of EVM data collection and analysis (Wilson et al., 2013).

2.10. CAPABILITIES OF MONTE CARLO SIMULATION

Monte Carlo simulation can be implemented using several computer programs on a large number of trials to analyse the impact of risk and uncertainty of a probabilistic range of data, that's why it is employed to analyse cost data so that a probabilistic model can be built, allowing for early cost estimation (Loizou and French, 2012, Alashwal and Chew, 2017). A feature of Monte Carlo simulation is that it provides a range of cost values against specific degrees of certainty, offering great flexibility in cost predictions (Potts and Ankrah, 2014). The process of developing a simulation to obtain a cost range entails cost data collection; formulation of a statistical model by choosing one available distribution (beta, normal, etc.); analysis of the cost data by running the model; result visualisation of the whole-cost estimates, and, finally, the provision of a sensitivity analysis chart (Chou, 2011). As a result, Monte Carlo simulation has been described as the most important statistical technique that are utilised for evaluation and probabilistic cost estimation (Khedr, 2006), the most used technique in the literature for early cost estimation of construction projects (Alashwal and Chew, 2017); and one of the earliest methods available for property evaluation purposes (Jahangirian et al., 2010).

Zhu et al. (2016) assert that the Monte Carlo simulation is a proven tool to deal with the high level of uncertainty in the cost estimation by considering multiple variables. The Monte Carlo Simulation was used as a tool to optimise the cost for the probabilistic project during the last decade such as determining the satellite cost with considering multiple factors, Monte Carlo simulation enhanced the precision of cost estimation for the satellite almost 10% compared to the traditional cost estimation (YAN and LI, 2007a, Yan and Li, 2007b). Another successful case of using Monte Carlo was by integrating it into the market investigation drivers to enable determining the cost for specific products at the early production stage (Li et al., 2014).Cassettari et al. (2016) designed a model to

integrate the Activity Based Costing (ABC) into Monte Carlo Simulation to enhance the cost estimation of the probabilistic activities. The Monte Carlo Simulation showed a capability to be used for the sophisticated estimation such as the aircraft components through enabling building a cost estimation model from the given input, therefore, this enhances the regression process and maximise the precision percentage (Huang et al., 2010). In addition to using Monte Carlo Simulation to predict the cost of a project from the historical data, it is also used to establish yield cost associated with desired best/worst input data and provide a range of cost against a range of certainty percentages (Belova et al., 2000).

2.11. INTEGRATED PROJECT DELIVERY (IPD)

IPD is a project delivery approach that integrates all project dimensions such as people, organisation, and business structure from the conceptualisation stage, as well as, mobilising all participant's resources to achieve the project goals with maximising value and minimising the waste (Kent and Becerik-Gerber, 2010). In this approach, all participants are responsible to share risk/reward throughout all project stages (AIA, 2010). Wan and Yu (2019) state that IPD is a concentrated delivery approach, all participants should have the same level of interest towards the project objectives, therefore, a fully open communication, sharing risk/reward, cooperation should be considered in order to receive the desired return beyond using IPD.

Kent and Becerik-Gerber (2010) argue that IPD is mainly developed to eliminate the fragmentation that is caused when the project is led by a 'master builder' throughout the entire project stages. The movement to a collaborative, systematised and an integrated delivery approach is highly recommended, particularly, with the increase in the complexity of the construction projects (Mesa et al., 2016, Singleton, 2010). Even though, IPD is not widely used in the construction industry, however, there are many successful cases that were implemented using IPD (Zhang et al., 2012). Therefore, the benefits and shortcomings of the IPD approach should be discussed to enable maximising its benefits and managing its shortcomings. The IPD includes seven distinguished stages; each stage should be managed by different tools and techniques according to the availability of data (AIA, 2010). Figure 6 shows that almost all project stakeholders participate in the conceptualisation stage except the trade contractors start to involve the criteria design (Allison et al., 2018). Moreover, the role of the owner is influenced across the seven-stage

which can fill the gap between the client requirements and design experience (Rowlinson, 2017).

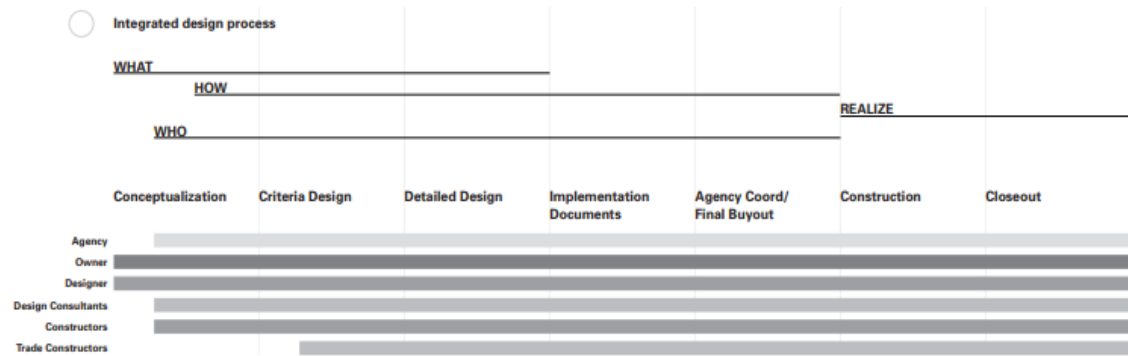


Figure 6. The IPD stages and the involved parties during each stage (AIA, 2010).

Figure 7 depicts the differences between the allocation of the design effort curves of the traditional method and the integrated method (AIA, 2010). Regarding the IPD approach, the design effort/effect starts higher than the traditional and increase steadily until the construction documentation stage. From figure 2.4, the peak design effort is located in the detailed design stage for the IPD, then the curve begins to decrease steadily during the construction stage (Jones, 2014). However, the traditional method starts with a lower needed amount of effort and increases steadily to reach the highest point in the bidding stage (Ashcraft, 2012).

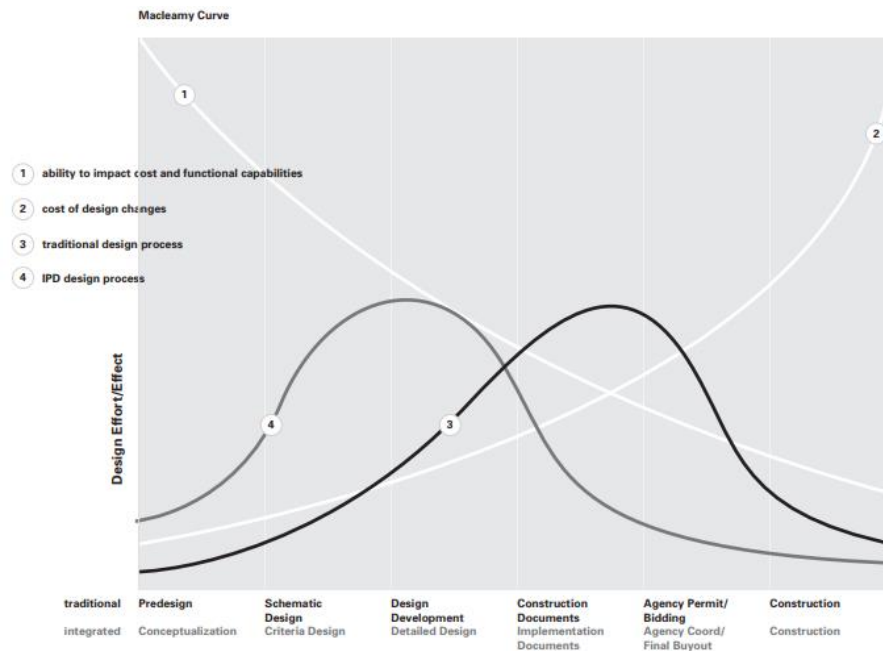


Figure 7. Design effect/effort for traditional and integrated methods (AIA, 2010).

2.11.1. The Benefits of IPD in Construction Projects

As aforementioned, IPD relies on the collaborative environment (Ashcraft, 2012, Allison et al., 2018). Consequently, the project can be successful If the project core team member shares the same goals and objectives (Allison et al., 2018), the following points show in-details the significance of implementation of IPD in the construction industry:

- Mutual respect and benefit: all of the core team members participate under the same conditions which reflect the same level of interesting to undertake the project under the agreed specifications (Rowlinson, 2017). As well as, using a single compensation structure declares that sharing in benefits and risks make the participant as one team toward a single objective, however, this needs to create a distinguished and special business structure (Teng et al., 2017).
- The goals have been set early: as a result of the early involvement of all stakeholders, this leads to create the goals and objectives early and mobilise all project capabilities toward these objectives and allow them to work in a collaborative environment (Pishdad-Bozorgi and Beliveau, 2016). As well as, this

allows to apply the value management procedures—concepts and methodologies of value engineering such as the Target Value Design (TVD)— to increase the value and minimise the waste (Allison et al., 2018).

- Enhance the communication: according to the well-defined responsibilities from the beginning which leads to creating an honest and transparent environment, this will avoid the blame cultures and try to solve the problems more than determine the liabilities (Ahmad et al., 2019).
- High performance: the integrated delivery approach relies on optimising the whole process for a design solution, high performance, and developing a sustainable design (Nawi et al., 2014, Pishdad-Bozorgi and Beliveau, 2016). According to (El Asmar et al., 2013), the IPD has proven its capability regarding six performance metrics, which are quality, schedule, project changes, communication among stakeholders, environmental, and financial performance, these findings have been determined through a statistical (quantitative) analysis of (n=35) projects that were fully implemented using IPD approach.
- Proper technology: The ICT is highly recommended to be utilised with the IPD approach in order to build the needed collaboration and trust environment among IPD core team members such as BIM and web applications (Glick and Guggemos, 2009, Nawi et al., 2014). The utilised technologies should be identified from the early stage; these technologies will maximise the function and the interoperability through the project stages (Rowlinson, 2017, Pishdad-Bozorgi, 2017, Ahmad et al., 2019). This benefit will be discussed in details in the next chapter.

2.11.2. IPD-Based Cost Estimation

IPD is a project delivery system for delivering value, where value might include considerations other than pure cost (Pishdad-Bozorgi and Srivastava, 2018). That said, even where the value has qualitative dimensions, the projection and tracking of costs will

be critical to IPD success (Ashcraft, 2012, Love et al., 2011). Cost estimation hence has a vital role in applying IPD (Zhang and Chen, 2010, AIA, 2007), 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 (AIA, 2007, Zhang and Li, 2014). The compensation approach structure must be capable of drawing upon effective methods, to determine cost overrun proportions, cost underrun, and any saving in the total budget under the agreed cost (Thomsen et al., 2009). That is because, risk/reward proportion rely on the degree of achievement during the entire project stages (Love et al., 2011). The compensation approach has two limits (as shown in Figure 8); 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 (AIA, 2007, Zhang and Li, 2014).

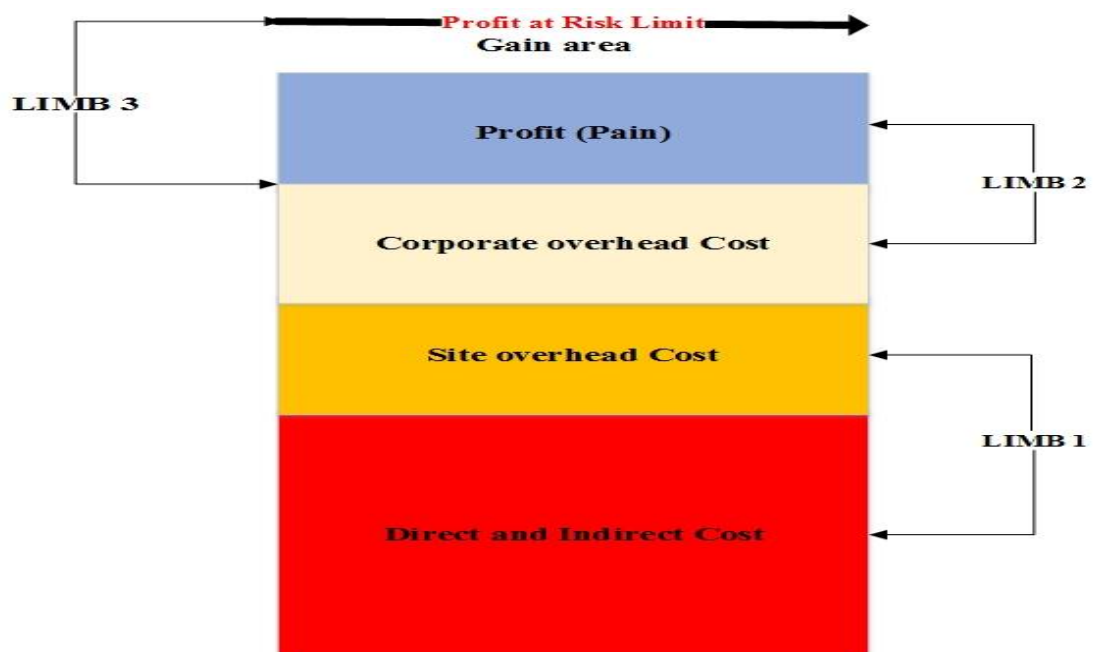


Figure 8. Compensation approach structure, adapted from Zhang and Li (2014)

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 (Das and Teng, 2001). Alliancing agreements, however, can reduce risk impacts through sharing information, given that the success in dealing with risks depends on data availability (Delerue and Simon, 2009)

As illustrated in Figure 9, 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 a risk/reward sharing model, must be specified at the beginning of the project (Ross, 2003). According to Ross (2003), 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 9). After computing the risk/reward ratio using OPS, the project participants should share this ratio in correspondence with the contract.

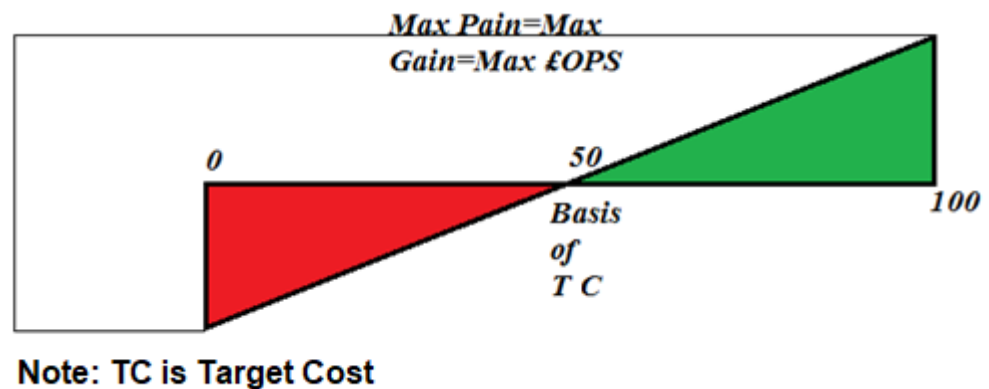


Figure 9. OPS ranges for Risk/Reward ratio, adapted from Ross (2003)

2.11.3. TARGET VALUE DESIGN (TVD)

Target value design (TVD), an emerging practice in the construction industry, is a management strategy that aims to eliminate waste and deliver value using a ‘design-to-

cost' method (Meijon Morêda Neto et al., 2019). The thrust of TVD is to position a client's value (e.g., cost, schedule, etc.) as the driver of design to reduce waste and satisfy the client's expectations (Zimina et al., 2012). Target value design (TVD) thus introduces a philosophy towards design based on the budget, in contrast to the idea of budgeting for the design – a traditional design concept – and, therefore, cost estimating becomes a crucial part of design development (Allison et al., 2017). Empirical research shows that TVD projects can achieve cost reductions of 15–20% and contingency costs of approximately 3.5% compared to 7.9% for non-TVD projects (Silveira and Alves, 2018, Meijon Morêda Neto et al., 2019).

Consequently, 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 (Alwis 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, Alwis et al., 2018, Alves et al., 2017, Allison et al., 2017).

2.12. BUILDING INFORMATION MODELLING/MANAGEMENT

2.12.2. Overview of BIM Dimensions and Levels

Due to the increase in complexity of the construction industry, it becomes more complicated to be managed due to the reciprocal interdependencies between different stakeholders (Alshawhi and Ingirige, 2003, Qureshi and Kang, 2015). Therefore, utilising technologies to enhance the management processes have been highly considered in order to enable managing the project communication and information data (Taxén and Lilliesköld, 2008). During last few years, the enhancing in managing project information has been developed and Building Information Modelling (BIM) is one of these developments, therefore, BIM can be identified as “a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle” (Succar, 2009). Consequently, UK begins to recommend BIM as a way to approach projects from 2014 in order to reduce transaction costs, as well as, minimising the design errors, the government set adopting BIM as a condition for many projects to deliver the project documentations as fully collaborative BIM 3D model (Smith, 2014b). BIM is not only geometric model which includes all design elements, nonetheless, BIM is a holistic process that contains several tasks such as project management tools and techniques, 3D design, contractual issues, and facility management in order to lean the construction process and maximising value of a constructed asset (Bryde et al., 2013).

The UK Department of Business Innovations and Skills (BIS) proposed different levels from 0 to 3 in order to identify the adopted level of BIM rapidly with respect to the adopter internal capabilities, the external supply chain factors and other stakeholders (Succar et al., 2012).

Figure 10 illustrates the differences between BIM maturity levels, the main difference between each level is the degree of integration between different types of data such as design data, cost and schedule data. As long as, the integration and collaboration between all BIM levels such as 4D, 5D, and 6D BIM in a single context increase, the position of adoption in the maturity levels will be directly increased (Barlish and Sullivan, 2012).

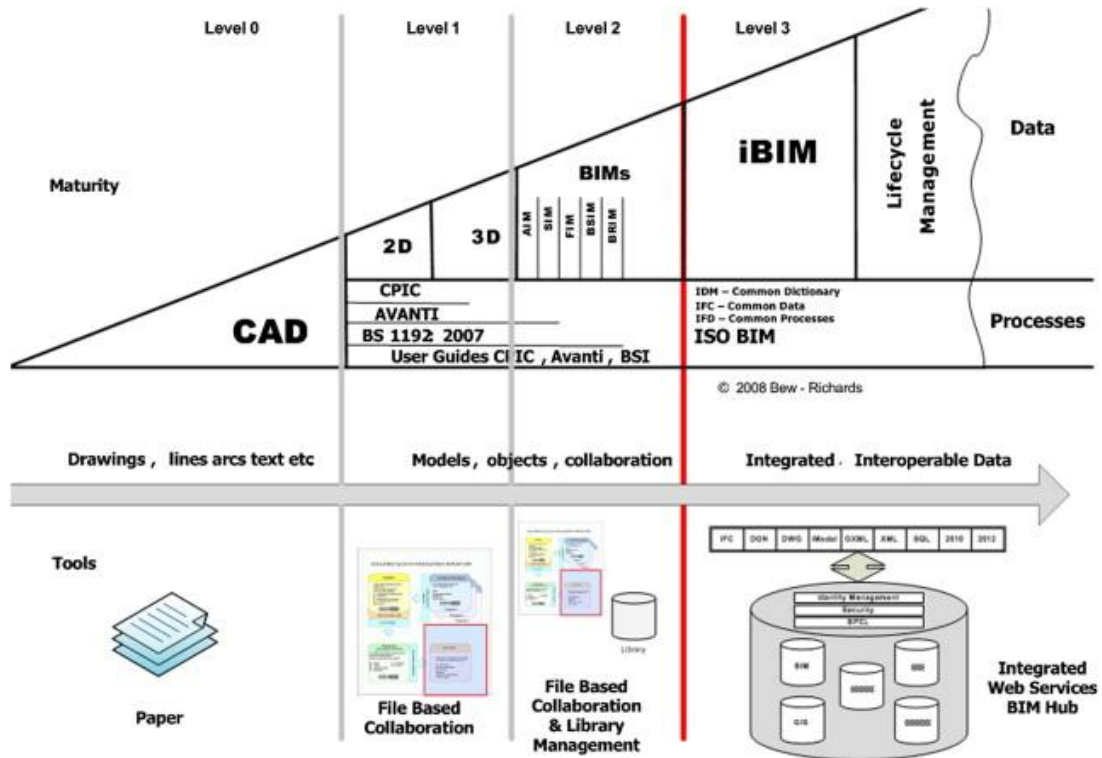


Figure 10. Illustrates the differences between the different levels of adopting BIM (Porwal and Hewage, 2013).

According to (Porwal and Hewage, 2013, Succar, 2010, Succar et al., 2012), the BIM maturity levels can be concluded as follows:

- BIM level 0 can be identified as delivering the project design as 2D CAD without any collaboration between the project parties and these 2D drafts could be delivered whether manually or electronically (Eadie et al., 2015).
- BIM level 1 which is considered as a point of departure towards creating conceptual 3D BIM designs and the actual designs will be implemented as 2D

design to finish all statutory approval documentation and Production Information. The CAD standard is followed BS 1192:2007 and sharing data will be implemented by a common data environment (CDE) which represents the pool of data which share the information between all stakeholders, the data will be transferred within electronic document management system (EDMS) (Underwood et al., 2015).

- BIM level 2, the collaboration and integration become more efficient between all stakeholders in different stages whether the construction or operation stage within a distinguished system which is called Construction Operations Building Information Exchange (COBie) (Succar, 2010). All documents should adhere to PAS 1192 specifications, these series of specifications contain four documents (Eadie et al., 2015), namely, (1) PAS 1192-2: 2013 which describes the requirements of the project stage, (2) PAS 1192-3: 2014 which deals with the operation stage, (3) BS 1192-4: 2014 is developed as a code of practice rather than a specification standard, (4) PAS 1192-5: 2015 as a set of specification for security-minded BIM. The majority of companies are still attempting to adopt BIM level 2, however, Level 1 is already implemented in most of UK companies (Ganah and John, 2014).
- BIM level 3 which doesn't have a specific definition yet, however, there are some criteria to address the target of adoption BIM level 3. These criteria can be concluded as follows (1) the collaboration must be globally on the market level, not project/enterprise level, (2) using integrated contract which declares the collaboration, sharing risks and reward and opening new opportunities on domestic/international levels which relies on using the technology in AEC industry (Khosrowshahi and Arayici, 2012). As it can be seen from the figure 10,

level 3 is divided into two sections, so that iBIM shows the specification of building an Integrated data in a single/dynamic model and the Life Cycle Management which considers the Capital cost (Capex) and operating expenditure (Opex) (Succar, 2010). There are some stages to enable the movement to BIM level 3, These stages are Level 3A which interests by improving BIM Level 2 designs, Level 3B enabling to embed using technology in the construction industry, Level 3C considers the business level rather than project level, and Level 3D which capitalise the world leadership (Government, 2013).

In addition to BS1192, the American Institute of Architect (AIA) has developed Model Progression Specifications (MPS) in order to specify the requirements and deliverables for each stage and the Level of Details (LoD) is used to measure the degree of accuracy in the created models. The measurement scale begins by (100) that describes a poor information model and end by (500) that represents a higher degree of embedded information in the BIM model (Porwal and Hewage, 2013).

2.12.3. 4D BIM Implementation and Challenges

BIM 4D is defined as the way of improving the function of the planning process (Sloot et al., 2019). These functions can be concluded as follows (1) the function of extracting the needed planning information from BIM 3D design model (Turkan et al., 2012) ; (2) the function of identifying the activities by analysing the extracted design elements via specific constructability methods (Hartmann et al., 2008); (3) estimation and processes interdependences functions (Heesom and Mahdjoubi, 2004); (4) planning project resources and site logistic data (Barry and David, 2016). 4D planning is mainly related to link project schedule to BIM 3D design elements in order to improve the buildability of construction process, addition to aforementioned functions, there are several capabilities such as visualisation of time and construction process (Büchmann-Slorup and Andersson,

2010); analysing the project schedule to determine the suitable buildability method (Koo and Fischer, 2000); minimising the construction errors through exploiting the virtual simulation before emerging the construction phase as well as improving the collaboration and communication between project parties (Dawood, 2010). However, 4D BIM is not a new phenomenon, it backs to 1980s when Bechtel and Hitachi Ltd attempted to produce a visual 4D model and throughout the time the technology has been developed, and this enhanced the 4D BIM technology as well (Dawood and Mallasi, 2006). Currently, 4D BIM platforms enable to incorporate several models and data whether schedule or cost in order to link all design elements in an intelligent system via logical relationships (Tulke and Hanff, 2007).

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).

2.12.4. 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 (Ashcraft, 2014b, Oraee et al., 2017). 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 (Redmond et al., 2012, Merschbrock et al., 2018, Abrishami et al., 2015). BIM design elements must contain the required information in various natures, including design or management (Banihashemi et al., 2018), to acquire smartly-designed elements, rather than traditional 3D components (Fu et al., 2006, Pärn and Edwards, 2017). BIM users should be capable of acquiring all the required information from a single BIM element, to make informed decisions (Motamedi and Hammad, 2009, Shen et al., 2012, Abrishami et al., 2014). Four-dimensional modelling (4D BIM) can embed progress data in 3D model objects by adjusting the task-object relationship (Hamledari et al., 2017). Application of 4D BIM leads to easily operate workflows, efficient on-site management,

and assessing constructability (Hartmann et al., 2008). As for the cost management, BIM is one of the most efficient Architectural, Engineering, and Construction (AEC) tools in increasing productivity on construction projects (Wang et al., 2016, Aibinu and Venkatesh, 2013, Lee et al., 2014). Colloquially termed as 5D BIM (Aibinu and Venkatesh, 2013), this capability of BIM offers the preferred technique for extracting quantities from 3D models, allowing cost consultants to incorporate productivity allowances and pricing values (Eastman et al., 2011a, Lee et al., 2014). 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 Materials (BoM) are generated and exported to an external database (Aibinu and Venkatesh, 2013). Prices and productivity allowances can also be added to project schedule preparation (Eastman et al., 2011a, Lee et al., 2014). 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 (Wang et al., 2016, Popov et al., 2010).

2.12.4.1. 5D BIM and Quantity Surveying

Quantity surveying has been a vital part of the construction process for more than 170 years (Cartlidge, 2011). From that time, the role of the quantity surveyor has been to manage cost estimation and control as well as to optimising contractual and financial trade-offs, such as in the valuation and payment of construction projects (Ashworth et al., 2013). The role of the quantity surveyor has been developed to meet the requirements of value management approaches more than the construction method, and has been implemented by developing the tools and techniques used to capture cost management parameters, such as automated measurement (de Andrade et al., 2019). Moreover, the emergence of BIM has enabled the support and delivery of facilities management tasks

as well as enhancing the holistic management process. Hence, the role of the quantity surveyors has changed in parallel with the BIM progress (Stanley and Thurnell, 2014). The introduction of BIM has required a change in the manner of building in terms of the design, procurement strategy as well as all other parameters in order to achieve the necessary collaboration and integration in the AEC industry (Aranda-Mena et al., 2009, Qian, 2012). Consequently, cost management must change in order to be compatible with these approaches and an effective part of this process (Hanid et al., 2011).

Most of the definitions state that BIM 5D is the preferred method for extracting the quantities from the BIM 3D model in order to enable cost consultants to commence the costing process by inserting the productivity allowances and pricing values (Eastman et al., 2011a). Forgues et al. (2012) recommend that output data should be supported by another format used to complete the measurement and pricing process. The cost estimation process begins by importing the BIM 3D model to any BIM-based cost estimation software, such as Exact cost-x or Visio office, to prepare take-off of quantities (Mitchell, 2012). After that, generating the Bills of Quantities (BOQ) and exporting it to an external database where prices and the productivity allowances are added to prepare the project schedule (Eastman et al., 2011a, Forgues et al., 2012). Moreover, Hannon (2007) points out that such automated quantification will shorten what is a time-consuming process, as well as being able to automatically take account of any changes in the design development process.

2.12.4.2. BIM 5D Implementation Barriers and Challenges

Sylvester and Dietrich (2010) reported that 5D BIM has changed the quantity surveyor roles from spending much time to extract the quantities from the drawings to analyse and validate the cost data in order to reach the optimal cost estimation value. Moreover, Shen and Issa (2010) asserted that using 5D BIM platforms reduce the generated errors of

misleading manual calculations and this leads to effectively estimated durations. In general, 5D BIM introduces a comprehensive process of taking the early decision at an early design stage by offering an automated quantity take-off for all designs whether concept or detailed design (Forgues et al., 2012). Therefore, Smith (2014b) asserted that the BIM process introduces a holistic approach for all project functions such as design, management, construction, and sustainability matters simultaneously. McCuen (2008) reported that exploiting 4/5D BIM in the AEC industry leads to increase the profitability. Moreover, Franco et al. (2015) claimed that the model has proven comprehensive and durable enough to assist in all phases of the project lifecycle—from conception, through design and construction, to operations and maintenance.

Nassar (2011) argued that the estimation process is more than listing the design objects and the prices, thus BIM only is not adequate to be used in the cost management process. Therefore, linking cost estimation programs and BIM design platforms is important to accomplish the entire cost management process. Stanley and Thurnell (2014) reported that exploiting BIM estimation software produce an accurate cost estimation, and give the estimator reliable indicators to light the future works. Nevertheless, McCuen et al. (2011) claimed that it is not necessary the derived information from BIM model to be completely precise. On the other hand, the transferring of data between several platforms cause waste in data which reduce the accuracy of the information (Azhar et al., 2012). Moreover, Sunil et al. (2017) reported that BIM leads to enhance cost estimation, and control tasks and this affects directly the role of cost managers and increase their abilities and way of making the decision. Moreover, BIM increases the involvement of quantity surveyors in different tasks of the project and eliminating the traditional QS isolation working environment which reduces the availability of information. Nonetheless, the integration and coordination between different models are not adequate, thus the QS is still responsible to articulate the cost report semi-manually via linking several models

such as 3D design model, 5D platform to extract quantities and Excel sheet to determine the prices by exporting the derived quantities (Smith, 2014a). On the other hand, the integration between cost estimation and schedule remains proceeding manually by the QS which makes this process is complicated and takes a long time (Sunil et al., 2017). Moreover, Cho et al. (2012) also claimed that the project data remains to undertake by a set of spreadsheets, and estimating software, therefore there is no a single/dynamic platform to proceed the entire cost management without any other supporting programs. There is no balance in the relationship between the amount of information required for the cost estimation and the data added by the designers (Kiviniemi et al., 2007). Moreover, the pricing format is not considered in BIM models, but it is required by the quantity surveyors to modify the BOQ model for each project in terms of their breakdown structure (Wu et al., 2014).

The lacuna is caused by the traditional approach of working in separate environments, whereby each discipline is implemented by using a different model and the frequent question is which one is the cost estimating process should follow? (Stanley and Thurnell, 2014), Consequently, the project core team member usually loses countless hours in adapting one model to meet the needs of the cost process (Meadati, 2009). Boon and Prigg (2012) contend that a balance of the information between the different disciplines, such as the architecture and QS information, must be considered.

Stanley and Thurnell (2013) state that the nature of the construction industry is the reason for the late or less efficient implementation of BIM 5D. To address this, the BIM 5D software companies should consider collaboration regarding the workflow of the cost data throughout the project stages or between the different participants who lead, in order to make the cost management process effective and efficient (Olatunji et al., 2010).

2.12.5. BIM and cash flow

Interdependencies between the cost (BIM 5D) and schedule (BIM 4D) are obvious, because the integration between cost and schedule processes in a single system is necessary to establish appropriate control. However, in practice, the two parameters are still separate given that the schedule is represented by Work Breakdown Structure (WBS), whilst the costs are identified by Cost Breakdown Structure (CBS) (Fan et al., 2015). Hence, during the budgeting stage the integration between the WBS and CBS becomes complex, thus leading to potential errors and mismatch (Jung and Woo, 2004)

Fan et al. (2015) state that the initial steps to integrate BIM 4D and 5D are creation of the project schedule as well as BIM models, the next step is the cost estimation of all design elements. Subsequently, the generated cost items need to be linked with the project schedule (BIM 4D), and the BIM element linked to the schedule. However, this process has some shortcomings when it comes to implementation, particularly linking the BIM schedule to the generated cost. In sum, the BIM elements should be linked directly to the cost items to avoid the complicated process in of integrating these elements with the schedule.

Kim (1989) developed a costing system model to manage cost estimation, budgeting control, however the proposed model which was named basic construction operation, which indicates the lowest level in construction operation, and this level has linked to three sources, namely: WBS, CBS, and design files. However, this system has been criticised by (Rasdorf and Abudayyeh, 1991) due to it is required a high level of details as well as refining each operation in order to reach sub-task, this is not practical and applicable in AEC industry.

Since the classification of construction works is vital to reliable budget, therefore, Kang and Paulson (1998) developed a classification system based on four categories, namely, facilities; Spaces; elements; operations. Subsequently, the cost and schedule will be considered for each level in each category for a construction project, however the proposed classification system is not suitable for quantity take-off in cost estimation process (Wang et al., 2016). Therefore, the challenge of detailed cost estimation with consistent WBS hierarchy remains persist in AEC industry, particularly when using the work-packaging (WP) method which relies on the cost/schedule control system criteria (C/SCSC) in the package level, however this is not efficient due to the construction operations involves long hierarchy levels to reach sub-task level (Moder et al., 1983). Even though the method assigns the cost to WBS regardless CBS, however Rasdorf and Abudayyeh (1991) assert that it needs some improvements to make it applicable in complex project.

Yang et al. (2007) developed a model to integrate the budget (override the resources) directly to the schedule in daily proportion to develop BCWS, and each activity will be weighted daily as ratio relative to the schedule, and this ratio will be used to measure the progress, however daily scale in construction projects may be impractical (Wang et al., 2016). Cho et al. (2012) developed a model which is entitled a 5W1H (what, when, where, who, why and how) in order to solve the challenge of integrating cost/schedule in construction project. So that, the planner can follow the operation as multi-function within multi-level such as the what (would be a column), how (framework), and answers of other questions give more details to enable the integration.

According to (Eastman et al., 2011b), there is no a full functional BIM cost management software, therefore the quantity surveyor should link between different platforms in order to carry out the main three tasks, namely: estimation, budget and control. Even though,

Lawrence et al. (2014) developed a model to update the estimated cost automatically based on design changes, however the entire estimation will be unreliable due to miss plenty of information which is not embedded in the design. Moreover, Wang et al. (2016) developed a model to integrate cost/schedule based BIM, the developed model links between the BIM design object, cost item, activity and area (zone/floor). Even though, the proposed model used BIM in formulating project budget, however the process does not support the automation.

2.12.6. 4D/5D BIM 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 (Omar and Dulaimi, 2015). As such, El-Omari and Moselhi (2011) 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 the collected data and reduce human interference in the data collection process (Hartmann et al., 2008, Hamledari et al., 2017). Similarly, 5D BIM provides an effective methodology for cost data collection and analysis of construction projects (Wang et al., 2016, Aibinu and Venkatesh, 2013, Lee et al., 2014, Popov et al., 2010). Furthermore, Lee et al. (2014) 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 barcoding, radio frequency identification, 3D laser scanning, photogrammetry, multimedia, and pen-based computers (El-Omari and Moselhi, 2011, Turkan et al., 2012, Turkan et al., 2013). Eastman et al. (2011a), 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 analysing data in efficient ways (Wang et al., 2016, Hosseini et al., 2018).

2.12.7. The Applicability of Integrating IPD, BIM and TVD

Kent and Becerik-Gerber (2010) state that there are some criteria which distinguished using IPD in BIM projects, these criteria are multiparty agreement; early involvement of all parties; and shared risk and reward. 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 at the early design stage (Ashcraft, 2008). Subsequently, DeBernard (2008) argued that implementing IPD can optimise the delivery timeline of construction projects by reducing waste within better planning and shared risk/reward. Therefore, the optimisation of 4D BIM can play a vital role in reducing cost and enhancing the entire efficiency for construction process (Rowlinson, 2017).

The integration of BIM and IPD received the attention of researcher during the last decade, Zhang and Wang (2009) recommended the utilisation of IPD project using BIM technologies in order to change the old production paradigm in the construction industry. With the increasing of adopting BIM in the construction industry, new contractual arrangements and relationships should be formed, particularly to enable the collaboration and sharing risk/reward among project participants, that's why IPD is necessary to maximise the benefits of BIM adoption (Lancaster and Tobin, 2010). Even though the alliance contracting method has mutual concepts with the IPD such as sharing risk/reward, however, accompanying the Information and Communication Technologies

(ICT) with the IPD such as BIM and 'Big Room' environment can enhance the project performance (Raisbeck et al., 2010). The benefits beyond the real applications of BIM and IPD together appeared in several studies such as Dossick et al. (2013), the coupling of BIM, IPD and lean concepts supported the integrated teamwork which enhanced the design outcomes and construction products. Through analysing the outcome of implementing BIM in 145 projects, Chang et al. (2017) asserted the ability of BIM to maximise the acceptability of IPD, particularly, BIM projects require a flexible supply chain approach and improved communication quality among project participants.

The implementation of IPD requires some principles such as communication, interpersonal and negotiating skills in order to influence the effectiveness of team members and performances (Mathews et al., 2017). After building the contractual agreement among participants, the organisation structure of the IPD should be articulated, the main features of this organisation are the ability to offer a collaboration platform in order to enhance the communication among participants, therefore, BIM is recommended to provide the desired collaboration platform within the IPD organisation (Rowlinson, 2017, Ahmad et al., 2019). Although, IPD can be implemented without BIM, however, BIM is the most vital factor to ensure the integration/collaboration in IPD (Pishdad-Bozorgi et al., 2013, Rowlinson, 2017) and Unrestricted shared information (Sun et al., 2015, Ma et al., 2018).

According to (Yee et al., 2017), IPD can be implemented in four levels so that each level describe a different level of collaboration and BIM integration. Level 1 represents the lowest level of collaboration, however, the philosophy of IPD in terms of mutual trust and open communication are considered. From level 2 to level 4, the degree of integration increases with minimising the degree of liability allocations among the project participants, the IPD has transformed from philosophy adoption to complementary

delivery adoption, level 3 and level 4 reveals the importance of utilising BIM within IPD approach in order to successful integration/collaboration management (Yee et al., 2017). Moreover, the coupling of BIM and the “internet+” technologies can improve the network environment for the IPD approach (Wan and Yu, 2019).

A recent study by (Nguyen and Akhavian, 2019) explored the current status of integrating IPD, BIM and other lean techniques such as Target Value Design (TVD) in around 72 vertical projects, the quantitative and qualitative analysis of these project outcomes, particularly the cost/schedule performances revealed that there were significant improvements for the projects schedule, as well as noticeable cost reduction. Jang et al. (2019) assert the importance of implementing TVD with BIM whether through adopting IPD or two tender stages under Design-Bid-Build (DBB) approach, this enables subcontractors to involve in the design process, which, enable finish the design in accordance with the client’s budget.

The cross-functional organization in integration with the IPD approach is highly needed for successful implementation of TVD and meet the set requirements for both schedule and cost, the IPD approach can leverage the full potential of individuals to contribute efficiently in the design process (Laurent and Leicht, 2019, Ebrahimi and Dowlatabadi, 2018). The proper management of the incentive in the IPD and TVD approach can avoid the misalignments of commercial incentives among IPD core team members (Do et al., 2015). A comparative study between IPD based on TVD and Design-Build (DB) approach using the game theory, findings reveal that a set of managerial target costing strategies is needed to shift from the traditional design to the full TVD adoption with the IPD (Jung et al., 2012).

Raisbeck et al. (2010) mentions that IPD is different from alliancing approach as IPD has been supported by BIM, therefore the BIM environment which is called "Big Room"

enables participants to discuss all project issues in a virtual environment which enhance the collaboration and integration (Allison et al., 2018), additionally, BIM dimensions allow to discuss schedule/cost between all participants with using visualisation and simulation features to enable well-understanding (Ashcraft, 2012), particularly for owner party and non-experienced participants. Since IPD is a continuous approach during the entire project stages, therefore it is required a map of workflow such as Toyota's lean manufacturing process (Lichtig, 2005, Forbes and Ahmed, 2010).

According to Raisbeck et al. (2010), the ability of BIM to detect the clashes at an early design stage could save incredible cost due to all clashes will be solved in the virtual environment just by spending a little effort and short time, rather than solving these clashes in the physical environment. Therefore, IPD enables bring all participants together from the concept stage which allows acquiring the needed information to detect proposed clashes (Solihin and Eastman, 2015). Moreover, BIM offers strong IT infrastructure platform to facilitate the movement of data between multi-sources in the project, hence this increases the innovation as all information is presented digitally (Ma et al., 2018, Allison et al., 2018).

Popov et al. (2010) developed a model to integrate 3D, 4D and 5D BIM in a single environment in order to enable the integration throughout the different project stages, this model includes three stages, namely: design and determination of resources, organization and simulation of construction works, and asset management. Each stage has been refined to sub-tasks in order to facilitate its implementation (Popov et al., 2010). Therefore, Ilozor and Kelly (2012) state that "BIM is envisioned as a tool for project integration". However, the researcher recommends that further research should be carried out in order to measure the impact on real projects.

AIA (2010) states that IPD showed promising results when it has been implemented in California due to its ability to offer close collaboration between owner and non-owners parties. Moreover, implementing BIM within IPD can offer the advanced technology to all participants, regardless the size of the project or the size of party's organisation (Pishdad-Bozorgi et al., 2013, Rowlinson, 2017, Nawi et al., 2014). Yee et al. (2017) assert that the organisational issues play a major role in minimising the benefit of implementing IPD because the unclear organisation could cause a fragmentation between the relationships of project elements. Ghassemi and Becerik-Gerber (2011a) assert that technology plays as a vital barrier to implement IPD such as the interoperability of information among participants, moreover, copyright of drawing and designs need to be considered in order to protect the copyrights of participants. Costa and Tavares (2012) developed a social e-business model to improve the collaboration and enhance the trust between project parties within using networks which exploited satellite technology. Moreover, Porwal and Hewage (2013) articulated BIM partnering framework in order to maximise the value of implementing BIM in governmental projects within enabling involving contractor and sub-contractors at an early design stage and IPD was proposed as a solution.

2.13. THE REQUIREMENTS OF THE COST MANAGEMENT PROCESS — THE HIGHLIGHTED RESEARCH GAP—OF THE IPD APPROACH

2.13.1. Research Gap in Cost Estimation Operation within IPD

The review of the literature revealed several research trends on this topic. Most research has been aimed at informing practitioners of the potential of the available tools and techniques, such as TVD and BIM, and at providing an outline of how they contribute to the development of better IPD solutions. Pishdad-Bozorgi et al. (2013) discussed the potential of integration between TVD, BIM and IPD cost estimation, while Alves et al. (2017) presented various techniques commonly used for TVD and applicable to the IPD context. Zimina et al. (2012) and later de Melo et al. (2016) showed how systematic TVD can result in noticeable enhancement of project performance. Several studies have also mentioned the potential of BIM to add value to a project's objectives through IPD implementation (c.f. Ahmad et al., 2019, Chang et al., 2017, Succar, 2009, Fischer et al., 2017a, Hosseini et al., 2018, Azhar et al., 2015).

Another stream of studies discussed the challenges and barriers of using TVD or BIM for IPD cost estimation tasks. For example, Ghassemi and Becerik-Gerber (2011c), Manata et al. (2018), Pishdad-Bozorgi (2017) and Kahvandi et al. (2018) focused on various key critical success factors, largely from a managerial perspective, with limited attention to cost estimation issues.

Tillmann et al. (2017) discussed the underlying mechanisms of TVD cost estimation within IPD-oriented projects, exploring the factors that influence success when TVD is applied to these projects. Despite their study's contributions, it does not focus on the tactics of allocating overhead resources. Earlier, Ballard et al. (2015b) explored the relationship between IPD and TVD and recommended a set of procedures to enhance the

chance of success in applying TVD to IPD cost management processes. Although the authors acknowledged that following TVD principles are a critical success factor, no explicit technique or procedure was recommended to make the recommendations useful in practical terms. Roy et al. (2018) identified the challenges and cost structure of implementing IPD: profit pooling, misunderstandings in risk contingency accounting and hard pricing are presented as critical barriers to IPD implementation. No workable solution was provided by these authors to address these challenges.

Some researchers attempted to provide models and frameworks to address IPD cost estimation issues. Zhang and Li (2014) combined risk perception and the Nash bargaining solution (NBS) techniques to formulate a risk-reward compensation model. However, the model was not sufficiently comprehensive to cover all possible types of engineering data, lacked empirical validity and, hence, required empirical studies. In addition, Pishdad-Bozorgi and Srivastava (2018) developed a model to share risks and reward using a game theory approach, particularly for cases in which project cost exceeds the profit-at-risk percentage. Their study only provided an overview of the model with future empirical research needed to assess its practicality and to quantify its impacts.

In summary, the review of the literature revealed that IPD, TVD and BIM are regarded as a winning combination for improving project delivery success (Pishdad-Bozorgi et al., 2013). However, very limited research is available to validate the positive aspects of these relationships by providing workable solutions appealing to practitioners (Azhar et al., 2015, Kahvandi et al., 2017). The need to conduct the current study is thus acknowledged.

2.13.2. Cash Flow-Cost Budgeting— Research Gap

According to (Kim and Grobler, 2013), state that utilising BIM can improve the traditional cost/scheduling processes. Lu et al. (2016) state that there have been several

studies for analysing cash flow processes, however, most of the research does not consider the differences between project delivery approaches. Given that each delivery approach has the distinguished relationship between project parties, therefore, the management of cash out should be compatible with the delivery approach.

Batselier and Vanhoucke (2017) exploited the EVM metrics along with the exponential smoothing forecasting approach to articulate a systematic model to predict project costs and durations. Moreover, Andalib et al. (2018) developed a model to predict the owner's financial behaviour during the project execution, using the previous financial records. Even though, the developed model gives a forecasting index with respect to the risk perception to similar projects but generally was designed to predict the cash inflow, regardless of the delivery approach used. Furthermore, Carbonara and Pellegrino (2018) developed a methodology to determine the optimal values of the revenue floor, as well as, revenue ceiling. This methodology was designed particularly for Public-Private Partnership (PPP) and there are two caps either to share risks or revenue; these are the revenue floor to ensure the minimum revenue for contractor, and the revenue ceiling, which defines maximum profit can be achieved by the contractor, and any amount of revenue after the revenue ceiling will be shared. Even though this payment is partly similar to the IPD structure, however, it is missing a crucial limb, which is the cost saving sharing. Moreover, the contractor in IPD could yield to zero revenue in case that the cost/schedule performance is poor.

Even though BIM has been considered to develop the cost budget in some research such as Lu et al. (2016) developed a methodology framework to analyse cash flow, which consists of cash in and cash out. The developed model exploited the 5D BIM capabilities to determine the precise costs of resources for reliable cash outflow. The model used BIM

tools for developing the cash flow curves, however, this study did not consider specific delivery approach for BIM projects.

2.13.3. Research Gap Regarding Cost Control and Sharing Risk/Reward within IPD

A review of the literature shows several trends of research on the risk/reward sharing. 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) (Holzer, 2011, Hosseini et al., 2018). 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 (c.f. Pishdad-Bozorgi et al., 2013, Pishdad-Bozorgi and Srivastava, 2018, Ilozor and Kelly, 2012).

BIM in integration with IPD practices are also discussed in several research studies (Mason, 2017, Rowlinson, 2017, Allison et al., 2018, Ilozor and Kelly, 2012, Nawi et al., 2014, Ashcraft, 2012). The challenges of such integrations are explored in another stream of studies; financial challenges, the difference in cost accounting between participants, and the lack of risk/reward sharing mechanism that can be accepted by all participants (Roy et al., 2018, Zahra Kahvandi, 2018, Holzer, 2011). No workable methodology is however provided to demonstrate the interrelationship among BIM tools/dimensions and IPD stages in practical terms (Roy et al., 2018, Zahra Kahvandi, 2018).

Some researchers have directly attempted to provide effective IPD compensation structures and frameworks. As an example, Zhang and Li (2014) developed a risk/reward compensation mechanism by combining risk perception and the 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 (2013) 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 (Allison et al., 2018, Ballard et al., 2015a). This gap supports the necessity of conducting the present study.

Table 1 shows a summary of the revealed challenges of IPD in corresponding to the three main cost management stages, as well as, the BIM and IPD integration challenges.

Table 1. Cost management challenges of IPD approach

Stage	Challenges	References
Cost Estimation Challenges	The existing accounting system is unclear and unreadable for all IPD core team members due to having different educational backgrounds.	(Roy et al., 2018)
	Given that the Target Value Design (TVD) is a part of the IPD approach, continuous estimation feedback is needed to accomplish the pre-construction IPD stages, as well as, making proper decisions.	(Allison et al., 2018; Zimina, Ballard, & Pasquire, 2012)
	Given that LIMB- 2 represents the overhead cost in addition to the profit at risk percentage, hereby a detailed estimation technique is needed to ensure that the contractor does not hide any profit into overhead cost.	(Ashcraft Jr, 2011)
Cost Budget and control (Risk/Reward sharing) Challenges	Although BIM adoption can improve the traditional cost/scheduling processes, however, the existing budgeting systems do not consider the differences between project delivery approaches.	(Lu, Won, & Cheng, 2016)
	Given, the IPD approach stages do not include a tender stage to select the optimal bid, therefore, a methodology framework to develop a cash flow system using BIM tools within documentation and buyout stage is needed.	(Wang, Mei, Kong, & Xiao, 2016)
	Sharing risk/reward requires an automated/immutable system to record achieved profit; cost-saving and reimbursed monetary values for each member due to the IPD core team members cannot receive their profits and reward until all project works will be delivered.	(Ashcraft, 2012; Zhang & Li, 2014b)

	Cost and schedule are relatively easy to measure. If there are early profit distributions, however, there must be a method for comparing progress achieved to the progress required at that milestone. This will invariably involve some level of estimating using a modified earned value calculation with claw-back and true-up provisions	(Ashcraft Jr, 2011)
	Given, all participants sharing their profit/risk regardless the timeline of executing their works, therefore, an automated system is required to ensure that all profits and risks will move to the profit/risk pools accurately.	(Allison et al., 2018; Roy et al., 2018)
BIM and IPD Integration Challenges	IPD, TVD and BIM are regarded as a winning combination for improving project delivery success. However, very limited research is available to validate the positive aspects of these relationships by providing workable solutions appealing to practitioners.	(Do, Ballard, & Tommelein, 2015; Pishdad-Bozorgi, Moghaddam, & Karasulu, 2013)
	There is not a workable methodology to demonstrate the interrelationship among BIM tools/dimensions and IPD stages in practical terms.	(Allison et al., 2018; R. Holland et al., 2010)
	There are significant issues regarding how BIM is specified, what the process should be for developing BIM communication standards, and how the BIM should be managed and administered.	(Glick & Guggemos, 2009)

2.14. CONCLUSION

This chapter explored the interrelationships between BIM, IPD and cost management from different aspects. The extant and intensive literature review gave a direction that IPD in integration with BIM is the optimal delivery method for AEC projects. After exploring the IPD's characteristics, given that the existing cost structure profile for IPD

is not clear enough for lean implementation, thus it needs integration with another costing method in order to improve the entire IPD's cost management system. Accordingly, the advantages of ABC are able to manage the IPD's cost structure. Since the proposed cost management system will be designed to support the automation, thus the literature review revealed that BIM is the best process to automate the cost management system through its main dimensions 4D (Schedule) and 5D (Cost). From the literature review, there are relevant researches in terms of 4D/5D BIM, therefore, the literature review highlighted the recent contribution of each research as well as its limitations in order to take this in the research scope for the improvement purpose. On the other hand, the integration of 4D and 5D BIM to draw project budget (S curve) has been explored in this chapter in order to define the knowledge gap and related researches, thereby the ABC is the optimal method for this integration due to its ability to work with cost and schedule using the same hierarchy levels and solve the conventional-issue for incompatibility between CBS and WBS. The integration of BIM and IPD is highly recommended to achieve the project objectives, however, a workable methodology is needed to facilitate this integration.

CHAPTER THREE: OVERVIEW OF INFORMATION COMMUNICATION TECHNOLOGY (ICT) AND BLOCKCHAIN IN CONSTRUCTION MANAGEMENT

3.1.INTRODUCTION

This chapter presents a theoretical background regarding using ICT applications (i.e. web-based information systems, blockchain and smart contracts) in the construction industry. It discusses the applicability of ICT through appraising the previous attempts, subsequently, deciding what the ICT applications could be integrated into the IPD process. The previous applications of the web-based management system are presented. Moreover, the blockchain technology—Distributed Ledger Technologies (DLT)—as a concept and applications are discussed and linked to the IPD characteristics. Additionally, a critical analysis of different platforms (n=5) of the blockchain is carried out to determine the suitability to work with the IPD characteristics.

3.2.OVERVIEW OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN CONSTRUCTION

Jacobsson and Linderöth (2010) state that the increasing of shared information in construction industry lead to the necessity of utilising Information and Communication Technology (ICT). There are several reasons beyond calling ICT applications in construction industry, namely, lack of integration between design and production (construction stage), facilitate the communication among different disciplines (teams) whether internal the same organisation or cross different organisations (Söderholm, 2006, Dainty et al., 2007, Wikforss and Löfgren, 2007). In addition, ICT has been widely used to control project costs throughout last few years, particularly the web system applications to display and share the project status among project participants (Cheung et al., 2004, Chou et al., 2010, Ozorhon et al., 2014). The diffusion of ICT has faced several issues,

mainly resistance to change from construction organisations (Peansupap and Walker, 2006), however, the companies could avoid this through understanding diffusion constraints and articulate a strategy to manage these constraints (Stewart et al., 2004). Peansupap and Walker (2006) classify the adoption of ICT in construction to two categories, the stand-alone (inter-organisational) adoption for specific software such as computer aided design (CAD) (Adriaanse et al., 2010), and intra-organisational—integration— this level of adoption is highly recommended as it helps companies to integrate different software to achieve the data sustainability among and across different organisations (Peansupap and Walker, 2006).

There are several applications of ICT in construction, these applications can be concluded as (1) enabling integration between 3D design, visualisation and Virtual reality (VR) features (Ding et al., 2014), (2) collaboration and knowledge management through offering smart decision for decision making process (Beliakov, 2007), (3) procurement and site management through digitalising all information and sharing it using mobiles/web applications (Wong and Sloan, 2004). Recently, BIM is considered as one of the application of ICT in construction industry (Davies and Harty, 2013, Latiffi et al., 2013), throughout last few years, BIM becomes mandatory in many countries, thus the rate of adopting ICT generally has been raised (Eadie et al., 2013). BIM has improved the intra-organisational applications of ICT in the entire construction process through using the Common Data Environment (CDE) to share data among the same organisation or outside in case that the project will be delivered as consortium (Preidel et al., 2017, Khaja et al., 2016). ICT web systems are proven their abilities to work efficiently and effectively in cost control tasks in construction industry, as web system enables all project participants to see the project status easily regardless of the participant geographical place (Cheung et al., 2004, Chou et al., 2010, Ozorhon et al., 2014), for example, Li et al. (2006)

developed and tested web systems to manage and display the project performances through using EVM method. Web system is used in data management in construction throughout last decade, particularly, the application of Map-based Knowledge Management (MBKM) for contractors (Lin et al., 2006). ICT in data management facilitated the understanding through digitalising the knowledge as a map, therefore, information is presented graphically as symbols and huge data is embedded, the designers and users can easily communicate through specific symbols, thus redundant texts will be minimised (Wexler, 2001).

3.3.WEB APPLICATIONS IN DATA SHARING FOR CONSTRUCTION

INDUSTRY

Dunn and Varano (1999) predicted earlier that the web-based systems will have unprecedented opportunities to enhance the business process, in terms of easy access to information, as well as, eliminating communication challenges among business environment. Throughout last two decades web system has been positively affected the trading process through increasing electronic marketplaces, online supply chain and sharing information among enterprises (Linthicum, 2003). The construction industry has catch up the benefits of information technologies, particularly project cost/schedule monitoring and the supply chain tasks (Aouad et al., 1999, Mohamed, 2003). Web-based information systems have been utilised successfully in supply chain management due to its ability to share data through inter and intra organisations levels (Mohamed, 2003). The awareness of inter-organisational applications have been raised, and Adriaanse et al. (2010) proposed comprehensive solutions to all challenges at that time and the impact becomes obvious as BIM level 2 is considered as one of the applications of inter-organisational IT (Lindblad and Vass, 2015). The research of utilising web systems in monitoring cost/schedule projects have received significant attentions (Cheung et al.,

2004, Chou et al., 2010), particularly, utilising EVM method to display the schedule and cost simultaneously to enable stakeholders understand and track their tasks easily (Li et al., 2006).

3.4. BLOCKCHAIN/DISTRIBUTED LEDGER TECHNOLOGY (DLT)

Tapscott and Tapscott (2016) define blockchain as a distributed ledger that records all shared data among different members in a network. Each transaction represents a block in the network and subsequently new blocks are linked to the previous, in order to create a chain (Li et al., 2018b). The interrelationships among all blocks maximise the opportunity of security (Liang et al., 2017). That is, each block carries data and hash for previous blocks to reduce the chance of hacking (Nofer et al., 2017). Li et al. (2018b) mentioned that there are two categories of blockchain networks (BCN), namely, *public BCN* that can be accessed publicly under the generic consensus mechanism. It however remains secure due to its cryptography power mechanisms like Bitcoins (Andoni et al., 2019); *private BCN* that is characterised by having pre-identified users, for which the mechanism to get their consensus should be also identified clearly (Li et al., 2018c). The private BCN represents a single BCN platform for specific organisation, and the data are centralised in this organisation, however, it is decentralised between network users (Andoni et al., 2019) .

Kumar and Mallick (2018) define BCN as a tamper-proof technology that makes it fit to multifunction, a promising technology for avoiding a wide range of bad practices across various industries. Similarly, BCN provide high level security, as the block recorder can check all the recorded data, in terms of the sequence and the interrelationship of data in the network (Banafa, 2017). This prevents the likelihood of tempering data in BCN (Kumar and Mallick, 2018). As such, BCN are efficient in supporting computing solutions (Turk and Klinc, 2017, (ICE), 2018, Lamb, 2018). Implementing blockchain

cost is justified, compared against – the cost of – using third parties to implement financial tasks (Alternative, 2018).

Blockchain networks (BCN) include nodes that are divided into two categories: the network member nodes and the orderer peer nodes that direct the information inside the BCN. Smart contracts include a set of functions for sending any new data to BCN. These can be invoked anytime to send data within BCN, as described next.

3.4.1. Smart Contracts

The development of smart contracts dates back to 1994, defined as an automated system to perform contract terms such as payment transactions through an automated/agreed protocol (Tapscott and Tapscott, 2016, Christidis and Devetsikiotis, 2016). Accordingly, the traditional trusted third party is not needed, due to contract terms being executed based on pre-identified consensus mechanisms (Mason, 2017). Meanwhile, Peters and Panayi (2016) proposed a comprehensive definition for a smart contract: a platform for enforcing and monitoring the data entered by trusted sources, to be stored in BCN, based on pre-identified contract terms. These pre-identified terms should be coded/written using a program language like Go (see Donovan and Kernighan (2015) for details). This is one of blockchain features and a result of evolving BCN – ability to transfer cryptocurrency/data over blockchain – throughout the last decade (Christidis and Devetsikiotis, 2016). Andoni et al. (2019) states that smart contracts use peer-to-peer (PTP) networks that enable multi-trusted parties to manage data simultaneously, so that each chain in BCN carries its own data and subsequently all data will be stored in the ledger, according to the agreed consensus mechanism (Watanabe et al., 2016). Additionally, smart contracts reduce dependency on lawyers/ third persons in executing and monitoring contract terms like financial transaction, and therefore, the accuracy and transparency of data can be enhanced (Mason and Escott, 2018). In fact, as Christidis and

Devetsikiotis (2016) point out, smart contracts benefit users by giving an automatic audit for the transferred data. And once the data have shown validity, the data can be immutable, to enhance transparency and security. The smart contract is named as chaincode in the hyperledger fabric; the chaincode ensures that all transactions are linked and sequenced properly.

3.4.2. The Blockchain Platforms and Consensus Mechanisms

There are several platforms to develop a blockchain networks that the smart contracts can be developed and submitted through these networks (Brandenburger et al., 2018) such as Ethereum, Hyperledger, R3 Corda, Ripple and Quorum (Fersht, 2018). There are different features and capabilities for each platform and according to the requirements and characteristics of the smart contract, the platform can be chosen (Turk and Klinc, 2017).

Consensus mechanism is defined as a set of protocols that ensure the all network's nodes are dealing with the network according to agreed conditions, as well as, defining the path of endorsing the transaction (Andoni et al., 2019, Cachin and Vukolić, 2017, Kasireddy, 2017). Lai and Chuen (2018) state that there are several proposed consensus approaches, namely, Proof-of-Work (PoW), Proof-of-Stake (PoS), Delegate Proof-of-Stake (DPoS), Practical Byzantine Fault-Tolerant (PBFT), Paxos and Raft. Due to the permissionless (Public) blockchain does not have pre-identified participants, therefore PoW and PoS are most appropriate for this kind of blockchain, due to their abilities to support for safety, fault tolerance and scalability of the public network (Lin and Liao, 2017). However, since permissioned blockchain has a whitelisted participants, other consensus approaches are suitable such as PBFT and Raft (Cachin, 2016). Klaokliang et al. (2018) state that Solo and Kafka are main two used consensus mechanism for permissioned blockchain, Solo is centralised approach that relies on a single node to perform all decision to export all blocks to peers, which, limit its deployment due to it affects the availability of network,

as well as, scalability. Whereas, Kafka relies on export the block to blockchain, as well as, making a copy of information to specific network member through a cluster, which, prevent a single failure to the blockchain as Solo mechanism (Klaokliang et al., 2018, Tosh et al., 2017). Additionally, Byzantine Fault Tolerant (BFT) can be used in hyperledger due to its ability to remain valid as long as the number of malicious under the pre-estimated according to Byzantine equation, however Kafka remains more valid since it can be customised according to the each hyperledger case (Sousa et al., 2018).

The permissionless blockchain allows anonymous users to act in the blockchain and add new transaction based on generic consensus mechanism such as Proof of Work (PoW) (Cachin, 2016). The characteristics of permissioned blockchain are, participants are known, vetted and includes a governance approach that regulates the relationships among participants, which maximise the trust (Vukolić, 2017). Since all entities are well-defined in the chain, the permissioned blockchain can use very cheap consensus models such as crash fault tolerant (CFT) or byzantine fault tolerant (BFT), due to the malicious opportunities are diminished (Baliga, 2017, Cachin, 2016).

3.4.3. Hyperledger-Fabric and Chaincode

According to Androulaki et al. (2018), the smart contract in hyperledger is called chaincode, which can be written in different programming language such as GO and Java script (Cachin, 2016). The program could be articulated separately and using API to interact with the blockchain (Androulaki et al., 2017). The user interacts with multiple nodes simultaneously through a channel, this is in order to create a business layer software development (Vukolić, 2016). In any organisation, the channel could be used to share specific information to specific node, which keep the information private (Cachin, 2016). Transactions management is the philosophy of splitting transactions logs and the ordering process, thus this allows to perform parallel transaction concurrently, accordingly, the

ordering will be solely implemented for endorsed transactions (Androulaki et al., 2018, Brandenburger et al., 2018).

Dhillon et al. (2017), Hyperledger (2018) state that blockchain network comprises of several peer nodes, which each peer node includes different smart contracts and ledgers. The application is used to propose the transaction to perform a smart contract, accordingly, the proposed smart contract after the validation will be recorded in specific ledger (Androulaki et al., 2018, Vukolić, 2016). In order to link among mutual smart contracts for different peer nodes, a channel is used to send the proposal transaction as well as reflecting the response to the application (Benhamouda et al., 2018). The order of transaction is pivotal task to package multiple transactions in a single block, subsequently, record the block to its peer node (Dhillon et al., 2017, Hyperledger, 2018).

Xu et al. (2017) defines Consensus mechanism as a set of roles (algorithms) to ensure the correctness of performing set of transaction through a blockchain network, these specific algorithms are unified within a single function, and the consensus mechanism is responsible to order the transaction, check its validity via different endorsers, and allocate validated transaction to their ledger (Androulaki et al., 2018, Hyperledger, 2018). There are two main properties, namely, safety, and liveness (Cachin and Vukolić, 2017, Hyperledger, 2018). Whereas, existing smart contracts use order-execute architecture that requires all nodes to validate and execute every transaction, along with the consensus should be completely deterministic (Androulaki et al., 2018).

In this essence, hyperledger works based on modular environment, which includes pluggable consensus mechanism, management process, ordering approach, chaincode, and membership service (Androulaki et al., 2018, Androulaki et al., 2017, Benhamouda et al., 2018, Brandenburger et al., 2018, Cachin, 2016). Accordingly, each organisation could adapt the hyperledger in accordance with its hierarchy of data sharing, and the

hyperledger can be configured by multiple users to provide flexible platform for different industry purposes (Hyperledger, 2018).

Klaokliang et al. (2018) mentions the structure of hyperledger as follows:

- Ledger: a set of blocks that records multiple transactions.
- Peer: a pool that contains ledgers and smart contracts.
- Chaincode: it is the smart contract to perform transaction according to the hyperledger concept.
- Channel: it is the path that the transaction and blocks take it to be allocated among different peers.
- Endorsement policy: a set of instructions that provide specific metrics to the peer to decide whether the received transaction valid or invalid (Hyperledger, 2018).
- Ordering service: a node (Ordering Service Node (OSN)) that are exploited to order the transactions and blocks based on agreed consensus mechanism such as Kafka, this node should include specific information regarding the size of blocks, maximum time, and number of allowed transaction for each block before assigning it to the peer through the channel (Androulaki et al., 2018, Hyperledger, 2018).

3.5.BLOCKCHAIN/SMART CONTRACTS IN CONSTRUCTION

Blockchain has not been widely adopted across the construction industry, however, there are several attempts towards using it by developing business models (Tozzi, 2018). As an example, Bimchain is a proof of concept to integrate BIM into blockchain in the form of a plug-in for BIM platforms (Bimchain, 2018, Lamb, 2018). Fox (2019) states that there are several cases of adopting smart contracts in the construction industry: delivering the agreed contracts automatically with enabling parties to update any variations; enhancing copyright for project documentation; automated payments among project parties; it can

also work as acclaim submission platform (Lamb, 2018, Tozzi, 2018). As such, smart contracts will be valuable, in terms of the automation of some construction processes that traditionally rely on multi-interactions and contribution from project participants in making decisions (Mason, 2017, Mason and Escott, 2018).

Cardeira (2015) states that late payments and insolvencies in the construction industry lead to several claims, for which adopting smart contracts can significantly reduce the negative consequences (Fox, 2019). Therefore, (ICE) (2018), Lamb (2018) contend that a smart contract is a simple and quick executable solution, which makes it promising for business developments. In fact, complex transactions are relatively expensive, therefore, adopting smart contracts will reduce such accumulative costs (Seetharaman, 2018).

Uncertainties in construction payments are a challenge in developing reliable cash flow that subsequently lead to claims that affect the business growth (Carmichael and Balatbat, 2010). With the construction trust account being recommended (Cardeira, 2015), smart contracts can work as trust accounts that hold the money to be transferred automatically to the party who deserves it (Cardeira, 2015). Project participants will trust smart contracts outputs, given that all the embedded data are immutable and decentralised (Lamb, 2018, Mason and Escott, 2018).

Koutsogiannis and Berntsen (2019) argue that digital construction is an integrated process. With the growth of digitalisation across the AEC industry, smart contracts can be implemented for a wide range of activities. The utilisation of smart contracts with cryptocurrencies can provide a contract draft, where specific funds can be kept to avoid the common insolvencies issues or late payments (Cardeira, 2015). In addition, the cross verifications by several references lead to acquiring an efficient, robust, secure and reliable system, to build a trust environment among project parties (Mason, 2017, Mason and Escott, 2018).

Despite Blockchain does not creep into the construction industry like some other technologies, there are several attempts to adopt it by emerging business models, as an instance, Bimchain is a proof of concept to integrate BIM into Blockchain as a plug-in into the BIM platforms (Bimchain, 2018, Lamb, 2018). There are several benefits of adopting smart contracts in the construction industry, such as; delivering the agreed contracts automatically with enabling parties to update any variations, enhancing the copyright for the project documentations, automated payments amongst project parties, and potentially it can work as a claim submission platform (Lamb, 2018, Tozzi, 2018). As such, smart contracts will be valuable, in terms of automation of some construction processes that traditionally relies on multi-interactions and contribution from project participants to make a decision (Mason, 2017, Mason and Escott, 2018).

Uncertainties in construction payments are a challenge in developing reliable cash flow and subsequently leads to several claims that affect the business growing (Carmichael and Balatbat, 2010). Since the construction trust account is recommended (Cardeira, 2015), Smart contracts can work as a trust account that hold the money and transferred automatically to the party who warranted it (Cardeira, 2015). That is because, the project participants will trust the smart contracts outputs, as all embedded data is immutable and decentralised (Christidis and Devetsikiotis, 2016, Lamb, 2018, Mason and Escott, 2018, Watanabe et al., 2016).

Koutsogiannis and Berntsen (2019) argue that digital construction is an integrated process, thus when a building's real-time digital will be implemented, the smart contracts will be more effective and applicable. Exploiting smart contracts with cryptocurrencies supports articulating a contract draft that specific funds can be embedded to avoid the common insolvency issues or late payment in the construction industry (Cardeira, 2015). In addition, the cross verifications by several references lead to acquiring an efficient,

robust, secure and reliable system, which build a trust environment amid project parties (Mason, 2017, Mason and Escott, 2018).

3.5.1. Previous Works

Through using Scopus, Web of Science (WoS) and google scholar research repository, researcher has used relevant keywords in order to find the relevant papers in implementing blockchain and smart contracts in construction industry/built environment. The used keywords were, namely; “blockchain in construction”. “Blockchain and smart contracts in built environment”. The below table 2 shows the contribution of the selected relevant papers to raise the awareness of implementing blockchain and smart contracts in construction industry, whether thorough addressing it directly or indirectly in different disciplines (see table 2).

Table 2. The related works of blockchain

Discipline	Contributions	Authors
Construction management and built environment	<ul style="list-style-type: none"> • Highlighting the potential of blockchain in construction management; • Providing a map to direct potential users to select the suitable type of blockchain based on the nature of the data, as well as, the hierarchy of the organisation. • Illustrating the blockchain interoperability with other systems (data storage) 	Turk and Klinc (2017)
	<ul style="list-style-type: none"> • Highlighting challenges that face implementing smart contracts in construction industry. • Articulate specific steps that should be considered by industry participants in order to implement smart contracts in the future. 	Mason and Escott (2018)
	<ul style="list-style-type: none"> • Providing an emergent framework that considers multi-dimensions, namely social, political and technical. This is in order to enable potential developers/users of blockchain in construction to highlight the potentials and challenges. 	Li et al. (2019b) and Li et al. (2018a)
	<ul style="list-style-type: none"> • Asserting the importance of intelligent contract (smart) for construction industry through saving the cost of employing third party. And, minimising needed time to perform new transactions. 	Mason (2017)

<ul style="list-style-type: none"> • Highlighting the importance of integrating smart contracts into BIM in order to automate the entire construction process. 	
<ul style="list-style-type: none"> • Presenting an outlook for implementing blockchain to revolutionize the persist issues in managing the supply chain, contract management and resource management, particularly lasing equipment. 	
<ul style="list-style-type: none"> • Providing a taxonomy of blockchain implementation challenges in AEC industry, namely technical, construction business (the conflict between blockchain system and others implemented resource management system such as ERP, particularly in case of using permissioned blockchain), and human challenges. 	Wang et al. (2017)
<ul style="list-style-type: none"> • Developing a framework to utilise the blockchain and smart contract to deal with the challenges of the supply chain management for the precast construction. The solution includes “(1) information sharing management, (2) real-time control of scheduling, and (3) information traceability”. 	(Wang et al., 2020)
<ul style="list-style-type: none"> • Linking the current challenges that face construction industry to the potential benefits of blockchain to provide reliable solutions. 	
<ul style="list-style-type: none"> • Researchers articulated a framework—Presenting the socio-technical dimensions— this could facilitate implementing blockchain in seven areas of the built environment as categorised by researchers. 	Li et al. (2019a)
<ul style="list-style-type: none"> • Identifying making decision criteria in terms of adopting blockchain will be a useful or redundant technology feature to the organisation structure. 	
<ul style="list-style-type: none"> • Authors recommended the utilisation of the blockchain technology with the Common Data Environment (CDE) in order to enable tracking the recorded data with displaying recorders as the data will be stored as a set of nodes. 	Parn and Edwards (2019)
<ul style="list-style-type: none"> • Integrating BIM and blockchain to governing construction project contract through utilising the hyperledger fabric as a blockchain tool. Authors also noted that “the notion of having to translate all the traditional contract clauses to the computer program is shown to be unnecessary and to some extent not suitable for construction, due to the complexity, fluidity, and high uncertainties involved in each project”. 	(Shojaei et al., 2019)
<ul style="list-style-type: none"> • Providing a strategic plan to integrate blockchain into the construction process in order to solve the existing challenges in the construction 	(Safa et al., 2019)

	management field. This research is a foundation for further and real applications of the blockchain in construction management.	
	<ul style="list-style-type: none"> • Providing a model to show the possibility of integrating Blockchain into IoT, and highlighting the potentials of this integration. • Further to the mentioned model, authors present a detailed list of blockchain usages in different sectors. Moreover, authors underpin the new concepts of chain of things, and blockchain of things as extant attempts to achieve desired integration. 	Reyna et al. (2018)
Blockchain and Internet of Things	<ul style="list-style-type: none"> • Authors articulated a decentralised blockchain based supply chain management model to overcome the current challenges of supply chain. • The proposed Supply chain via blockchain MAS uses the smart contracts into blockchain in order to automate the contractual agreement among different parties who are a part of the MAS model. 	Casado-Vara et al. (2018)
	<ul style="list-style-type: none"> • Pointing out the benefits of blockchain and IoT to support shared economy such as Uber. • Presenting examples of shared economy applications such as AutoPay, which is used to pay car parking fee and recording the data using smart contract feature. 	Huckle et al. (2016)
Data movement in Energy sector	<ul style="list-style-type: none"> • Highlighting the potential benefits of using blockchain in energy sector such as price discovery, logistics, identify customers, reconcile any problem and reporting it. • Presenting a MicroGrid based blockchain to manage and control energy demands among the produces, prosumer and end-consumer. 	Andoni et al. (2019)
Generic application of blockchain and smart contracts	<ul style="list-style-type: none"> • Providing a study map to point out the needed future research to implement blockchain and smart contracts. • Authors concluded (n=16) issues in implementing smart contracts. Therefore, the findings of this paper could be used by researcher and developers to try finding remedies for mentioned problems, and the users to be aware regarding the potentials and challenges. 	Macrinici et al. (2018)

3.6.BIM, IPD AND SMART CONTRACTS INTEGRATION

Turk and Klinc (2017) state that blockchain platforms (i.e. Ethereum, hyperledger) can be integrated into BIM to add new features. These features can record all the changes in

3D BIM models throughout the design and construction stages, subsequently enabling stakeholders to track these changes easily (Lohry, 2015). Mason and Escott (2018) assert that BIM in integration with smart contracts will be attainable by 2020, due to the foreseeable increase in the number of sensors in devices, up to almost 25 billion. The promise of BIM level 2 is minimising paper-based communications and exchange (Gibbs et al., 2015), therefore, a platform that shares information among project parties with high levels of transparency and tracks all possible changes is much needed (Mosey, 2014).

Cousins (2018a) argues that BIM processes require a 3D contractual model that includes all the needed data for validation and authorisation of all possible tasks. Bimchain is a plug-in for BIM platforms to minimise the existing gap between 3D BIM models and paper-based legal documentations (Bimchain, 2018), Bimchain is in fact an attempt to manage BIM using smart contracts that enable automated payments, insurance and project information tracking (Bimchain, 2018, Lamb, 2018). As such, smart contracts can be coded for integration into BIM process/platforms, to enable executing traditional provisions in an automated way. This will facilitate all stakeholders' access to all the data available in a secure way, to manage project funds and release the owed payments based on a set of agreed upon rules (Cardeira, 2015, Fox, 2019). Additionally, blockchain can provide a secure and collaborative environment for BIM process (Li et al., 2019a, Ahmad et al., 2019), where all project parties can get the same benefits in access to all the information. Stakeholders will also have the chance to control project changes, due to the main principle of blockchain regarding neutrality (Li et al., 2019a).

Mathews et al. (2017) contends that IPD requires a high level of trust and a collaboration network among core team members; all IPD members are supposed to be all for one and one for all (Ashcraft, 2012). Blockchain by its capabilities in terms of transparency immutability and automated data validation will be able to create a new proposition (Li

et al., 2019a, Vukolić, 2016, Watanabe et al., 2016). Therefore, all sorts of reward can be extracted be it tangible or intangible (Pishdad-Bozorgi et al., 2013). Moreover, blockchain allows several participants to work collaboratively in a single project. And blockchain supports a data-driven digital environment for better project delivery (Koutsogiannis and Berntsen, 2019, Li et al., 2019a). Bimchain (2018), Cousins (2018a) asserts that the combination of BIM and blockchain can provide incorruptible, reliable and transparent system to record, update and maintain the project database. In addition, blockchain and smart contracts can enhance collaboration in the construction industry, along with keeping all participants informed of the project status and all the changes: 3D BIM design, construction site procedures and the flow of supply materials (Mathews et al., 2017).

3.6.1. Decision Criteria for Selecting a Suitable Blockchain Platform for IPD

A major hallmark of IPD is its compensation system for allocating gain and pain ratios among project participants (Fischer et al., 2017). This necessitates a cooperative contracting relationship that ties the individual success of participants to success in achieving the project objectives (AIA, 2007). All participants must agree on a suitable compensation scheme (Pishdad-Bozorgi and Srivastava, 2018), with this scheme determining the proportions of cost overrun, cost underrun and any other fees within the total budget and under the agreed cost (Pishdad-Bozorgi and Srivastava, 2018, Fischer et al., 2017). The cost scheme must comprise direct, indirect and overhead costs and capture the risk/reward proportions based on the degree of achievement during project delivery (Pishdad-Bozorgi and Srivastava, 2018, Zhang and Li, 2014). In IPD, three components or limbs can be defined: Limb 1 represents the reimbursement of project costs and captures all project implementation costs (guaranteed); Limb 2 refers to the

overhead costs for all participants, in addition to the profit (at-risk); and Limb 3 is the pain or gain ratios (the contractual agreement) (Zhang and Li, 2014).

Table 1 shows the IPD characteristics in terms of financial processes, illustrating the five common permissioned blockchain platforms. The suitable platform is the one with characteristics matching the corresponding IPD characteristics. The five platforms can be summarised as follows:

- Hyperledger fabric, as discussed.
- Ethereum, an open and programmable blockchain platform: (1) enables anyone to sign up and create an Ethereum account; (2) enables decentralised applications to be built, as well as smart contracts to be deployed; and (3) uses a cryptocurrency called Ether and has a consensus mechanism that is not fabricated (Bahga and Madiseti, 2016).
- R3 Corda is designed as a specialised distributed ledger platform for the financial industry: it is classified as a permissioned blockchain platform, with a token able to be sent using a smart contract (Sandner, 2017).
- Ripple is an open payment system: as well as a digital currency called ‘XRP’, it has a consensus mechanism called Ripple Consensus Algorithm (RPCA) that is not fabricated. It has its open source project for smart contracts (Armknrecht et al., 2015).
- Quorum is designed to provide security and maintain a desired level of privacy for financial and banking services. Interested readers are referred to Baliga et al. (2018) for details.

The consensus mechanism should be modular and flexible to enable IPD parties to develop a suitable mechanism, according to the team and project environment;

therefore, Ethereum, Ripple and Quorum cannot be used to develop an IPD financial system.

The consensus mechanism, privacy, sending transactions as fiat currency or by tokens and the functionality of smart contracts are the main distinctions among the five listed platforms. Of these platforms, the Ethereum platform is a private blockchain; hence, any interested entity can join based on agreed algorithms (Perna, 2018, Valenta and Sandner, 2017). It is, however, not designed for business networks. Regarding the consensus mechanism, Ripple and Quorum use probabilistic and major voting techniques, respectively (Fersht, 2018). Accordingly, these two platforms are not sufficiently flexible to enable the design of a consensus mechanism based on agreement among an IPD's core team members. The R3 Corda permissioned blockchain platform enables a network's participants to modularise the consensus mechanism, with transactions able to be sent and recorded as fiat currencies (Sandner, 2017, Valenta and Sandner, 2017).

The hyperledger fabric has a consensus mechanism that is modular and can be fabricated according to terms agreed among network (project) participants (Androulaki et al., 2018). Regarding the applicability of permissioned blockchain platforms, several commercial packages are available, for example, the IBM® Blockchain Cloud, the Oracle Blockchain platform and the SAP Cloud, among others (Van Mölken, 2018), with these able to work in cooperation with the hyperledger platform to facilitate its implementation. It can therefore be inferred that the hyperledger platform is the most appropriate for IPD projects, as shown in Table 3.

Table 3. The permissioned blockchain platforms and the IPD financial characteristics

No	IPD characteristics	References	Blockchain platforms					References for blockchain platforms
			Hyperledger fabric	Ethereum	R3 Corda	Ripple	Quorum	
1	IPD core team members are pre-identified entities; all members should acquire the same information at the same time as it is released.	(AIA, 2007, Allison et al., 2018, Rowlinson, 2017, Zhang and Li, 2014)	✓	✗	✓	✓	✓	(Perna, 2018, Fersht, 2018)
2	Risks/reward are shared among parties; this requires all parties to be able to track project progress (cost and schedule) and having access to all data, regardless of their location.	(Ballard et al., 2015b, Pishdad-Bozorgi and Srivastava, 2018, Zhang and Chen, 2010, Zhang and Li, 2014)	✓	✗	✓	✓	✓	(Fersht, 2018, Team, 2019)
3	A new party can join at any time after the core team members are formulated.	(Ashcraft, 2012)	✓	✗	✓	✓	✓	(Androulaki et al., 2018, Androulaki et al., 2017, Fersht, 2018, Hirai, 2017)
4	Three financial transactions should be invoked in each payment milestone (reimbursed cost, profit and cost saving).	(Ballard et al., 2015b, Roy et al., 2018, Thomsen et al., 2009)	✓	✓	✓	✗	✓	(cointelegraph, 2019, Cachin, 2016, Dhillon et al., 2017, Fersht, 2018)

5	The consensus mechanism should be flexible, so it can be changed based on agreed conditions.	(Ahmad et al., 2019)	✓	✗	✓	✗	✗	(Baliga, 2017, Cachin, 2016, Cachin and Vukolić, 2017, Wang et al., 2018)
6	As IPD core team members come from different backgrounds, the financial system should be friendly for various users, understandable and flexible: a platform that uses commercial packages is preferred.	(Allison et al., 2018, Mathews et al., 2017)	✓	✗	✗	✗	✗	(Vukolić, 2016, Van Mölken, 2018, Ranade et al., Woodside and Amiri, 2018)
7	Financial transactions should be invoked and recorded in specific tokens (fiat currencies such as dollars).	(Allison et al., 2018, Roy et al., 2018)	✓	✗	✓	✗	✓	(Kiviat, 2015, Fersht, 2018, Dhillon et al., 2017, Hyperledger, 2018, Prerna, 2018)

3.7.BARRIERS TO IMPLEMENT BLOCKCHAIN/SMART CONTRACTS FOR CONSTRUCTION PROJECT DELIVERY

Given that the construction industry relies on fiat currencies on its payment, therefore blockchain needs to be changed to transfer fiat currencies, instead of cryptocurrencies as exist (Cousins, 2018a). In addition, the bank is currently using private ledger, therefore, the linking between smart contract and bank accounts is not attainable (Pisa and Juden, 2017). However, if any commercial/ central bank accepted to be a part of the distributed ledger, therefore the payment can be sent/received in a fiat currency (Brody). The coding of unstraightforward legal concepts are considered as a practical challenge in using smart contracts such as ‘good faith’, ‘negligence’ and ‘reasonableness’ (Sherborne, 2017). Additionally, Raskin (2017) contends that smart contracts cannot fully include all legal terms, for instance, the legal contracts should include the elements of offer, acceptance and clear expression to show the intention of parties to enter into a legal agreement. However, the user can articulate a draft contract and subsequently code all possible terms, thus, the draft contract can work as a recovery for any issues that have not been coded (Clack, 2018).

Intellectual copyrights are sensitive and important for construction companies, however, the shared data in hyperledger is decentralised and the copyright issues should be considered (Cousins, 2018a). As such. Arnaud Gueguen, founder and CEO of Bimchain argues that “We believe a country like the UK, which is more contractual than France, or Scandinavian countries, could deploy our solution more fully” (Cousins, 2018b). Allison et al. (2018b) states that application of blockchain requires new regulations, law and governance system in order to overcome all possible challenges. In addition to, The currently set up cost of blockchain is very high , however, the potential benefits of

implementing blockchain can cover the needed resources in a short term (Andoni et al., 2019).

There are several technological issues face blockchain implementation in construction industry such as sufficient bandwidth and capacity that are required to ensure that all data will be transferred without any lack in the time (Kasireddy, 2017). Additionally, the entire technological state of AEC industry is not entirely digitised to adopt blockchain and smart contracts technologies (Li et al., 2018a). Andoni et al. (2019) asserts that blockchain must prove its scalability, viability, and its speed to different cases, as well as, the consensus algorithms research is still ongoing to combine all desired characteristic in an integrated consensus protocol (Wang et al., 2018).

ICAEW (2018) states different challenges, the fees per transaction is from £5 to £8, the period between sequential transaction is around five minutes, and the capacity of transaction is low compared to the traditional banking visa. Although the high reputation of blockchain in terms of security (Kollewe, 2018) , however there were several successful attempt to hake it during last few years and the most recently amount around £27 million (Lamb, 2018). As such, each organisation should determine the potential minor and major breaches in case using cybersecurity. Indeed, Pradhan et al. (2017) state that "Full blockchain development could take five to seven years or longer, or may not occur at all". Early adopters who commit to testing blockchain across the supply chain must be prepared to accept significant levels of risk — and be prepared to fail fast and try again”.

3.8.JUSTIFICATION OF USING BLOCKCHAIN IN THE CONSTRUCTION PROJECT DELIVERY

The review of the literature indicates that research on blockchain has received much attention in recent years (Turk and Klinc, 2017, Ahmad et al., 2019). Some researchers have demonstrated the importance of implementing specific features of blockchain like smart contracts in automating payments in the construction industry (Mason, 2017, Mason and Escott, 2018). And there is evidence in the literature to acknowledge the wide applicability of blockchain and smart contracts. As an example, Mathews et al. (2017) proposed that the integration of BIM and blockchain can maximise trust among project participants in the AEC industry, and Li et al. (2019a) proposed that blockchain can be useful in enhancing supply chain management. However, to date, available research studies on the topic have not gone beyond proposing conceptual proposals and recommendations. As such, research on the topic has been limited to the theoretical conceptualisation of possible applications of blockchain in the AEC industry.

The above gap can be a major issue across the AEC industry. That is, with the growth in adopting BIM level 2 and moving towards the full integration of all dimensions in the form of BIM level 3 (Succar and Kassem, 2015), there is increasing need for using IPD (Pishdad-Bozorgi et al., 2013, Rowlinson, 2017, Zhiliang and Jiankun, 2011). However, there is need for much more research on integrating BIM and IPD (Wickersham, 2009). Moreover, some aspects of implementing IPD, particularly, that of financial management act as major barriers: sharing risk/reward requires an automated/immutable system to record achieved profit; cost saving and reimbursed monetary values for each member due to the IPD core team members cannot receive their profits and reward until all project works will be delivered (Pishdad-Bozorgi and Srivastava, 2018, Ballard et al., 2015a, Roy et al., 2018).

Through comparing the requirements of an efficient IPD financial system and the current blockchain capabilities, specifically the hyperledger fabric, the utilisation of hyperledger fabric to build an IPD financial system is conceptually proven. This builds upon the proven capabilities in previous studies and provides a response to widespread recommendations for exploiting blockchain in its integration with BIM. The outcome will enhance the financial process in the AEC industry, particularly, for IPD projects (Bimchain, 2018, Mathews et al., 2017, Lamb, 2018).

3.9.CONCLUSION

This chapter explored the different ways to integrate ICT technologies into IPD such web-based management system, and blockchain to enable sharing data among IPD core team members. Regarding web system, it can be used to display the risk/reward values periodically in order to minimise the regular meetings for whom do not have any implemented activities. The blockchain, particularly hyperledger fabric to automate the payment process between owner and non-owner parties. Although, to date, the blockchain does not support the fiat currencies, however this is suitable for the IPD concepts as the risk/reward should not be paid until all projects works are executed. A critical analysis for selecting the best platform to conduct payments within IPD was carried out, the hyperledger fabric was chosen due to its abilities to fabricate the network's consensus mechanism, and it is mainly designed to work as business network. On the other hand, there are many commercial platforms such as IBM and Oracle in collaboration with hyperledger (Linux) to make its implementation more attainable, workable and applicable. Furthermore, successful integrations of BIM into Blockchain were discussed, as well as, challenges that face maximising the value of these integrations were also highlighted in this chapter.

The extant literature review proves that the blockchain is promising technology to achieve the intra-organisational ICT, and IPD is mainly required an intra-organisational collaboration platform, thus the implementation of blockchain and web based management system can work efficiently within the IPD organisation. Moreover, the challenges that face the utilisation of blockchain in construction industry are discussed to be managed when the solution will be developed.

CHAPTER FOUR: RESEARCH DESIGN AND METHODOLOGY

4.1.INTRODUCTION

An overview of the research designs, methodological approaches, and different research methods and techniques with respect to the different paradigms are elaborated upon and the corresponding issues of validity and reliability are discussed. Following that, the selected paradigm of this research and its corresponding ontology, epistemology, and axiology are explained. The employed stages in this research (i.e. framework development, framework validation, prototype development, and prototype validation) are stated. Finally, there is discussion of the methods and techniques used for the data collection and the corresponding issues regarding validity and reliability of the data.

4.2.RESEARCH PHILOSOPHY

Guba and Lincoln (1994) state that the research paradigm is a set of beliefs which direct the research, the research paradigm comprises of four elements, namely, epistemology, ontology, methodology and axiology (Scotland, 2012). Kivunja and Kuyini (2017) assert that the understanding of the mentioned four elements is essential to ensure acquiring proper research design. Moreover, it is also important for the researcher to ensure that the selected methodology is consistent with the concept of the research (Crotty, 1998). The understanding of the reality is called ontology, however, the epistemology refers to the way of getting the knowledge relative to the specific phenomenon (Kivunja and Kuyini, 2017). Meanwhile, Stenbacka (2001) defines the methodology as a question about how the valid knowledge can be acquired or in other words, it is the study of appropriate methods in order to achieve the aim of the research, as well as, validating the achieved objectives (Stenbacka, 2001). The axiology refers to the philosophical evaluation of research values and how the researcher reflects the research values in corresponding to the articulated objectives (Saunders et al., 2009). Therefore, Ponterotto (2005) states that

research philosophes should be identified and analysed as these philosophies shape the research context and affects the reliability of achieved objectives.

According to Saunders et al. (2007), the research process is a set of layers similar to the “onion” as shown in figure 11. The process of the research methodology goes systematically from outer—begins by the research philosophy—to the core till reach the research data collection methods. In this chapter, all layers will be discussed and according to the research’s aim and objectives, thus the adopted philosophy or method will be selected.

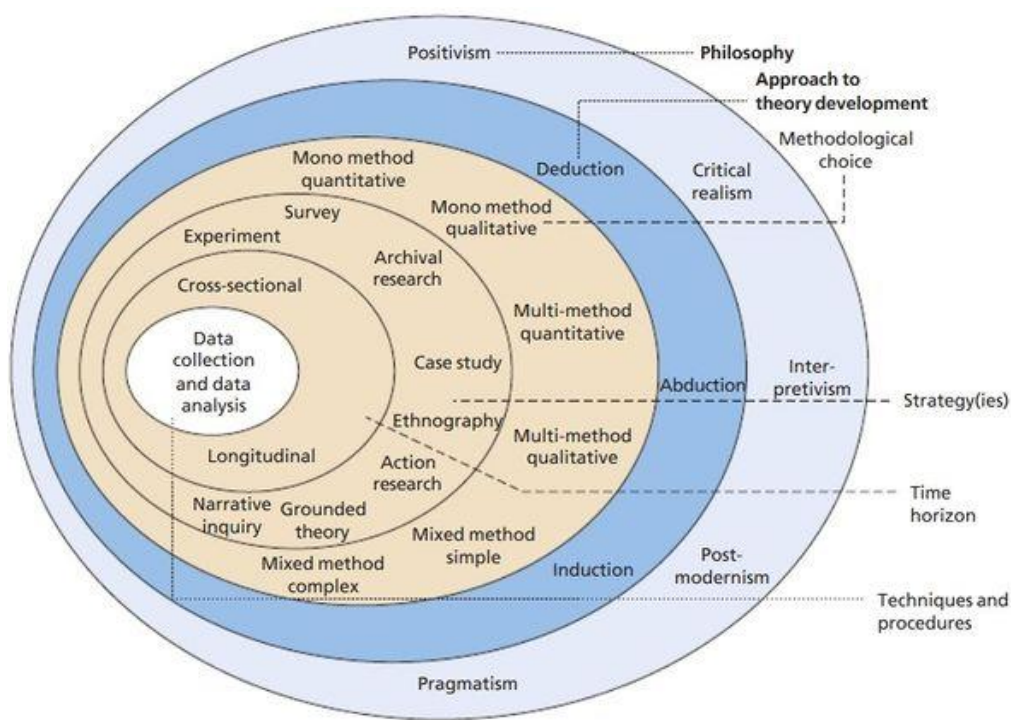


Figure 11. The research onion (adapted from (Saunders et al., 2007))

4.2.1. Ontology

Scotland (2012) defines the ontology as the structure and nature of reality or conception of what exists, in other words, the possibility to know about the world (Snape and Spencer, 2003). Moreover, Richards (2003) argues that ontology is a set of assumptions that are created to enable a researcher/investigator to understand the nature of reality.

Bryman (2008) defines the concept of ‘social ontology’ as a philosophical consideration in research which pertains to the nature of social entities, e.g., either these social entities are objective entities that exist independently from social actors or these entities are constructed in themselves built up from the perceptions, actions and conclusions of the individuals in society. There are two social entities perceptions are categorised as objectivism and subjectivism positions. The objectivism is defined as the entities exist independent from the perception, therefore it can be exploited to describe any nature phenomena (Austin, 2009). Subsequently, the ontology will be objective without any human interactions and the interpretation of the social entities will be under social conditioning (Saunders et al., 2009). Whilst, the subjectivism is defined as the perception of specific social entities through human actors with respecting their positions and other factors which affect their views (Bryman and Becker, 2012), hence, the ontology as subjectivism cannot describe a single fact since it relies on the place as well as the time of observing the phenomena (Nightingale and Cromby, 2002). Lee (2012) argues that the term subjectivism is used interchangeably with constructivism, however, the subjectivism perception for any object, in reality, is completely denied due to social actors try to observe the phenomena based on their situations and build their understanding based on subjective views.

As stated, the relativism (subjectivism) ontological position represents the perception of specific social entities that are affected by human actors, and this research explores developing solutions to the cost management practices of the IPD due to the revealed deficiencies by the practitioners. Therefore, this research can be described as relativism.

4.2.2. Epistemology

Epistemology is a philosophical term that discusses the nature, structure and scope of the knowledge, therefore, the epistemology explores the sources that shaped the knowledge

such as perception, memory, and different types of reasoning (Goldman, 2004). To be more specific, epistemology is exacting the theories that provide answers to questions, which, are raised to understand the nature of the knowledge (Knight and Turnbull, 2008). Defining the relationship between ontology and epistemology is an important for the researcher as there is directional and inextricably relationship that enables the researcher to understand the nature of the research problem, as well as, the knowledge that is structured to understanding/perception of the problem (reality) (Essays, 2018, Furlong and Marsh, 2010).

Riege (2003) state that positivism refers to the nature with social science can provide a set of methods that can provide understanding regarding an independent fact that is assumed to exist as apprehendable reality, this fact is driven by natural law and mechanism. The positivism approach relies on empirical methodologies that extracted from the natural science to interpret specific phenomena (L BERG, 2001), therefore this approach is mainly used while conducting quantitative research (Yu, 2003). This is asserted by Merriam (1998), quantitative research utilises positive-science through testing the research hypothesis using a wide range of rigorous, reliable and verifiable empirical data.

Meanwhile, Interpretivist refers to discovering the reality from human views (human experience and perceptions) (Cohen and Manion, 1994). Therefore, The Interpretivist paradigm is used to understand the contexts and beliefs that are socially constructed (Willis et al., 2007). As such, this paradigm is used when the research is conducted qualitatively since there is an interconnection between qualitative research and Interpretivist paradigm (Silverman, 2013, Willis et al., 2007). To assert, Thomas (2003) points out that the Interpretivist is used with qualitative research due to it portrays the world in case the reality is socially constructed and characterised as complex and rapid

changing. As well as, qualitative research usually provides long/rich reports that require employing Interpretivist to understand the research outcome/ findings (Willis et al., 2007).

As such, Positivism and Interpretivist approaches have some limitations regarding the positivism is mainly driven by the universal law, therefore it is considered as an over-deterministic approach that limits the choices, on the other hand, the Interpretivist approach is highly contextual and relativist (Calado et al., 2009). Hence, a third approach which is a realist is recommended to deal with mentioned shortcomings of the other two approaches (Olsen, 2004). Niiniluoto (1999) states that “Epistemological realism claims that it is possible to obtain knowledge about mind-independent reality”, therefore, the reality can be socially constructed, however, the understanding is limited and all findings could be fallibilism through scepticism and dogmatism (Boyd, 1980).

Given, the research includes objectives that require human views in order to fulfil them such as questionnaire and interview in order to develop the solution and validate it. Accordingly, this research epistemology can be classified as ‘Interpretivist’. On the other hand, this research can also be described as positivism since a new cost management system is needed for the IPD approach and this is an independent fact that is explored by the empirical investigations.

4.2.3. Axiology

Smith and Thomas (1998) define the axiology as a branch of the practical research philosophy that is concerned with the nature of value, it is also classified into two concepts, which are value-free/neural or value-driven/value-laden, therefore, this branch of study considers the individual effects such as political, social and ethical on the research directions and findings (Lekka-Kowalik, 2010). That’s why Heron and Reason

(1997) argued that the research findings are usually affected by the axiological attitudes of the researcher through expressing their values that direct the path of research. The research has several phases that are affected by spectrum axiological attitudes, it extends from value-free to value-driven (Mingers, 2001). However, Douglas (2009) contends that it is not applicable to conduct a research based on the value-free axiological concept even if the employed ontological paradigm is objectivism, and this is more unattainable in case that the constructivism ontological paradigm is applied since the researcher often interacts with the research subject, therefore, all proposed claims are affected by the research participants (Riege, 2003). Particularly, when the research includes methods such as interviews or questionnaire, the participants' cultures and the background will be presented in their responses (Knox and Burkard, 2009).

Given that this research relies on conducting a questionnaire to explore the current practices of cost management within the IPD approach and evaluating BIM tools practices, in addition, conducting interviews with experts to evaluate the proposed cost management system, therefore, the research can be classified as “value-driven axiology”, however, the researcher considers the validity and reliability of the results through applying statistical tests and other validity and reliability tests (see section 4.8 for more details) to avoid any biased views that could affect the research findings.

4.3.RESEARCH APPROACH

There are three main approaches that were highlighted in the research onion, these approaches are deductive and inductive approaches.

4.3.1. Deductive Approach

The deductive approach is used to develop the hypotheses for a specific problem, based on the extant literature, subsequently, articulating the suitable approach to validate and

test the significance of assumed hypotheses (Silverman, 2013), therefore, the deductive approach is a progress of a specific theory that is methodically validated. This approach is highly utilised in natural science research since it relies on objectivism ontological paradigm that is used to describe any independent nature phenomenon (Collis and Hussey, 2013). Hyde (2000) states that the deductive approach begins by building general thinking (understanding) to more particular thinking (top to down methodology). According to Bryman (2016), the exploration steps begin by defining the gap (research problem), followed by articulating hypothesis based on existing theories, investigating the significance of proposed hypotheses through suitable techniques and methods, analyse the findings and reflect these findings on the tested theories to improve them based on the results that retrieved from the valid hypotheses. Positivism is the proper epistemological paradigm to work with the deductive approach since the researcher is exploring to validate the theory in value-free statistical as axiological practice (Hyde, 2000). Accordingly, the findings will be only derived by the statistical parameters regardless of the researcher views/attitude (Levin-Rozalis, 2004).

4.3.2. Inductive Approach

Locke (2007) noted that the origin of utilising the inductive thinking backs to Aristotle (384-322 B.C.) who adapted it from Socrates (470/469–399 B.C.), contrary to deductive thinking, the inductive approach process begins from specific to the general. In addition, the inductive approach is concerned with building the theory rather than testing it as the case with the deductive approach, so in inductive approach the research begins by observing specific event, followed by building general understanding about this event, then, developing set of tentative hypotheses to understand the characteristics of the observed event, finally, articulating a theory to describe the observed phenomena (Hyde, 2000). As the aim of adopting this kind of thinking (reasoning) is to build an

understanding of a specific event, individual or group attitudes (Bendassolli, 2013). Since inductive reasoning is used in most of the research as an exploratory approach through open-ended inquiry, therefore, most of the research adopt both deductive and inductive throughout the entire research stages in order to narrow the research scope and therefore articulating valid findings (Bryman, 2016, Kothari, 2004, Teddlie and Tashakkori, 2009). Accordingly, mixing between deduction and induction reasoning in research is applicable and acceptable as each stage in the research has distinct characteristics that need various thinking approaches (Douven, 2011).

4.3.3. Abduction Approach

After discussing the two ways that are used to develop a research hypothesis and showing that the research stages are different and requires implementing both of them in order to avoid their individual shortcoming, therefore, the abduction approach is genuinely proposed by Charles Sanders Peirce (Krupnik and Turek, 2014). The abduction approach is concerned with providing answers as reasons in forms of “what and why” questions, therefore, this way of reasoning provides understanding rather than explanation (Blaikie, 2007). Therefore, it is a middle-ground position between the inductive and deductive reasoning approaches, and the researcher who adopts abductive thinking should provide research with clear explanations of its process, ethical considerations, and this can ensure the reliability and the validity of the research tasks and findings (Timmermans and Tavory, 2012). There are several disciplines adopt the abductive approach, however, each discipline adapted the abductive reasoning approach with its requirements and characteristics (Haig, 2005). Bryman (2016) argues that if the research can be purely conducted using either deductive or inductive reasoning approach, this will be much satisfactory rather using the abductive approach. According to Bendassolli (2013), the research process begins by observing the phenomena that the data could be retrieved

experimentally or using natural design and the inductive reasoning will be employed to infer the nature of the observed phenomena, subsequently, related theories will be determined by the deductive approach to investigate the observed phenomena. In addition, two or more tasks can be implemented in a parallel way with implementing abduction such as while developing a framework to describe an observed phenomena, another data collection can be conducted towards creating new knowledge, therefore, this approach is like a loop with two directions, one towards developing theory and another is to implement more empirical studies to open new directions (Dubois and Gadde, 2002).

With all above in mind, this research adopts the abductive reasoning since the inductive approach will be utilised to build a critical understanding regarding BIM-based cost management practices within the IPD approach, and determining all related theories, followed by revolutionise and validate the initial understanding through collecting experts views (survey using questionnaire tool) and providing tentative hypotheses. Whilst, the deductive approach will be implemented through testing the proposed hypotheses (BIM is the best approach to be integrated within IPD, ABC can enhance the IPD's cost structure, Mixing ABC into EVM can provide mathematical models that can facilitate automating risk/reward sharing, Blockchain (hyperledger fabric) is efficient to provide an automated financial system that can keep all data immutable after applying agreed automatic endorsement policy). Therefore, the abductive reasoning approach will be implemented since it accepts utilising qualitative and quantitative methods (mixed research methods) (Yvonne Feilzer, 2010), and this is required in this study, all utilised methods will be clearly explained/extended later in this chapter.

4.4.RESEARCH CHOICE

Punch (2013) divides the research approaches into two categories, quantitative and qualitative methods, these methods can be employed as a mono method, mixed methods

and multi-methods (Saunders, 2011). The mono method refers to employing one approach to conduct the research (i.e. quantitative or qualitative), the mixed methods mean that methods from both quantitative and qualitative approaches are utilised, the multi-methods means that several methods are used, however, these methods could be all quantitative or/and qualitative (Halcomb and Hickman, 2015, Jick, 1979). To be more specific, mixed-methods approach is set of methods that are mixed to collect data for a single data (Flick, 2017), however, the multi-methods is when the research project is divided into stages so that each stage requires specific methods whether quantitative or qualitative methodologies to collect its data (Yvonne Feilzer, 2010).

4.4.1. Quantitative Research

Abowitz and Toole (2009) state that the quantitative research utilises scientific methods to collect the data when the initial study such as literature review leads to a better understanding of research nature and subsequently articulating reliable aim and objectives. Newman et al. (1998) confirm that the quantitative research is often utilised when the reality (subject) independently exists (epistemological paradigm is positivism) and research fields such as chemistry, physics and mathematics. Therefore, qualitative research is utilised particularly to describe empirical data into specific phenomena through employing statistical/computational techniques to provide interrelationships between the measured and analysed empirical data (Denscombe, 2010). As such, it is recommended to address the research questions such as what, how and many (Fellows et al., 2015). The quantitative research is often conducted using a survey (questionnaire), lab experiments and case studies (Saunders, 2011).

4.4.2. Qualitative Research

According to Maxwell (2008), qualitative research is concerned with exploring research subjects that have not formulated previously (there is any definitive finding), the objective often articulate a full understanding regarding the research subject to reveal the relevant theories. The researcher in this kind of research is a vital player in collecting data, formulating the research tasks and finally presenting research findings/outcomes in a proper and reliable way (Saini and Shlonsky, 2012). Therefore, qualitative study (methods) adopt the epistemological Interpretivism paradigm since the research data is usually collected as people perspectives and subsequently these data will be analysed in a single context to articulate the findings (Calado et al., 2009). The aim of adopting a qualitative approach is to understand and interpret the people attitudes and views (Sarantakos, 2013). That's why Strauss and Corbin (1990) assert that qualitative methods are the best choice in case the research explores new phenomena and there is a lack in understanding it. Therefore, it can be used to collect data regarding the research variables and finding the relationships among revealed variables, these variables can be tested and evaluated quantitatively (Patton, 1990), for this reason, the qualitative research (especially interview method) is highly employed in Information Systems studies (Silverman, 1998).

There is a wide range of strategies that are employed as qualitative approach such as action research, qualitative case study, interview, focus group, narrative research and ethnography (Saunders, 2011), as well as, using “words” to describe the research findings rather than using numbers compared to quantitative approach (Bryman and Becker, 2012).

Creswell (2013) states that the integration between quantitative and qualitative methods give the opportunity to collect all kinds of data to convergence among the results, this is

called mixed research methods or triangulation. And it is usually used to eliminate the shortcomings of quantitative and qualitative methodologies when it is utilised individually (Fellows et al., 2015, Creswell, 2013).

According to Van Maanen (1979), qualitative research approaches include set of techniques that are concerned with understanding, decoding or translating for phenomena in the social world, however it is not concerned with determining the frequencies or giving numerical indications. There are several strategies are used with the qualitative approach such as grounded theory, ethnography, action research and case study (Denzin and Lincoln, 2008).

4.4.3. Mixed Research Methods

Dainty (2008) states that mixing qualitative and quantitative approaches are utilised to reduce the shortcomings of using an individual approach and getting the advantages of each methodology. the mixed research methods refer to mixing quantitative and qualitative methods or mixing two methods from each approach such as using interviews and focus group at the same study for in-depth understanding and analysis (Flick, 2018, Corbin and Strauss, 2008, Fellows et al., 2015). In addition, the triangulation is adopted to validate the retrieved data or collecting more data about a specific problem (Corbin and Strauss, 2008). Furthermore, Bryman (2006) concluded the advantages of adopting mixed research methods as (1) triangulate the research findings that can be mutually endorsed, (2) mixing methods can offset the shortcomings of individual method and maximise its capabilities, (3) articulate completed findings that are generated by the combined methods.

This research adopted a mixed research methods approach to theory development since the literature review in conjunction with a survey (questionnaire) are utilised to develop

the research framework. Additionally, the proposed framework will be tested using a quantitative case study to apply all proposed tools and techniques on a real-life case study, subsequently, it is followed by qualitative approach, which is interview method to observe expert views regarding the proposed framework applicability, validity in the practical field.

4.5.Time Horizon

Saunders (2011) defined the research time horizon as a time framework which the research is designed to be completed, there are two types of time horizon in the research onion, namely, the cross-sectional and longitudinal time horizons. The first one refers to the research that should be conducted in specific point on time, meanwhile, the longitudinal refers to the research that is implemented through a long period of time (Saunders and Tosey, 2012). The research that is utilised by experiment method, action theory and grounded theory are usually considered as longitudinal time horizon research, however, the research that is utilised by methods such as survey is considered as cross-sectional research (Saunders and Tosey, 2012). Given, this research adopts methods that do not require a long time to collect the data such as literature review, survey (questionnaire tool) and interview, the research has been conducted in almost two years, therefore, this is cross-sectional research.

4.6.RESEARCH METHODS

Through reviewing the literature review, there are several methods are applied in the construction engineering field. These methods can be concluded as (1) experiments, (2) case studies, (3) Ethnographic Research, (4) action research, (5) grounded theory, (6) survey, (7) archival research. Each method will be discussed in this section to enable choose the suitable methods to conduct the research aim and objectives.

4.6.1. Experiments

Christensen and Waraczynski (1988) define the experimental research as a process to test the research hypothesis through examining the casual relationships among different variables and this is usually conducted in the laboratories (Chynoweth, 2008). The experiential research is associated with the quantitative studies and it is usually adopted in a positivism context (Hindess, 1977). Even though experiments method showed a great success in the modern science through giving the opportunity to understand the cause and effect relationships (Chapin, 1917), however, there are some disadvantages to use the experiment methods such as the personal bias to analyse the results, samples might be unreliable that provide misleading results, the outcome of the experiment represents a single situation which makes it hard for any replication in other research, the human actions cannot be observed, finally, the results might not describe the entire real-life situation (Mason, 1992). The ethical and practical issues play a vital role to determine whether the experimental methods can be applied or not as these methods usually take a long time and expensive, therefore, these methods are no applied in many areas of research (Cooper et al., 2006). Given, the aim of this research is to develop a cost management system for the IPD approach using BIM and blockchain technologies, therefore, there is no a direct relationship between the experimental methods and the aim of this research whether in the development stage or the validation stage.

4.6.2. Case study

Tellis (1997) states that the case study approach is an approach to investigate a particular phenomenon empirically within its real-life settings. The case study method is often used to respond to two types of questions which are “How” and “Why” (Baxter and Jack, 2008). The case study method is utilised for two purposes, namely, building an in-depth

understanding regarding the research context, subsequently, develop new themes, and validating any proposed theoretical ideas/framework (Morris and Wood, 1991). According to Fellows and Liu (2015), the used case study in the construction management field can be classified as (1) a source to provide ideas to the researcher, (2) describing the specific phenomenon, (3) describing/ abstracting projects, (4) evaluate previous studies. The case studies are categorised as single-case study and multiple case studies that are usually used to compare results to enforce/validate specific direction (Yin, 1981).

Bello (2003) notes that the case study can provide primary valuable information to the researcher due to the retrieved information is more concrete and contextualised since all case studies information should be well-analysed and examined (Saunders, 2011). The case study method can be used as an exploratory approach to test and validate the research hypothesis, on the other hand, the descriptive case study can be utilised to understand the situation around the specific phenomenon, hence set of hypothesis can be developed (Yin, 1981).

Davey (1990) defined the illustrative case study as method that is used to interrupt the data for an experience or program. As well as, it is used to make the unfamiliar things more familiar through explaining it to the reader and understanding the problem uses examples. This method has been used to test the usability of a developed prototype to test an idea (Corry et al., 1997). According to Fairley et al. (2005), there are two purposes of utilising the illustrative case study, namely, bridging the gap between the researcher understanding and the target audience and inform potential users about a topic of which it was previously presented—or widely utilised.

Regarding using an interpretive case study to validate or measure the usability of a proposed tool, Ponelis (2015) asserts that using an interpretive case study can enable the

researcher to explore interesting and potentially relevant topics to the research problem while collecting the data.

There are several similar research that its developed tools have been validated using an illustrative case study through using a real BIM model, subsequently, apply the developed tools to measure its applicability such as research by (Zou, 2017, Montaser, 2013).

As such, in this research, an illustrative case study is used to test the usability, scalability and practicability of proposed tools—Prototype testing. A framework is developed based on the highlighted gap and retrieved information from the literature review and the questionnaire. The framework includes specific tools and techniques that should be validated/verified empirically. The researcher using real data such as using 3D, 4D and 5D BIM models and develop an IPD context including the compensation model for all IPD core team members, subsequently, develop scenarios to measure the applicability of the proposed tools of the framework.

4.6.3. Ethnographic Research

Hammersley (2016) states that the ethnographic research is when the researcher is involved in a specific period in a social life that is required to be explored, and the conclusion is usually articulated by the researcher's observations. The qualitative approach is generally utilised in this type of research, meanwhile, several methods can be applied such as observations, interviews whether face-to-face or digitally by emails (Szewczak and Snodgrass, 2003). Some research mentioned that ethnographic research is an instrument to collect data rather than a research design (Wilkinson, 2011). Given the aim and objectives of this research do not explore the attitude and behaviour of any specific group, therefore, this method is not considered in the research design.

4.6.4. Action Research

When the researcher study-specific problem within an identified environment and all participants have similar/common background and the researcher is actively acting as a participant rather than observer, this is called action research (Cunningham, 1995). This type of research is usually implemented to solve a specific social problem (Fellows and Liu, 2015). This type of research is often to be employed in business management area since the researcher can be included in a specific organisation to identify and solve a problem with a group of professionals (Bell and Bryman, 2007). Given this research characteristics—the required data—do not meet what this method can provide, therefore, this method will not be employed here.

4.6.5. Grounded Theory

Glaser and Straus (1967) developed the grounded theory in order to derive the theories that can describe human behaviours and experiences in specific situations through the derived empirical data. The process includes several steps for collecting data, and after each step, an analysis is often conducted while another data collection is progressing (Straus and Corbin, 1997). It begins by coding the emerged issues to formulate statements until the final theory will be grounded (Jones and Alony, 2011), there are different types of coding, open coding is utilised for classified and categorised data (Moghaddam, 2006), in case that there are interrelationships between data, the axial coding technique should be utilised (Kendall, 1999). When the integration of categories is used to develop a theory, selective coding is appropriate to be employed by the researcher (Charmaz and Belgrave, 2007). Given, this research relies on developing a practical solution based on exploiting existing theories, therefore, this method is not adopted in this research.

4.6.6. Surveys

Saunders (2011) states that the survey method is usually utilised to collect quantitative and qualitative data through a specific period. There are two main types of research that employ this method, which is exploratory research and descriptive research (Groves et al., 2011). A survey can be conducted using several techniques such as questionnaire, interview and observation (Fellows and Liu, 2015). In the management research, the survey is often utilised to respond to questions like ‘who?’, ‘what?’, ‘where?’ and ‘how?’. Moreover, This method can be used to compare between the existing conditions and the standard one, this leads to building relationships between different events in common points over a specific time (Groves et al., 2011). Tan (2002) asserts that the survey method is the best approach to understand the responder’s meaning to enable developing a new hypothesis that can be developed as theories.

Given that one of the research objectives is to evaluate the current practices of BIM and IPD processes such as the challenges that face the implementation of IPD regarding the cost management within the AEC industry practitioners, therefore, the survey method will be employed using the questionnaire technique.

4.6.7. Questionnaire

The questionnaire is a survey instrument that is usually employed to collect quantitative data (Thomas, 2003). The questionnaire tool is advanced by giving the respondent enough time to understand the questions and answer them, most of the questions are multiple choices such as using Likert-type scales (Converse and Presser, 1986). The risk of a low rate of response should be highly considered if the researcher is planning to use this tool since it is very hard to convince the respondents without direct conversation (Berdie, 1973). The questionnaire that consists of close-ended questions can easily be analysed

through descriptive analysis using statistical platforms, therefore, this technique is employed in this research (Labuschagne, 2003).

4.6.7.1.Questionnaire Design and Survey Implementation

An online questionnaire was designed for two purposes, first is to check the validity of the proposed methods to enhance the cost management process for the IPD approach such as ABC and EVM, as well as, the current status of implementing BIM-based cost management. The second purpose is to validate a set of proposal-solutions-to deal with the revealed issues of IPD cost management practices. The researcher has carried out a pilot study with six BIM and IPD experts before releasing it online in order to check its logic of questions, fit of the two mentioned purposes and easy to follow. The details of the questionnaires can be seen in Appendix B. The questionnaire has been divided into four sections as follows:

1. Personal and demographic information about the participants and the general BIM implementation status in their organisation to enable check the validity of their answers.
2. BIM-Based Cost Management Process
3. 4D/5D BIM optimisation and automation
4. BIM-Based Integrated Project Delivery (IPD) approach

4.6.7.1.1. Data Sampling

As aforementioned, the purpose of the questionnaire is to collect data from BIM and IPD experts regarding the practices of cost management of the IPD approach. Therefore, the population size cannot be determined. That's why, this research relies on Purposive sampling, which is defined as a type of nonprobability or non-random sampling where members of the target population that meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or the willingness to

participate are included for the purpose of the study and they have specific defined characteristics (Etikan et al., 2016). In this research, there are a set of criteria that have to be met by participants in order to be able to fill the questionnaire. These inclusion criteria are (1) have a theoretical and practical background regarding BIM, (2) Participants should have a proper level of understanding for IPD approach, (3) most of the participants should be able to assess the cost management tools and methods whether traditional process/methods or 4D/5D BIM.

4.6.7.2.Data Collection

The questionnaire has been sent to the potential respondents after ensuring the questions' internal validity and reliability. As mentioned, the type of the sample is purposive, therefore, the selection of the participants have been carried out through checking the BIM and IPD expertise profiles in LinkedIn, as well as, sending the questionnaire to a professional group such as CNBR (Co-operative Network for Building Researchers). In addition, the researcher could identify a set of the IPD leader and contact them to ask their consent to take part in this questionnaire.

The duration of collecting the questionnaire was three months since that the questionnaire has been sent out to the potential respondents throughout this period, three weeks have been given to the participant to fill the questionnaire and a reminder was sent every week. Given, the questionnaire has been sent out to professional groups, therefore, the number of distributed questionnaires cannot be determined. More details regarding the number of respondents and their personal information are extended in chapter 5 (Point of departure).

4.6.8. Literature Review and Document Analysis

Webster and Watson (2002) state that the aim of the literature review is to address the research gap by identifying, evaluating, and integrating the previous findings for relevant

and similar studies. The mechanism of using the literature review should be as follows (1) understanding the progress which has been achieved by other researchers to build the research base that can be used as a point of departure (Cohen and Manion, 1994); (2) Build an integrated context which respects the arrangement between the different ideas with showing the contradiction between the theories in order to build reliable argument (Watson, 2002); (3) articulate specific statements and build argument around each statement through using different views with linking them together in a single context; The researcher has a right to comment and critique the theories (Baumeister, 2013). (4) The literature review should address much border issues and questions rather than a single question which relates to a single empirical study (Baumeister and Leary, 1997).

According to Corbin and Strauss (2014), there are three types of literature review, namely, Narrative or Traditional literature reviews, Scoping Reviews, Systematic literature Review. The traditional literature review builds an overview of a specific topic by pulling much information together in a readable format (Green et al., 2006). This way of presenting the data can lead to provoke many thoughts and controversies, therefore, the traditional review method can be successful in developing philosophical perspectives (Gehlbach, 1988). In another word, the narrative literature review is useful to give the reader a comprehensive understanding about a specific topic, highlighting the research areas, identifying the research gap and developing/refine the research questions (Green et al., 2006).

The systematic literature review can be defined as a clear review of the relevant studies which pertain to the proposed questions to explore the specific issue to fill the gap in specific knowledge or field (Cooper, 1984). Therefore, the systematic literature review is employed in this research to define the gap, as well as, evaluating methods that can be integrated to develop the solution.

This review should follow explicit methods and criteria to collect the data. Furthermore, conducting the literature review requires applying some specific steps such as scoping, planning, breakdown, screening, and finally check the eligibility of the collected data. The review texts should have some characteristics such as objective critique, systematic, transparent through writing the information in the same meaning with mentioning the writer. Kitchenham et al. (2009) argued that the research question should be explored sufficiently before starting to write the literature review, as well as, the literature review sections should be generated by refining the research question. Coughlan et al. (2007) state that the literature review can be used to develop the conceptual framework, and this is the target of using it in this research. Fixsen et al. (2005) asserts that the existing literature review can be used as the main source to collect data about the previous researches which have been undertaken before to explore the same entire topic or part of the proposed research.

4.6.8.1. Analysing and Synthesising the Literature Review

Hendry and Farley (1998) state that the evaluating of the literature review comprises from different stages, firstly, the initial review by exploring the abstract of the existing paper to ensure if these papers are compatible with the proposed research or not. Secondly, the systematic and critical review should be proceeded to Preview, Question, Read, Summarize the content (Onwuegbuzie et al., 2012). Thirdly, begin by highlighting the main research questions and collect the relevant data to each question from the appraised papers in the first and second stages. Eventually, the researcher attempts to collect answers to all the revealed questions and summarise all these arguments in a single context (Wakefield, 2015).

There are two methods to appraise and evaluate the literature review, Meta-analysis and Meta-synthesis. Polit and Beck (2006) state that Meta-analysis is the method of

conducting and gathering quantitative data to enhance the understanding of any specific topic. Meanwhile, the Meta-synthesis (the adopted technique in this research) is a non-statistical technique to evaluate and integrate the findings in a single context to identify the key elements in each study which enable to transfer this information to other research and impoverish the research environment.

4.6.9. Interview

Alshenqeeti (2014) state that the interview is a powerful technique to appraise the argument of people towards the meaning of a specific point. Moreover, Lune and Berg (2016) assert that interviews enable the interviews to speak by their voice and introduce their ideas by expressing all their views through different observation about the question and the interviewer can get a holistic snapshot of the interviewee's opinions. Moreover, an interview is an extendable conversation between some persons to get an in-depth understanding of any topic.

Kajornboon (2005) states that there are four types of interview, namely; structured interviews, semi-structured interviews, unstructured interviews and non-directive interview. The interview is categorised as a structure when the same questions are asked to all interviewees in the same sequence and words (Rogers, 2010). Moreover, all interviews should be conducted under the same conditions and administration procedures (Bryman, 2016).

Holstein and Gubrium (2011) state that the unstructured interview can be useful to collect more views and data because it gives the two side much freedom and flexibility to open any point which can be important to get a holistic view. However, the targeted kind of interview in this research will be the structured one, because the topic of the question is complex and the targeted interviewees are fresh graduate as well. Rubin and Rubin (2011)

state that there is a kind of interview which locates between the structured and unstructured interview, it is called a semi-structured interview. This kind of interview relies on left a space without highlighting a question to take the flexible views from the participants. This kind will be used in this research by expressing closed questions and open question to the participant, this leads to getting entire views, and the general recommendations can lead to develop the whole idea and direct the research to the new area. When the researcher cannot articulate the format of the interview, questions, therefore, the researcher can use non-directive interview type since it is free-flowing and flexible, as well as, questions are not pre-set (Whyte, 2003).

The relationship between the interviewer and the interviewees is important to ensure the interview will achieve its target. Therefore the power of the interview should be balanced between the two sides through following these points (Alsaawi, 2014):

- Express the value of the interview and reflect the values of the interviewees.
- The trust should be exchanged between the interview's sides.
- The meaning of the questions should be clear and direct to enable the interviewees to understand and express their opinions.

The usage of words and terminologies should be common and understandable to avoid any confusion. Therefore, justly remark that “the shorter the interviewer’s questions and the longer the subject’s answers, the better an interview is” (Alsaawi, 2014).

Given, the one-hour interview can take around 30 to 40 pages to record it, therefore, the analysing process should be organised to avoid missing the data. The analysing process begins by organising the data by coding through two stages, first, gather the similar data meaning in one unit, second arrange and code them as well. After that, check the validation of these data and the relevance of the main questions (Somekh and Lewin, 2005). Alshenqeeti (2014) clarifies that the reporting system relies on the kind of the

interview, for instance, if the interview is structured, the data can be presented in graphs or tables, and however, the unstructured interview can be presented as argument text.

4.6.9.1.Types of Used Communication in the Interview

According to (Opdenakker, 2006), there are two types of communication to conduct an interview such as (1) Synchronous communication in time/place, (2) Asynchronous communication in place/time. The first type can be conducted such methods “Face to Face (FtF)”, MSN messenger and Telephone regarding the time dimension, however, FtF technique is only synchronised in the place dimension. (2) The asynchronous communication is usually carried out using email regarding the time dimension and for the place dimension, email, MSN messenger and telephone are asynchronised. However, Burke and Miller (2001) telephone and MSN messenger could be considered as synchronised techniques in the cyberspace. This space is defined as a virtual space when communication through computer networks is conducted (Benedickt, 1991). In addition, Krysan and Couper (2003) define another method is called “Virtual/video interview”, this type of communication is asynchronised in time/place. It is characterised by (1) reduce the interviewer effect on the survey, (2) video can include more explanation and different type of contents to be evaluated by interviewees (Henry and Fетters, 2012), (3) interviewees have a choice of responding to send questions or withholding a response, therefore providing a noncoercive discursive environment (Given, 2008), (4) the ongoing discussion is structured as the same content is usually sent to all selected respondents (Ross et al., 2019). This type of interview is advantaged by enabling the interviewer to build a structured content —texts, graphs and audio, etc.— as well as linking these contents with the questions, that’s why, it is suitable to test the developed hypothesis (Given, 2008).

Given that the interview is used to evaluate the proposed research framework and prototype tools, therefore, the video/virtual semi-structured interview is the most suitable technique to collect the respondents' views. The procedures for conducting the interviews as follows:

1. Sending an email to ask the participants to take part in this interview.
2. After receiving the participant consent, another email will be sent including a video (50 minutes), this video includes explanations about the framework and the developed tools. A set of questions to evaluate each part in the framework and developed tools will be also sent by email (See appendix C).
3. In some cases, the respondents can ask for a phone interview to get more clarifications.
4. Receiving the answers and carrying out the thematic and content analysis.

4.6.9.2.The Adopted Data Analysis of the Interview

Braun and Clarke (2012) state that the thematic analysis is the most popular method of qualitative data analysis as it is accessible, flexible. That's why the thematic analysis was chosen to analyse the scripts of the interviews. It is defined as "a method for identifying, analysing and reporting patterns (themes) within data" (Clarke and Braun, 2013). The techniques and steps of identifying the themes have been listed by (Ryan and Bernard, 2003) as follows:

- Repetitions: whether using the same words or mention similar ideas
- Indigenous typologies or categories: "look for unfamiliar, local words, and for familiar words that are used in unfamiliar ways" (Ryan and Bernard, 2003).
- Metaphors and analogies: how participants say their idea regarding metaphors or analogies

- Transitions: the movement from a topic to another.
- Similarities and differences in the same topic between the interviewees
- Linguistic connectors: explores how the interviewees use specific words such as ‘because’ and ‘since’ to provide their justifications.
- Missing data: for example, some interviewees did not answer specific questions
- Theory-related material: in case that names of scientific theories are mentioned.

Given that the interviews have been carried out as a virtual/video interview, therefore, the answers were returned to the researcher in a google form. This enabled to export the scripts directly to “NVivo” to identify and build the themes of the interviews scripts due to its ability to help the researcher to analyse and summarise the qualitative data such as literature review and interviews (Denardo, 2002). Moreover, assisting in manipulating recorded data, browsing, coding and annotating them. As well as, it is user-friendly such as gaining access to data records quickly and accurately (Richards, 1999). Figure 12 shows a snapshot of the creation of themes using “NVivo”.

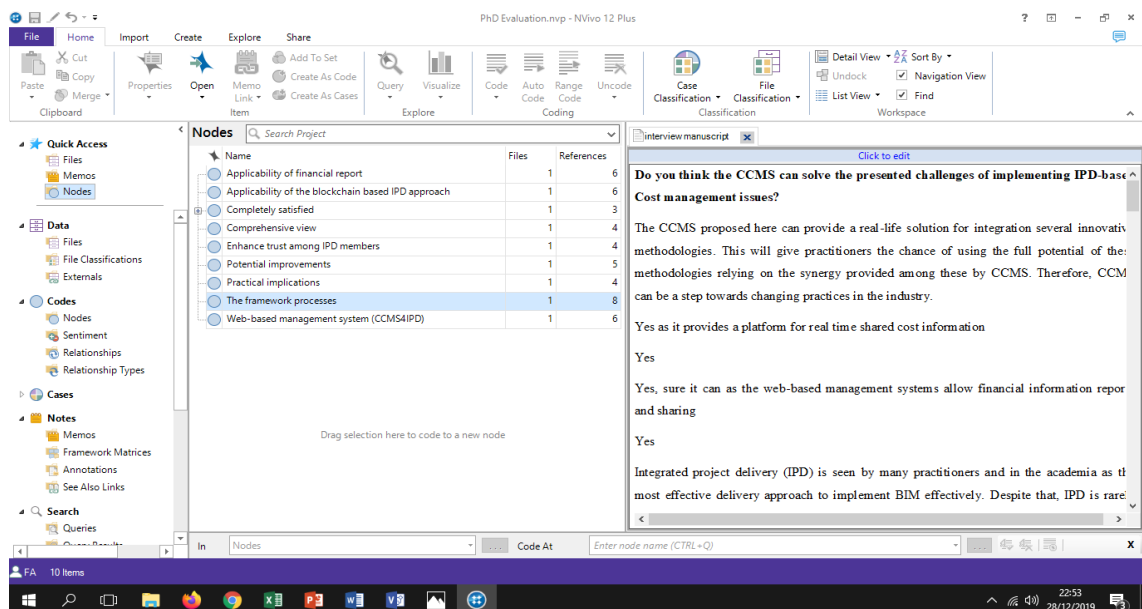


Figure 12. A snapshot of the creation of themes using “Nvivo”.

4.7.ADOPTED RESEARCH METHODS AND TECHNIQUES

Figure 13 shows the relationships between the research objectives and methods. It can be seen that the first two objectives have an exploratory nature, given that the first objective is to explore the existing practices of cost management within the IPD approach, as well as, the level of integrating BIM into the IPD process. Subsequently, a verification of the collected data will be conducted using the questionnaire method, the verification process has two main purposes, first is to measure the applicability of IPD in the industry, as well as, rating the retrieved solution from reviewing the literature such as the feasibility of ABC and EVM to enhance the cost management tasks for the IPD approach.

After that, the development of the framework will take a place, the framework shows how the integration between different methods can develop an integrated cost management system for the IPD approach. Subsequently, the validation of entire research will be conducted through developing a prototype to enable measuring the validity and applicability of the proposed tools in the framework. The prototype will be tested by using an illustrative case study. Given, the robust research which gives a clear conclusion as well as highlighting further research that can be started based on research's outcomes, thereby series of interviews will be taken a place with practitioners to evaluate the validated prototype from the academic/industrial perspectives in order to use their views in the future research.

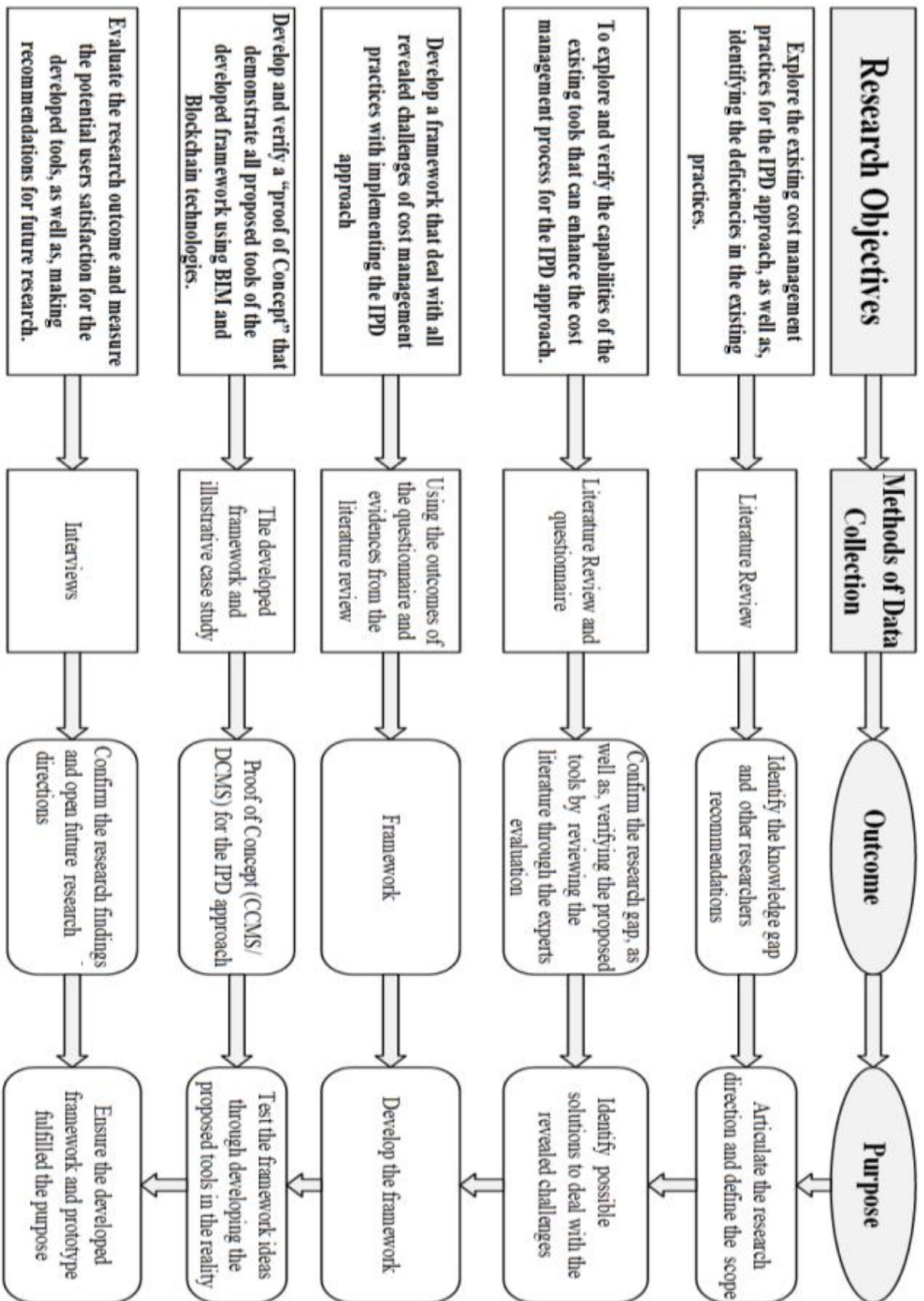


Figure 13.the entire research design

4.8.DATA VALIDITY AND RELIABILITY

Brink (1993) states that “Validity and reliability are key aspects of all research. Meticulous attention to these two aspects can make the difference between good research and poor research and can help to assure that fellow scientists accept findings as credible and trustworthy”.

4.8.1. Validity

Validity is defined by (Winter, 2000) as the formulation of the concept, notion, questions or hypothesis that direct the researcher about the data that should be collected, as well as, the proper methods to collect these data. There are five types of data validity that were adopted in this research as follows:

- Concurrent validity: it refers to how the findings of a new test compared to a well-established test. Moreover, it represents the practice of concurrently testing that has been carried out by two groups at the same time (Markham et al., 1994). This is utilised in this research by comparing the results of the literature review content analysis and the questionnaire results regarding the cost management practices of the IPD, as well as, the BIM implementation current status.
- Face validity: it is to evaluate the validity of the test regarding the suitability, procedures and relevancy (Holden, 2010). The used methods such as literature review, questionnaire, illustrative case study and interview are justified in this chapter against the research aim and objectives.
- Convergent validity: it examines the correlation between two tests to measure the validity of the same construct (Cunningham et al., 2001). In this research, there is a correlation between the used methods, particularly, literature review and questionnaire to assess the validity of the proposed solutions to enhance the cost

management practices based IPD. Moreover, the correlation between the illustrative case study and interview to assess the applicability and validity of the framework and developed tools.

- Construct validity: it is defined by (Schwab, 1980) “representing the correspondence between a construct (conceptual definition of a variable) and the operational procedure to measure or manipulate that construct”. In this research, the literature review was used to construct a comprehensive understanding to develop a solution, therefore, using interview and case study to evaluate the findings.
- Predictive validity: conducting a test to a specific construct, subsequently, compare the results with other results obtained at some point in the future (Singh, 2013). The outcome of the numerical verification of the developed cost management system will be validated by the interview method in order to open new horizon towards future research.

4.8.2. Reliability

The accuracy of the research findings is measured by evaluating the reliability degree (Noble and Smith, 2015). According to (Bryman and Bell, 2007), there are three factors that are used to measure the reliability of research findings as follows:

- Internal stability: it represents the correlation between different objects in the same test, the reliability is measured through a set of indicators. If these indicators show the consistency of the results, therefore, this means that the findings are reliable. This factor is used in this research using Cronbach alpha coefficient (CA) test (Tavakol and Dennick, 2011).

- Stability reliability: in case that the test is conducted several times on the same object, the results should be stable and if the time can be considered as a factor to change the results, therefore, a corrective factor should be added.
- Inter-observer consistency: It pertains to the extent to which two or more observers are recording behaviour in like manner.

4.9.ETHICAL CONSIDERATIONS OF THE RESEARCH

Ethical consideration is an important factor to ensure the integrity of the research, there are some ethical parameters that should be considered for the participants (i.e. dignity, privacy and confidentiality) (Munhall, 1988).

This research is conducted according to the ethical requirements to conduct post-graduate research at the University of Portsmouth. Given, this research involves a human in its data collection process, therefore, an ethical review application was submitted to the faculty ethical committee to seek their acceptance before proceeding the data collection. The application should include the research background that the gap showed be presented clearly here, the research aim and objectives, methods with showing the interrelationship with the objectives, all proposed templates of questionnaire and interview. Moreover, the application should include the participant sheet and the consent form for each method.

In this research, the ethical committee of Faculty of Technology has given the research as a favourable opinion regarding the proposed ethical considerations (see appendix A).

4.10. SUMMARY

This chapter has introduced the research methodology to achieve the research aim and objectives, justifications have been presented in relation to each adopted method in the research. Moreover, the mechanism to adopt any method within the research is presented by showing how the data move from a method to another to achieve the research aim.

The next chapter will present the point of departure towards developing the cost management framework, the next chapter includes the analysis of the questionnaire to confirm the recommended tools from reviewing the literature.

CHAPTER FIVE: POINT OF DEPARTURE

5.1.INTRODUCTION

Given that the literature review was used to highlight the research gap, build a theoretical background for the research components (BIM, IPD, ICT applications and cost management process) and analyse the retrieved solutions in terms of each component in the research. Accordingly, another method (questionnaire) is used in this chapter to define the gap (research problems) from industry practitioners/ researcher's perspectives, as well as, validating the proposed solutions that were collected from the literature review to bridge the gap.

The questionnaire as a survey instrument was employed for two reasons (1) a large amount of information can be gathered from a wide range of participants in timely manner, (2) The collected data can be quantified using a wide range of statistical platforms, therefore, the findings can be compared (Fellows and Liu, 2015). Most of the questions were closed-ended questions due to it is more specific and gives similar meanings to the respondents, these questions were developed based on the analysis of previous research.

5.2.RELIABILITY OF DATA

This questionnaire was sent to unlimited numbers of BIM, IPD adopters/users and project managers, due to the respondents should have various knowledge regarding BIM, IPD and project management. Given, this questionnaire has been posted on LinkedIn and sent to research groups such as CNBR. Therefore, the number of questionnaire receivers cannot be determined. The questionnaire was opened for three months, the valid received questionnaire was (n=50).

Given, the reliability is a statistical method that should be utilised to measure the validity of the collected data via questionnaire, the reliability test can be implemented

in three forms, namely, test-retest, alternate form, and internal consistency (Crowder, 2017). By reviewing the literature review, the internal consistency reliability is the most widely applied technique to test the validity of survey and scales (Streiner, 2003). The quantitative approach using the SPSS tool was used to assess the reliability of the collected data, the outcome was presented as Cronbach alpha coefficient (CA) and the range of this coefficient is from 0 to 1 (Tavakol and Dennick, 2011). There are specific ranges that indicate different levels of reliability as follows:

1. $CA < 0.6$: Bad sample, data cannot be used.
2. $0.6 < CA < 0.7$: Acceptable but not good enough for academic research.
3. $0.7 < CA < 0.8$: Good, can be used for academic research.
4. $0.8 < CA < 0.95$: Excellent, high reliability
5. $CA > 0.95$: Fake sample or identical variables

Table 4 shows the reliability test, the outcome of analysis 18 questions were (0.854), by comparing this value with mentioned ranges above, the questionnaire has high reliability. This indicates that all the questionnaire's questions are relevant to the scope of research (Field, 2013).

Table 4.the Cronbach alpha coefficient (CA) test for the questionnaire results

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.854	.858	18

5.3.THE DESCRIPTIVE FINDINGS OF PRIMARY DATA

The questionnaire was designed as four main sections, the first section is related to the respondent information, after that, the research components are explored by three sections, namely, BIM-Based cost management process, 4D BIM optimisation and automation, BIM-Based IPD approach.

4.10.1. THE CHARACTERISTICS OF THE PARTICIPANTS

5.3.1.1.The Profession of Participants

The questionnaire respondents were selected based on three main categories, namely, the current job (role), years of experience and their roles in adopting BIM.

Figure 14 shows the numbers of participants against their jobs, the total number of participants was 50, the most appeared job was the academic staff whether as lecturers or researchers by representing 30%, followed by the quantity surveyors that represented by 20%, the BIM jobs appeared by 16% as BIM managers, technician and BIM modular (4D/5D/6D), PhD students represented 10%, project manager (14%), other jobs appeared by (10%) including asset data manager, commercial director, head of digital built environment—BIM, digitalising and industry, and lean consultant.

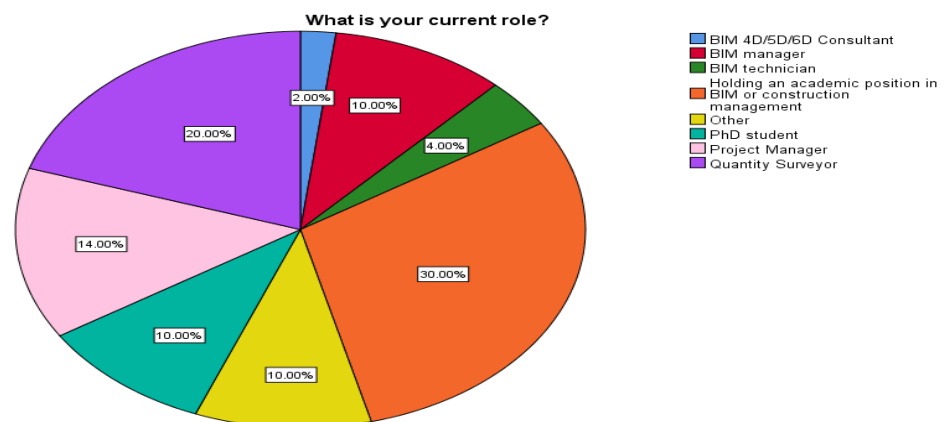


Figure 14.The profession of participants.

5.3.1.2.The experience of participants

A range from less than a year to more than 11 years was given to the participants to describe their range of experience. Figure 15 depicts the range of experience of the participants, The majority of participants recorded 1 to 5 years by (36%), their choice seems to be reasonable since the BIM just became mandatory applicable in some countries such as UK from 2016. The participants who have experience more than 11 years recorded 10% and most of them come from an academic background.

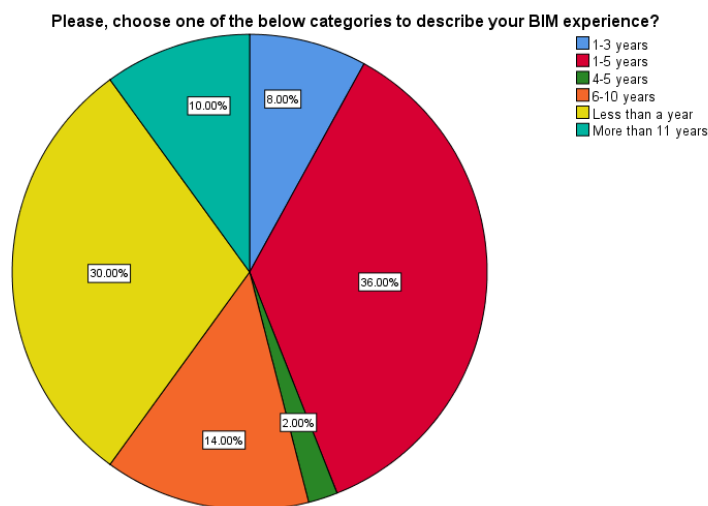


Figure 15.Shows the experience ranges of the survey participants.

5.3.1.3.THE BIM DISCIPLINES FOR PARTICIPANTS

In order to understand the attitude of participants and their background, a question was asked to identify their specif role in using BIM. From the figure 16, the majority of the participants are working to adopt the 4D BIM (planning and visualisation) by (46%) and 5D BIM (cost management) by (20%). This indicates that the management roles represent 66% and this gives a reliability to all their answers regarding the existing practices of 4D/5D BIM. There are 10% of respondents are doing more than two roles (i.e. 4D and 5D BIM).

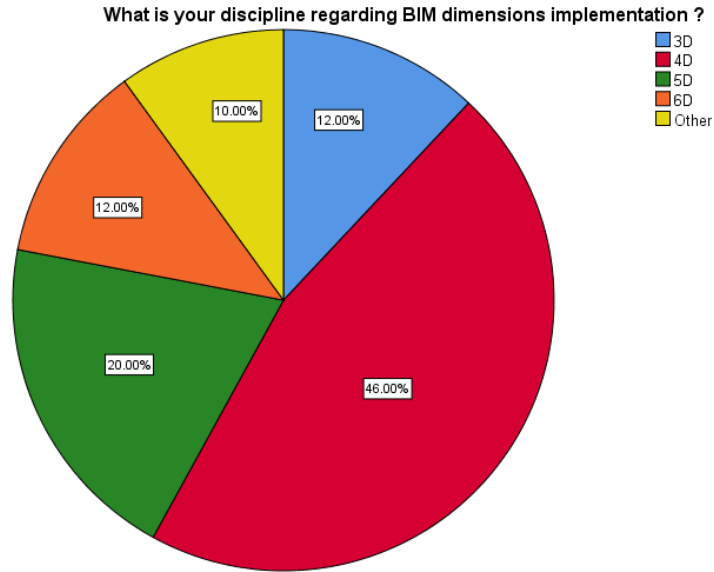


Figure 16.The BIM disciplines for participants

5.3.1.4.THE LEVEL OF BIM IMPLEMENTATION FOR PARTICIPANTS

Figure 17 shows the levels of adopting BIM in the participant's organisation, this is useful in this questionnaire to measure the reliability of the participants' understandings regarding the integration of main BIM dimensions (3D, 4D and 5D), and the integration begins to be implemented from level 2. Figure 15 shows the majority of the participants are adopting level 2 by 52%, meanwhile, levels 3 and beyond are appeared by 28% since most of the academic staff refers that they are adopting these levels either in their research or related industrial project. Additionally, BIM adoption without considering specific maturity level appeared by 20%.

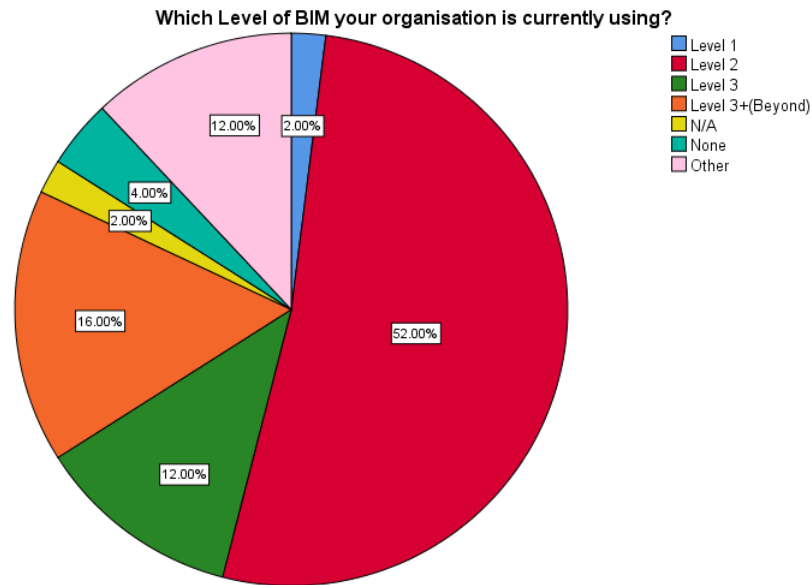


Figure 17.The BIM implementation level of the participants' organisations

5.4.THE BIM-BASED COST MANAGEMENT PROCESS

5.4.1. Cost Management Tools

Given that the cost structure one of the revealed issues in the IPD cost management practices (Roy et al., 2018, Pishdad-Bozorgi and Srivastava, 2018), as well as, BIM is highly recommended by both industrial and academic experts to be integrated into the IPD process (Rowlinson, 2017, Allison et al., 2018). Therefore, the capabilities of the 5D BIM required to be examined to inform the researcher whether it can be implemented directly or it requires additional improvements. Figure 18 shows that the majority of respondents mentioned that the 5D BIM does not consider the entire cost structure (direct, indirect and overhead costs) by 42%, meanwhile 32% agreed that 5D BIM considers all cost elements. Additionally, 26% of respondents chose “not sure” answer due to they are using other BIM dimensions. Therefore, the 5D BIM process needs to be enhanced and strengthened with other tools that their capabilities are proved from reviewing the literature.

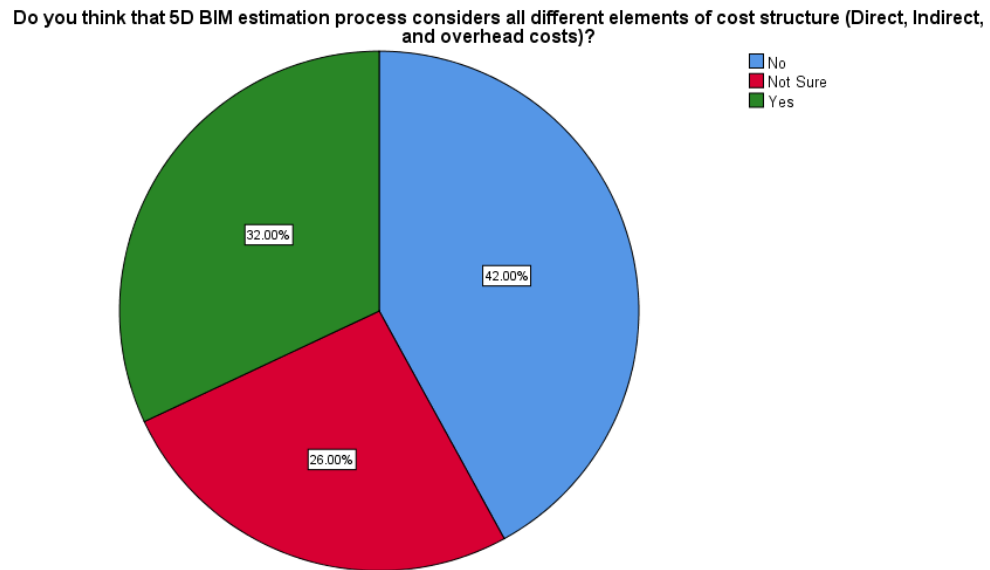


Figure 18.The performance of 5D BIM for cost estimation process

5.4.2. Overhead Costs in Construction Projects

Due to the overhead cost is a critical part in the allocation of cost elements among the project/organisation parties (Kreuze and Newell, 1994, Kumar and Mahto, 2013), as well as, IPD requires more overhead resources to be managed due to the project is usually managed by several parties and all of them should participate in the most of the project stages (Allison et al., 2018, Ashcraft, 2012). Figure 19 depicts the chosen overhead proportions in the participants organisations or projects. Given, this question requires a cost expert who is able to see the overhead cost records whether for the organisations or projects, therefore, 32% of respondent said “not sure”, and other gave different answers as seen from the figure 19. The results are matched with data collected from the literature review that the overhead cost range in construction industry is from 8 to 12% from the total cost (Janani et al., 2015).

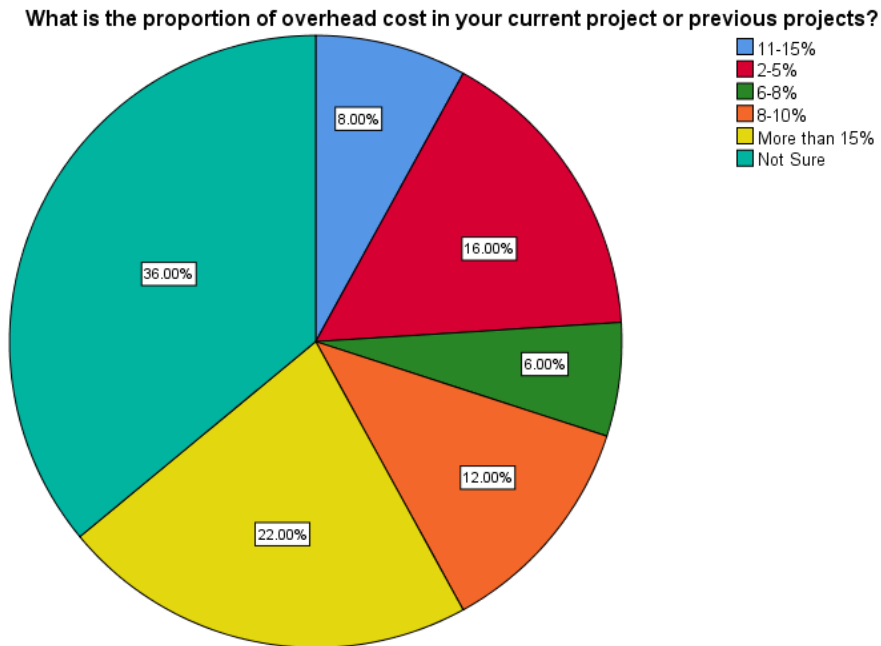


Figure 19.The proportion of overheard costs for participants' organisations/projects

A question was asked to the participants to retrieve which method is used to determine the overhead costs in their organisation, and according to the literature review, two main methods are usually utilised, namely, ABC and RBC. Figure 20 shows that the majority of respondents (44%) chose the ABC method, followed by the RBC around 40%, as well as, 2% mentioned historical database, mixing between ABC and RBC by 2%, experience is appeared by 2%, and finally, 10% said that they do not have idea.

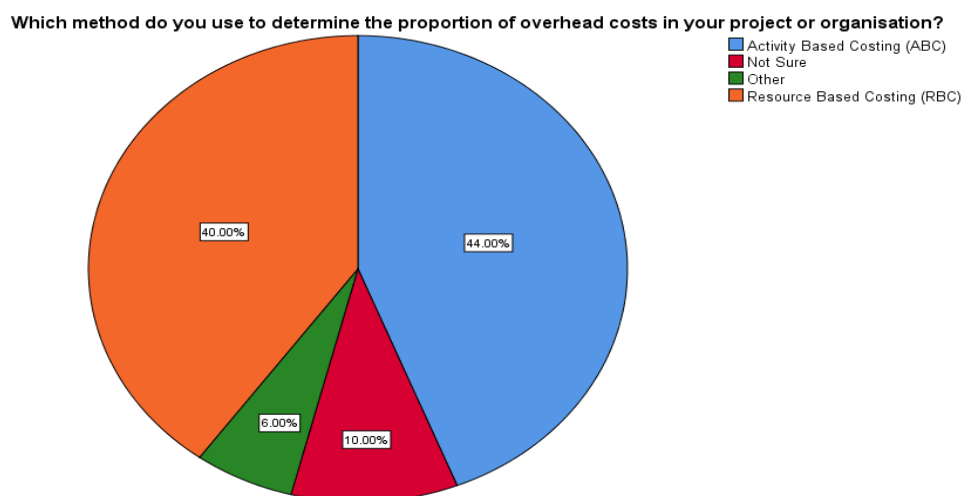


Figure 20.The Method of determining the overhead cost

By reviewing the literature review, The IPD requires a method to develop the cost structure properly with ensuring that there are no hidden overhead costs in the profit (Allison et al., 2018). Additionally, the ABC is proven its capabilities to optimise the structure of the cost and this could be a way to revolutionise the cost structure of the IPD, therefore, there is a question to see if the professional see as same as retrieved from the extant literature. Figure 21 indicates that 46% agreed the ABC is a competent method to allocate the overhead costs fairly, however, 36% recorded ‘not sure’ as they do not have experience with the ABC. Meanwhile, 18 % did not agree about this. As such, The ABC with some training can be accepted as a way to manage the project costs, particularly, if this method can be presented automatically in any platform, the users will not have a problem to implement it.

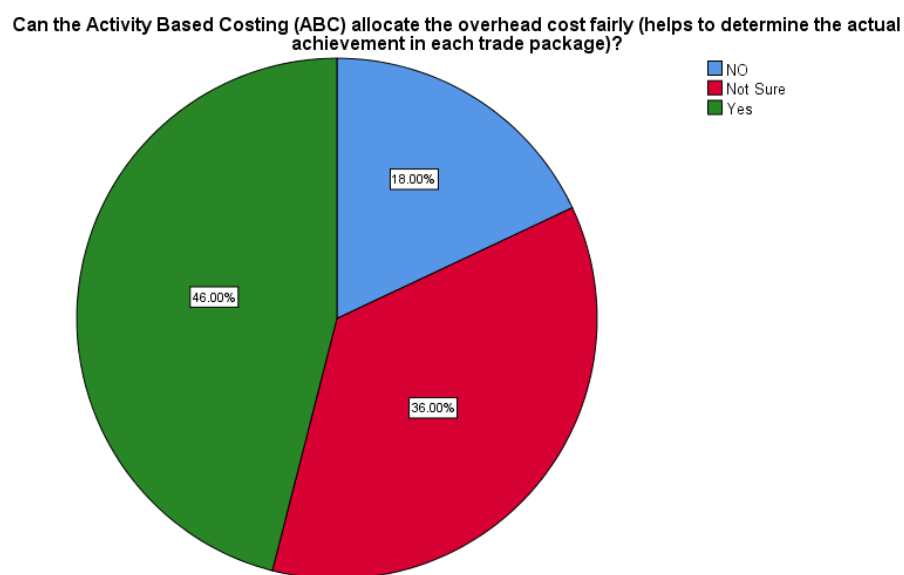


Figure 21.The applicability of Activity Based Costing (ABC)

5.4.3. Cost Control Practices in Construction Projects

Since BIM does not provide a significant improvements in the cost control processes (Mitchell, 2012, Smith, 2014a, Lee et al., 2014), therefore, a method should be integrated into BIM process to support the BIM-based cost management. By reviewing the literature

review, the EVM method is proven as a successful technique to conduct the cost control tasks (Huang et al., 2014, Cândido et al., 2014, Farok and Garcia, 2015), accordingly, a question was asked to appraise the current practices of the EVM in the industry. Table 5 shows the descriptive statistical indicators regarding the EVM performance to control the project costs, the average of responses was 3.56, this indicates that the majority agree and satisfy about EVM, however, if it is enhanced, this could increase the user satisfaction. The extant literature review refers that the performance of the EVM can be enhanced by extending its metrics such as Integrating the EVM into the project risk management process to link the output of risk analysis with the EVM metrics (Pajares and Lopez-Paredes, 2011). Moreover, the reviewing of the literature review indicates that the BIM should be integrated properly into the IPD stages for better project delivery. Given, the cost management is the scope of this research, therefore, the participants were asked to evaluate their satisfaction regarding using BIM to manage the project costs, the average of the responses was 3.5, this indicates that they agree about BIM provided a good tools to manage project costs, however, there are improvements and more features should be added.

Table 5. The descriptive statistics of the EVM performance and the generic BIM-based cost management

Questions	N	Range	Minimum	Maximum	Mean	Std. Deviation
Do you agree that EVM can facilitate the management of the project costs during the construction stage?	50	3	2	5	3.56	.812
Please rate current BIM-based cost management tools.	50	4	1	5	3.50	1.015
Valid N (listwise)	50					

5.5.Evaluation of the Current 4D/5D BIM Integration

Given that developing the cash flow is the second task of the cost management process, therefore, two questions were asked to (1) appraising the applicability of the 4D/5D BIM to develop the cash flow curves before the buyout stage, (2) evaluating the existing method to integrate 4D/5D BIM before the buyout stage. The participants in both questions recorded mean by (3.56), (3.64) accordingly (see table 6). This indicates that the BIM has relatively succeeded to provide project management service, additionally, other questions were asked to see how the user satisfaction can be improved as can be seen in the next section 5.5.1.

Table 6.The descriptive statistics of the evaluation of the current 4D/5D BIM integration

Questions		Do you agree that cash flow curves are easily formulated using 4D/5D BIM?	Do you agree that the integration of 4D and 5D BIM is applicable by existing methods to draw project budget (S curve)?
N	Valid	50	50
	Missing	0	0
Mean		3.56	3.64
Std. Deviation		.884	.749
Range		3	3
Minimum		2	2
Maximum		5	5

5.5.1. PROPOSING ADDITIONAL FEATURES TO IMPROVE THE PERFORMANCE OF THE IMPLEMENTATION

Given that the target of this questionnaire is to confirm the gap that is retrieved from the literature review, as well as, seeking for pieces of advice from the experts regarding the proposed tools to fill the revealed gaps. As such, two questions were asked regarding improving the current BIM-based cash flow management. The first question was to add

the overhead activities to the list of activities and the second question was to automate the process of developing the S curve. The mean of the responses were 3.8 and 3.92 respectively. This indicates that they agree regarding these two features and both features can be adopted in the framework to enhance the BIM-based cash flow management process (see table 7).

Table 7. Adding features to BIM-based cost management

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Adding the overhead activities to the list of activities to be able to measure its efficiency	50	4	1	5	3.80	1.161
Generating S curve automatically which includes all cost elements (Direct, Indirect and Overhead costs)	50	4	1	5	3.92	1.122
Valid N (listwise)	50					

5.6. BIM-BASED INTEGRATED PROJECT DELIVERY (IPD) APPROACH

In this section, a set of questions were asked to the participants, first is to appraise the respondents understanding/experiences regarding IPD implementation. Subsequently, appraising the existing practices of implementing the IPD and ranking the proposed solutions that have been retrieved from reviewing the literature.

5.6.1. The Participants' Experiences with IPD

Figure 22 shows the scale of the participant's understandings regarding the IPD concepts and processes, around 46% of participants have a high level of understanding, and about 28 % of the respondents have an average level, this indicates that almost 74% of the respondents are capable to respond to the high technical issues of the IPD implementation.

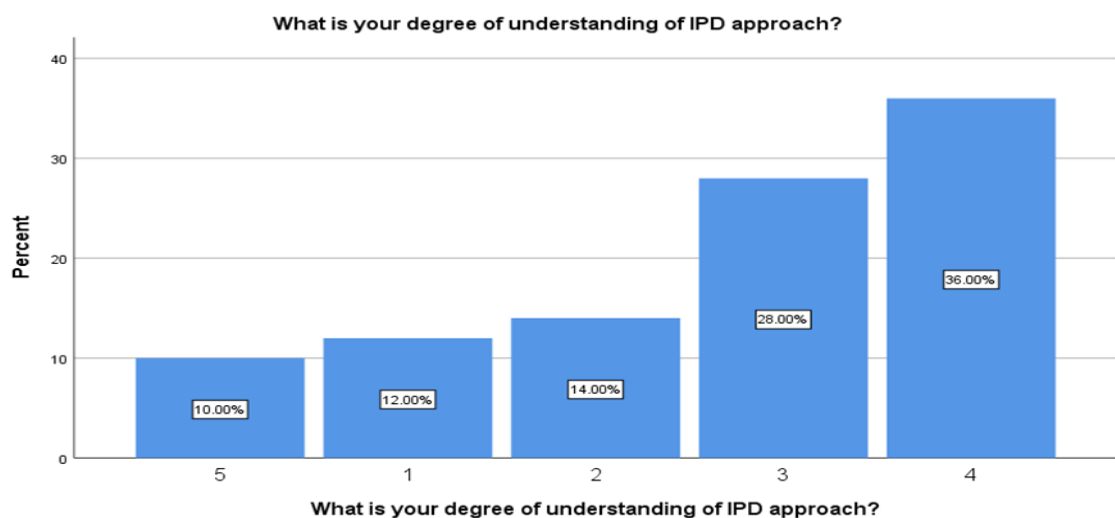


Figure 22.The participants' experiences with IPD

The literature review indicates that the IPD is not widely applied yet, however, it is highly recommended. Therefore, figure 23 shows the results from the question regarding measuring the implementation status of IPD in the industry, the results can be concluded as 24% are already using the IPD approach in their projects, the good indication that other 22% are planning to adopt IPD and this is matched with the results from analysing the literature review, however, 54% of respondents do not use IPD in any of their projects. The IPD approach is mainly applied in the US, however, there are other a few projects around the world, in this survey, the researcher was keen to find participants who actually involved in real implementation of the IPD in order to give credibility to the technical questions regarding the deficiencies and capabilities of adopting IPD, particularly, the cost management implications.

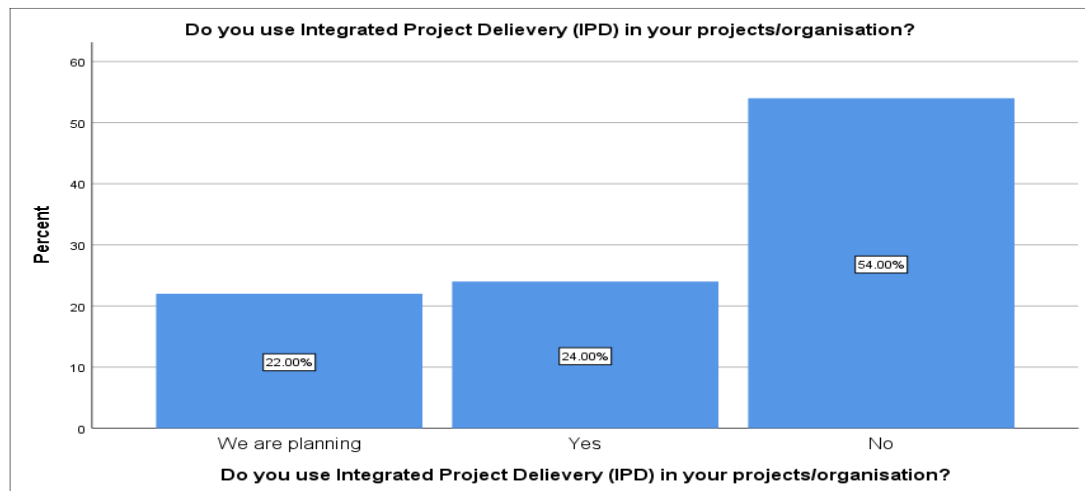


Figure 23.Measuring the understanding of participants in relation to IPD

5.6.2. Main IPD Barriers Based Cost Management

By reviewing the literature, There are four main challenges associated with the IPD based cost management. These issues are listed in table 8. The question was to ask participants to choose the most critical challenges from their views. The early involvement of all participants represented 30% of the answers, followed by Tendering method due to it is open pricing by (26%), then the compensation approach by 20%, the last one was The allocation of responsibilities and risks are not clear by (18%). Some respondents gave others (6 %) which can be concluded as they see all these factors are related to each other and all of them should be considered equally to foster the implementation of the IPD. Additionally, one of the expert mentioned that “Historical contractual models are often dictated by funders, they often seek to use D&B for example, which provides a perceived risk offload”, this is also related to the compensation model.

Table 8.The IPD main barriers

Please, choose one of the following points to describe what do you believe in terms of the main barrier to use IPD?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Other	3	6.0	6.0	6.0
	Tendering method due to it is open pricing	13	26.0	26.0	32.0
	The allocation of responsibilities and risks are not clear	9	18.0	18.0	50.0
	The Compensation approach (Risk/Reward sharing) is not matured completed	10	20.0	20.0	70.0
	The early involvement for all participants	15	30.0	30.0	100.0
	Total	50	100.0	100.0	

5.6.3. Adding Features to Foster IPD Implementation

The analysis of the literature review concluded that there are some capable methods that can be integrated/mixed to develop a cost management system that can manage all mentioned and revealed gaps in the literature and this survey. Table 9 includes the descriptive analysis for 10 questions were asked to evaluate the proposed techniques by the expert.

The questions were asked to measure the applicability of a set of proposed features regarding utilising EVM and ABC with adding specific extensions to their mechanism.

Table 9 shows the average of the respondent's responses regarding the proposed 10 features.

In terms of the questions are associated with using EVM in integration with ABC to develop an IPD compensation approach that considers the overhead costs as a separate limb, questions (Q1, Q2,Q8) that listed in the below table 9, these questions pertain to using EVM to provide metrics to share risk/reward among IPD patties, the respondents acted positively to these questions, the range of responses are from 3.36 to 3.82 with considering that the respondents they do not have intensive experience in the IPD chose neutral answer.

Using ABC to optimise the cost structure to enhance the trust among IPD core team members (Q4,Q6, Q7), the respondents answers were positive and the range of answers are from 3.64 to 3.72, experts who has long experience with implementing IPD recorded agree and strongly agree to those features.

Given that the conventional mechanism of developing the project budget does not comply with the IPD characteristics, therefore, two features were recommended to be employed in the proposed framework, these two features were presented in Q3 and Q4, questions propose to use the ABC to provide them by more details in terms of the minimum/maximum possible proportions of the profit for each party to enable them make the right decision, particularly, during the IPD's buyout stage. The average range of answers were 3.6 and 3.64 respectively, the experts that mentioned they have a high level of understandings of IPD recorded agree and strongly agree for both questions.

There are questions for using ICT to facilitate sharing the information among IPD core team members with minimising the human interference to maximise the desired level of trust, as well as, developing a tool to enable visualising the EVM metrics, Q5 and Q9 were asked to participants, the average of their responses were 3.64 and 3.86 respectively.

Table 9.The proposed solutions to improve cost management practices of the IPD

Questions	N	Range	Minimum	Maximum	Mean	Std. Deviation
1. Integrating EVM into IPD can easily facilitate its implementation regarding sharing risk/reward between owner/non-owner parties	50	4	1	5	3.36	.964
2. Developing an automated model to show the duo payment for all parties based on their achievement against planned values	50	4	1	5	3.58	.906
3. Providing a separate cash flow for each participant including the proposed proportional cash in based on agree profit at risk percentage	50	3	2	5	3.60	.700
4. Adopting ABC to develop a list of activities enable getting a reliable cash out curve (S curve) by considering (Direct, Indirect, and overhead).	50	3	2	5	3.64	.749
5. Developing an EVM-based Web report to enable tracking the project by all participants as well as easy access by different devices	50	4	1	5	3.64	.942
6. Utilising ABC in order to identify the different sources of overhead cost clearly	50	4	1	5	3.68	.935
7. A fair allocation system with clear implementation models can enhance implementing IPD.	50	4	1	5	3.72	.927
8. Adapting EVM with ABC to identify risk/reward sharing fairly	50	4	1	5	3.82	.896

9. Providing an EVM grid to locate the Cost Performance Ratio (CPR) and Schedule Performance Ratio (SPR) to determine the holistic view of project progress	50	3	2	5	3.86	.808
10. Providing a comprehensive framework for cost management within the entire IPD stages could increase its implementation and minimising the waste in time and resources?	50	4	1	5	3.98	.820
Valid N (listwise)	50					

5.7.SUMMARY

This chapter presented the data analysis of the questionnaire results. Given, the questionnaire was designed for two purposes, namely, highlight/confirm the research gap, exploring the proposed tools to develop an integrated solution. Therefore, the following points summarise the findings of the questionnaire:

- BIM-based cost management requires improvements regarding enabling it to consider all cost structure elements (direct, indirect and overheads);
- The overhead costs represent a significant proportion of the total cost since almost 22% of the respondents mentioned that it represents more than 15%, therefore, it should be managed properly, Specifically for the IPD approach, any misleading allocations of costs can adversely affect the performance of the core team members;
- There is a reasonable level of awareness regarding the proposed methods (EVM and ABC), almost 42 % of respondents are using ABC in their estimations and this is a positive indication, as well as, there is a positive response regarding utilising the EVM in the cost control tasks in the AEC industry, the average of responses is 3.56.
- The majority of respondents adopts BIM level 2 and beyond, this is a good indication as this allowed them to response the questions properly, due the BIM level 3 and beyond consider the integration of all BIM dimensions. This indicates that there is a growing in adopting BIM, hence the integration of BIM and IPD will be more workable with developing a detailed methodology to elaborate on the mechanism of this integration.
- Regarding the IPD challenges, all given factors have received a high attention by the respondents as they are dependent, particularly, “tendering method due to it is

open pricing”, “the allocation of responsibilities and risks are not clear”, “The Compensation approach (Risk/Reward sharing) is not matured completed”. All these factors are relevant to the existing lack of managing the cost.

- All the proposed ten features to enhance the IPD-based cost management process have received positive responses since the range of responses were scaled from 3.36 to 3.98 with noting that respondents who recorded a high level of understanding chose scales 4 and 5 to represent their satisfaction regarding the proposed solutions.
- The adoption of ICT features could foster the implementation of the IPD since it raises the level of understanding among project parties, subsequently, build a trusted environment.

The next chapter presents the framework development that includes the integration of specific tools and methods (ABC and EVM) to develop a cost management process for the IPD, the mechanism to manage cost tasks for each IPD stage will be presented and linked with each other in an integrated framework. The ICT applications such as web-based management system and blockchain will be employed to develop tools to share the financial data to minimise human interference and accordingly avoid any potential conflicts among IPD core team members.

CHAPTER SIX: FRAMEWORK DEVELOPMENT

6.1.INTRODUCTION

In this chapter, a cost management framework to deal with identified key challenges for all processes, namely, estimation, budget and control within IPD approach. The framework tackles this issue through presenting analytical aspects, theoretical grounds, and practical steps/procedures for integrating Target Value Design (TVD), Activity-Based Costing (ABC), and Monte Carlo Simulation into the IPD cost structure, within a BIM-enabled platform. The cost estimation tools and techniques are designed for multi-objective, firstly developing a method to predict whole cost at conceptualisation stage using Monte Carlo Simulation, thereafter, the 3D BIM model will be accomplished at detailed design stage, therefore a distinct cost estimation method is designed to be consistent with IPD's compensation structure which comprises from three limbs, first limb is direct and indirect cost, the second limb is overhead cost, literally limb3 represents profit at risk percentage.

Given that the IPD does not include a tender stage to select the optimal bid, therefore, this framework presents a methodology framework to develop a cash flow approach using BIM tools. As mentioned, ABC is adopted, due to its ability to allocate different costs precisely to each construction process. Given that the BIM and IPD target is to achieve the best collaboration among project parties, the proposed framework backing this by displaying all estimated cost data of each package as minimum/maximum estimated cash inflow, during the buyout stage, for informed decision making.

Regarding the cost control within IPD approach, this research introduces an innovated grid that locates the Cost Performance Ratio (CPR), and Schedule Performance Ratio (SPR) to determine the project situation 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, it includes 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 or organisation level and the project level. Additionally, the EVM-Grid has been developed as a web system to allow different participants easily track their project. Moreover, using the DLT (blockchain/smart contract technologies) to share the risk/reward sharing values among project parties, the framework shows how the transactions should be calculated, as well as, the mechanism of developing smart contract based IPD characteristics. The framework is divided into four main sections, namely, cost estimation, cost budgeting, cost control and risk/reward model and utilising DLT to share and validate the IPD financial transactions.

6.2.COST ESTIMATION BASED IPD STAGES

Integrated project delivery (IPD) has five pre-construction stages: conceptualisation, outline design, detailed design, documentation and buyout (AIA, 2007). The proposed cost estimation solution therefore involves tools to manage cost estimation at each of these stages, as described next.

6.2.1. Conceptualisation and Outline Design Stages

The conceptualisation and outline design stages begin by forming the core project team: the owner, the architect, the main contractor and all trade contractors. Given that TVD relies on developing the design according to a restricted budget, any change or new added element triggers a round of estimation for predicting the total cost. Key decisions about the project reflect owner's requirements, as well as, any design criteria at hand. Therefore, a conceptual BIM model – architectural and engineering intentions – is created, using an authoring tool (i.e. Autodesk Revit or Graphisoft ArchiCAD). This

BIM model is used to obtain indications of the proposed quantities and identities. At conceptualisation and outline Design Stages, project information includes much uncertainty: consequently, the cost estimation model is presented in the form of a range of total costs against the degree of certainty through Monte Carlo Simulation (due to its ability to deal with different types of cost data distribution). Once the architect has developed the BIM conceptual model, the quantity surveyor must begin to extract the quantities and type of the proposed materials/components. A BIM tool, such as Autodesk Navisworks, can be employed as follows:

- Navisworks in XML format, extracts quantities to build the pricing sheet (using Microsoft [MS] Excel) and prepare the proposed initial price sheet of materials. Given that TVD requires continuous cost estimation feedback, therefore, BoQ will be extracted from the BIM model regularly while the design is developing.
- The quantity surveyor collects the required cost data from the main contractor and trade contractors to build statistical samples of the labour and equipment required to perform the proposed design elements. These data include the range of material prices to draw reliable samples for each BIM design element, and allowances of labour and equipment that will be required to execute BIM design elements (preferred using analogous estimation (Amos, 2004), as most of project parties in IPD join the conceptualisation stage, therefore, the data should be easily accessible);
- The quantity surveyor explores the type of statistical distribution that will be compatible with the collected data (normal, beta, etc.);
- The quantity surveyor identifies each proposed cost element to estimate the total value of all distributed costs for all design elements and to enable the simulation to run;

- When the simulation (Monte Carlo) starts to run, the extracted graphs show the total costs for the project and individual items, corresponding to the percentage of certainty of the input data.

6.2.1.1. Formulation of Statistical Model

In order to determine the proposed total cost, the following equations are applied. Equation (1) represents the total cost that must be collected for each design element D to assign the package cost for contractor j :

$$PC_{Dj} = IQP + \forall L_{BM} \& E_{BM} \quad (1)$$

where PC_{Dj} is the proposed cost for the design element D that is proposed to be assigned to contractor j ; IQP is the initial quantity prices for Dj ; $L_{BM} \& E_{BM}$ are the labour and equipment price for the best scenario B for the specific material M .

The statistical model requires a wide range of proposed values to enable a reliable total cost to be obtained. Equations (2.1), (2.2) and (2.3) therefore show how the BIM data are integrated into a Monte Carlo simulation. These equations rely on using beta distribution; however, if a wider range of prices is used, these equations are extended to provide a more accurate material cost:

$$IQP_{AVM} = IQ_{BIM \text{ conceptual model}} \times RP_M \quad (2.1)$$

$$IQP_{OPM} = IQ_{BIM \text{ conceptual model}} \times OP_M \quad (2.2)$$

$$IQP_{PM} = IQ_{BIM \text{ conceptual model}} \times PP_M \quad (2.3)$$

where IQP represents the initial quantity prices for average, optimistic and pessimistic values; IQ is the initial quantities extracted using BIM tools; while RP_M is the recent price for material M ; OP_M is the optimistic price for material M ; and PP_M is the pessimistic price for material M . Other costs such as labour and equipment can be easily collected

using IPD core team members, drawing upon their early involvement. Equation (2.4) shows the formula for calculations:

$$\forall L_{BM} \& E_{BM} = UP_M \times TU_M \quad (2.4)$$

where $L_{BM} \& E_{BM}$ are the labour and equipment price for the best scenario B for specific material M ; UP_M is the unit price for material M ; and TU_M is the total units for material M . Equation (2.5) is another version of Equation (2.4) to capture the worst case scenario, as follows:

$$\forall L_{WM} \& E_{WM} = UP_M \times TU_M \quad (2.5)$$

Where $L_{WM} \& E_{WM}$ are the labour and equipment price for the worst case scenario W for specific material M . To complete the beta distribution, the average value is determined as in Equation (2.6):

$$\forall L_{AVM} \& E_{AVM} = \frac{(\forall L_{BM} \& E_{BM} + \forall L_{WM} \& E_{WM})}{2} \quad (2.6)$$

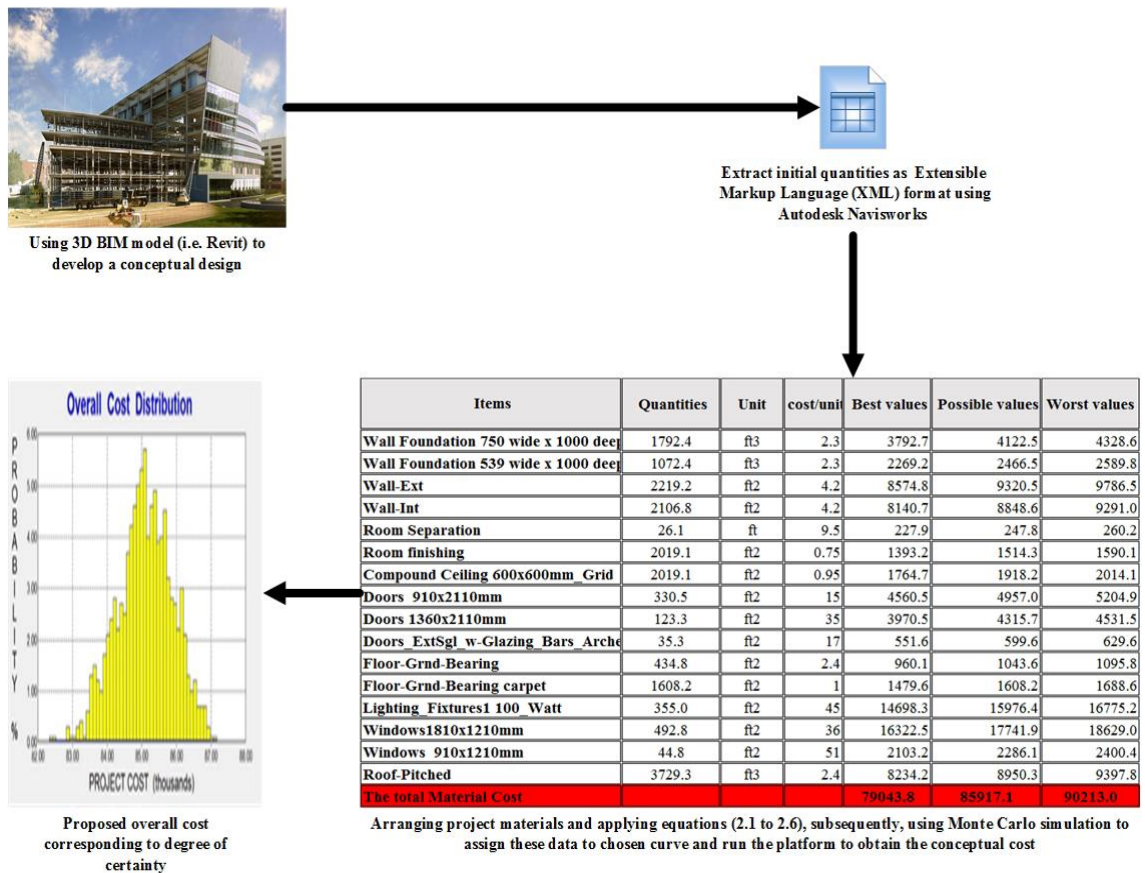


Figure 24.Cost estimation within conceptualisation and outline design stages

Figure 24 shows the interoperability and the process of integrating BIM data into a Monte Carlo Simulation to obtain the proposed material cost. Based on the data and using analogous cost estimation or expert judgement from core team members, the cost range of the statistical model is determined. For example, if core team members agree that three values for each cost element are reliable, the distribution is loaded for three probable costs. Based on the pre-identified range of costs, the distribution system is selected. The three values mentioned above are consistent with beta distribution and the normal distribution.

6.2.1.2.Obtaining Proposed Entire Cost against Certainty Percentages

At this stage, the model is ready to run. A Monte Carlo Simulation has two important features, the first of which is the total cost, corresponding to the degree of certainty. This cost range is necessary for developing the business case for the client, based on the TVD

system, before moving to the detailed design stage, as recommended by Allison et al. (2017). The second feature is the sensitivity analysis chart that presents the degree of importance of each project design element. This is vital for supporting decisions regarding the use of sensitive elements in the design. Through these features, the necessary data are available for making the right decision; therefore, the client can decide whether the proposed whole cost is located within the allowable budget. Once the client has approved the proposed cost, the project moves to the detailed design stage in which another cost estimation strategy is used.

If the client does not approve the proposed cost, an ongoing negotiation is necessary to fulfil the client's requirements. The sensitivity analysis chart plays a key role here, identifying the elements that are sensitive in increasing the cost, and seeking to minimise the total cost by targeting these elements.

6.3.DETAILED DESIGN STAGE

Detailed design, in which the most significant part of the project information is formulated, is the most vital stage of the IPD approach (Allison et al., 2017). In this stage, the 3D BIM model is enhanced by adding other dimensions: scheduling (4D BIM) and cost (5D BIM). The precise bills of quantities (BoQs) are then extracted using Navisworks in XML, with these including various data for each element, such as dimensions, the exact place in the project hierarchy, etc. The quantity surveyor next collects the corresponding unit price of each element used, in order to move to the documentation stage – with adequate information – and to prepare a reliable cost structure.

6.4.DOCUMENTATION AND BUYOUT STAGES

As discussed, the IPD cost structure relies on distinguishing all cost elements, which are direct, indirect and overhead costs, given that the risks/reward are determined based on the rate of achievement of each individual element. To extend this, according to AIA

(2007b), the overhead cost represents a separate limb after the direct and indirect limbs, and the final limb is the profit-at-risk percentage. The risks/reward are determined based on the progress of each individual limb (i.e. whether the progress indicates a cost saving or is located as a profit-at-risk percentage). However, if progress indicates that the expanded cost exceeds three limbs, the client is responsible only for the direct cost. Therefore, as discussed, having a scrutinising costing system is vital for successful IPD delivery.

Here, adopting the ABC approach provides a solution, with each stakeholder involved from the conceptualisation stage. Moreover, throughout the first three IPD stages (conceptualisation, outline design and detailed design), all stakeholders, even the trade contractors, participate in determining the cost of the project. The overhead costs represent a significant proportion of the whole project cost, the overhead cost for each construction package should be estimated for the activities required to proceed with that package. Therefore, the ABC system is able to allocate overhead costs to relevant activities to determine the overhead resources for each package. Figure 25 illustrates the comparison between the traditional ABC hierarchy levels and the proposed IPD based on ABC adapted levels to follow overhead resources within the defined and specific levels. As a result, overhead resources required at different levels can be evaluated.

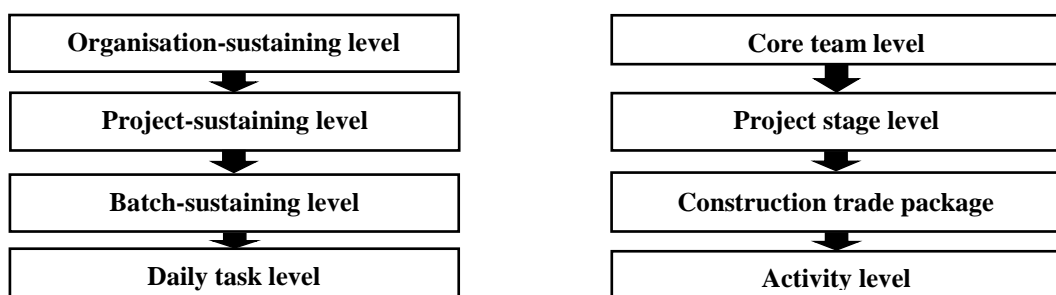


Figure 25.ABC Hierarchy levels: Comparison between traditional delivery operational levels (left) and IPD approach (right)

Overhead costs, such as inspection and quality control as well as cost control reports, should be estimated as a set of units that can be allocated as per its proportion of the cost driver. This process can generate an accurate cost estimation value for each trade package (i.e. civil package, mechanical package, electrical package, etc.). The target cost in the IPD payment method is fair for each package/party in the IPD project as some packages require a low consumption rate of overhead resources, while for others, a high consumption rate of overhead resources is required regardless of their proportion of the entire project. Nevertheless, the consumption of this significant proportion of overhead costs is needed; thus, it is imperative that these costs be allocated to overhead activity consumption.

6.4.1. Activity-based costing (ABC) estimation sheet

A proposed coding system is developed to work as a bridge between ABC and BIM tools. It includes digital numbers as well as alphabetical letters. According to the adapted ABC based IPD levels presented in figure 26, there are four levels will be presented as 010 for daily task level, 020 for the package level, 030 for the project stage level, and 040 for the IPD core team member. The project package will be identified using the initials of its names, for example the daily task level for the general package is 010G. For interoperability between ABC and 4D/5D BIM, the task type and code correlation is interconnected. Various colours are used to identify the task types, such as the colour red for the package level.

ID	Codes	Activities	Task type	Cost driver	Units	Co
1	010G	Setting out	Daily task Level	Number of days	1	
2	<input type="checkbox"/> 10	rection of formworks	Daily task Level	Number of inspections	1	
3	<input type="checkbox"/> 010WD	rection of rebar works	Daily task Level	Number of inspections	1	
4	<input checked="" type="checkbox"/> 010G	rection of foundation batch	Package Level	Number of inspections	1	
5	<input type="checkbox"/> 010F	ng out walls	Daily task Level	Number of days	1	
6	<input type="checkbox"/> 010LF	rection of masonry works	Package Level	Number of inspections	1	
7	<input type="checkbox"/> 010C	ng out separation of rooms	Daily task Level	Number of days	1	
8	<input type="checkbox"/> 20	ilise material	Package Level	Number of receipts	1	
9	<input type="checkbox"/> 020WD	rection of separation of rooms	Daily task Level	Number of inspections	1	
10	<input type="checkbox"/> 020G	ilise roof material	Package Level	Number of receipts	1	
11	<input type="checkbox"/> 020F	ng-out	Daily task Level	Number of days	1	
12	<input type="checkbox"/> 020LF	rection roof package	Package Level	Number of inspections	1	
13	<input type="checkbox"/> 020C	ng out of floors	Daily task Level	Number of days	1	
14	<input type="checkbox"/> 30	rection of floors	Daily task Level	Number of inspections	1	
15	<input type="checkbox"/> 030WD	ontrol report for general works	Package Level	Proportion of the Packe	1	
16	<input type="checkbox"/> 030G	ilise windows and doors	Package Level	Number of receipts	1	
17	<input type="checkbox"/> 030F	rection of D&W package	Package Level	Number of inspections	1	
18		ontrol report for D&W works	Core Team Level	Proportion of the Packe	1	

Figure 26. ABC structure sheet with correlation between 4D/5D BIM

6.4.2. Formulation of the IPD-based ABC model

During the buyout stage, each party needs to know the cost structure of the proposed works, with Equations (3), (4) and (5) able to be used to determine the total cost of each limb. Extracting BoQs using Navisworks is followed by pricing the extracted quantities and adding productivity allowances (labour and equipment) to complete the project pricing. Equations (3), (4) and (5) are used to categorise the estimated costs into three limbs for each package using the proposed coding system, as discussed below.

Equation (3) shows the structure of Limb 1, including direct and indirect costs, with these two terms able to be automatically estimated for each package (participant) through extracting costs using the coding system from the ABC sheet (see figure 26).

$$LIMB1_{ij} = \sum_{k=1}^n (CoDA_{Kj} + CoIA_{Kj}) \quad (3)$$

where $LIMB1_{ij}$ represents the direct and indirect costs for trade contractor i to perform trade package j ; $CoDA_{Kj}$ represents the cost of direct activity for design element k and

trade package j ; and $CoIA_{Kj}$ represents the cost of indirect activity for design element k and trade package j .

Equation (4) shows the structure of Limb 2, representing overhead costs as the summation of the number of overhead activities for each package multiplied by the cost driver's estimated costs. For the purpose of automation, all costs can be automatically extracted from the ABC sheet (see figure 26).

$$LIMB2_{OA} = \sum_{i=1}^n (NOA_{OA} \times MVoCD_{DA}) \quad (4)$$

where $LIMB2_{OA}$ represents the overhead costs of specific operation O , such as cost control to perform overhead activity A ; NOA_{OA} represents the summation of the number of operations O needs to perform in overhead activity A ; and $MVoCD_{DA}$ reflects the monetary value of cost driver D performing overhead activity A .

Equation (5) represents the structure of Limb 3, which can be estimated by adding the profit-at-risk percentage ($P@R\%$) to the pre-estimated Limbs 1 and 2.

$$LIMB3_{ij} = \sum_{i=1}^n (LMB2\&3_{ij}) \times P@R \%_{ij} \quad (5)$$

where $LIMB3_{ij}$ is the profit-at-risk percentage for trade contractor i to implement specific trade package j ; $LMB2\&3_{ij}$ reflects the total costs for each package assigned to a specific party in the buyout stage; and $P@R \%_{ij}$ represents the profit-at-risk percentage for trade contractor i to implement trade package j .

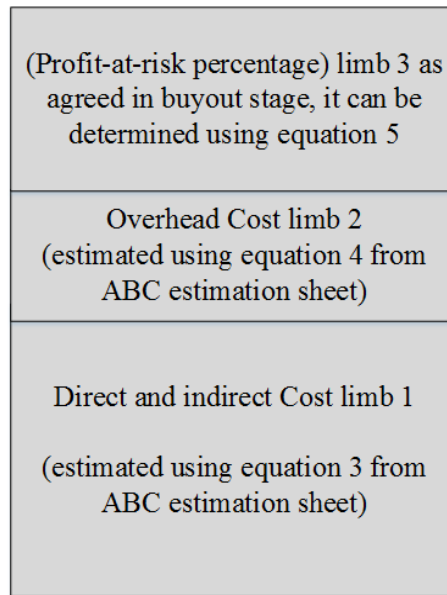


Figure 27. Compensation under the IPD approach using ABC estimation

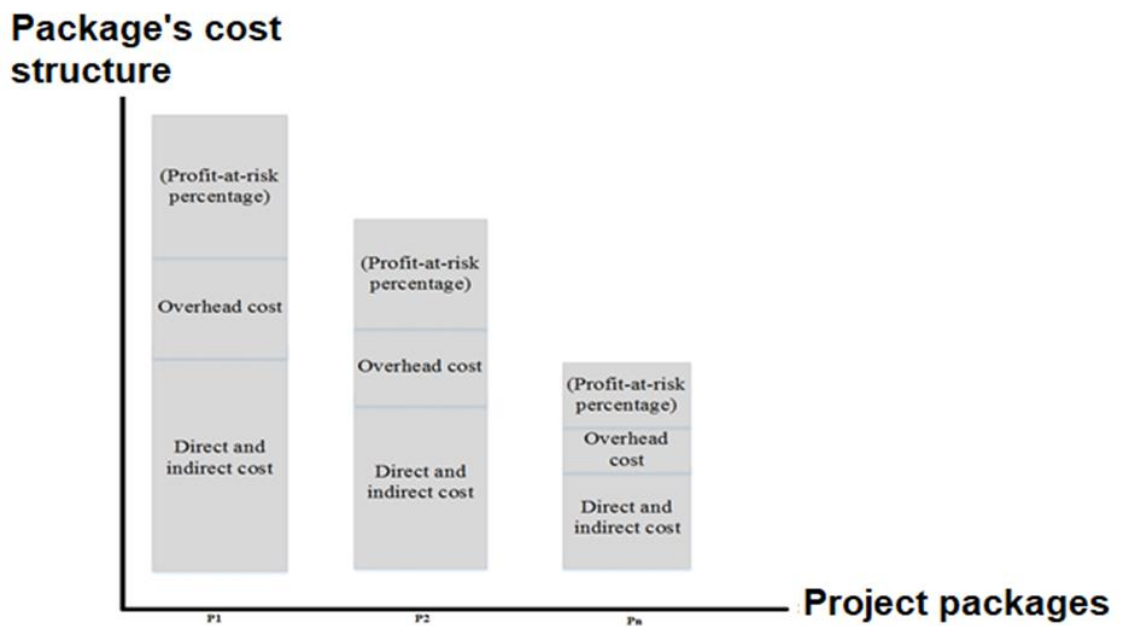


Figure 28. Structure of IPD cost estimation for each party

According to Allison et al. (2017), splitting all overhead resources in a single pool can help to avoid waste when some project members implement more work than is required. On the other hand, determining overhead resources for a separate limb minimises the opportunity to hide a proportion of profit in the overhead percentage (Allison et al., 2017). Figure 27 illustrates the structure of the IPD approach based on ABC estimation. As all non-owner parties carry the same level of responsibility, the relationships between

contractors and other parties are at the same level of inference. Therefore, as illustrated in Figure 28, the estimation for each party is individually delivered.

The IPD approach requires the completion of several tasks prior to the construction stage. Figure 29 illustrates these tasks: the cost estimation process within conceptualisation, outline and detailed design, and documentation stages; methods and tools to deal with various types of data; the amount of cost data to be analysed; the input and output of each stage; and the proposed tool to analyse the available data.

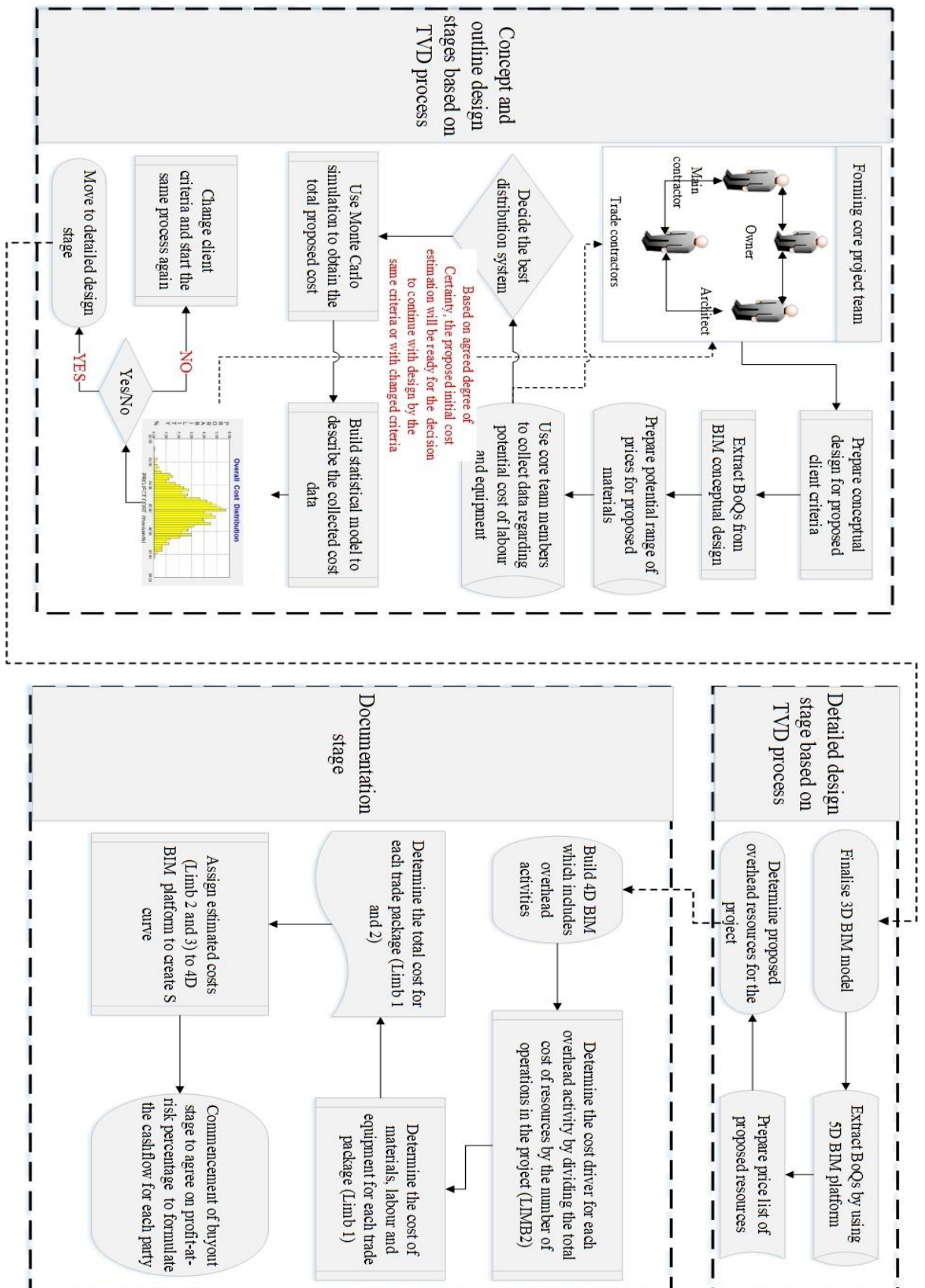


Figure 29.Cost estimation data flow within IPD pre-construction stages

6.5.CASH FLOW BASED IPD CHARACTERISTICS

This section presents a methodology framework to develop a cash flow approach using BIM tools. The development process comprises of proposing an integration methods of 4D and 5D BIM models with respect of the IPD financial characteristics. Moreover, developing mathematical models to determine the minimum/maximum estimated cash inflow. Furthermore, proposing a new presentation way of the project cash in/out, particularly, during the IPD buyout stage.

6.5.1. Data Integration (4d/5d BIM) Within IPD Approach

This part of the research focus on integrating 4D BIM into 5D BIM to prepare the budget of the project, namely S curve or cash out. This research adopts a new philosophy to manage the relationship between WBS and CBS, because it was found out that most of recent research asserts that the lack of integration and homogeneity between hierarchy of activities and assembled costs is the main barrier of acquiring a reliable cash out. The cash out is defined as Budgeted Cost of Work Scheduled (BCWS). Since this research adopts ABC to perform the entire cost management process, therefore BCWS will include all project costs (direct, indirect and overhead cost) which will reflect a high level of accuracy due to enable project participants to monitor all planned and expanded costs. Given, ABC relies on allocating the costs from resources to activities, the project costs are already assigned to WBS and this will solve the highlighted gap in the literature review regarding the fragmentation between WBS and CBS, which causes wastes in cost data and gives unreliable indicators during the construction stage. Given that IPD approach has five stages before commencing construction as well as two of these stages are to prepare the documentations and forward to buyout stage to reach their consent regarding expected cash flow (cash in and cash out), therefore, this part of research

focuses on documentation and buyout stage to formulate the model and create a reliable cash flow that is consistent with IPD requirements.

In documentation stage, 4D BIM should be built based on proposed method highlighted in the methodology section, such that the list of activities should include all types of activities whether direct, indirect and overhead activities in order to enable assigning all cost of resources to all activities without losing any data. In other words, when all activities absorb all resources, hence the prepared cash out will work effectively whether during buyout stage to enable participants to take right decision regarding accepting or rejecting the offer, or during construction stage to enable efficient and successful cost control, particularly in IPD given that the payment depends on the rate of achievement against planned cost and schedule. The quantity surveyor/project manager is responsible to prepare a separate cash out (S Curve) to each participant in this stage to move to the buyout stage and prepare the cash flow for each party after agreeing on the contractual payment clauses (i.e. risk/reward sharing percentage, cost control milestones, etc.). Figure 30 displays the steps of implementing framework in this stage. Regarding buyout stage, IPD approach does not have a tender stage like other approaches, subsequently, all project parties are equally responsible for tender price and the buyout stage is completely ongoing negotiation until an agreement is reached among all participants. Based on this reason, the buyout stage should start by preparing critical factors regarding payments such as; risk/reward percentage, namely: rewards percentage for owner whether cost saving in overhead levels or direct cost level, the reward percentage for each non-owner parties, the risk sharing percentage for each owner/non-owner parties. Moreover, the project milestones should be designed for payment purposes. After accomplishing the payment clauses, the quantity surveyor should start preparing the cash-flow curves for each participant, however in the developed framework the cash-in is linked to proportional equations, not exact values as traditional approaches. Thereafter, the core team members

should hold a meeting to display proposed cash flows to all participants, and ongoing negotiation will take a place to get the consent from each party to begin the construction stage based on proposed cash flow. In case of some participants reject, it means that the owner in cooperation with architect should attempt to find another party to perform the remaining works without contractor or trade contractors. However, agreed participants move to construction stage after attaching the agreed cash flows to contract documents.

The quantitative models to prepare cash-flow will be presented in next section.

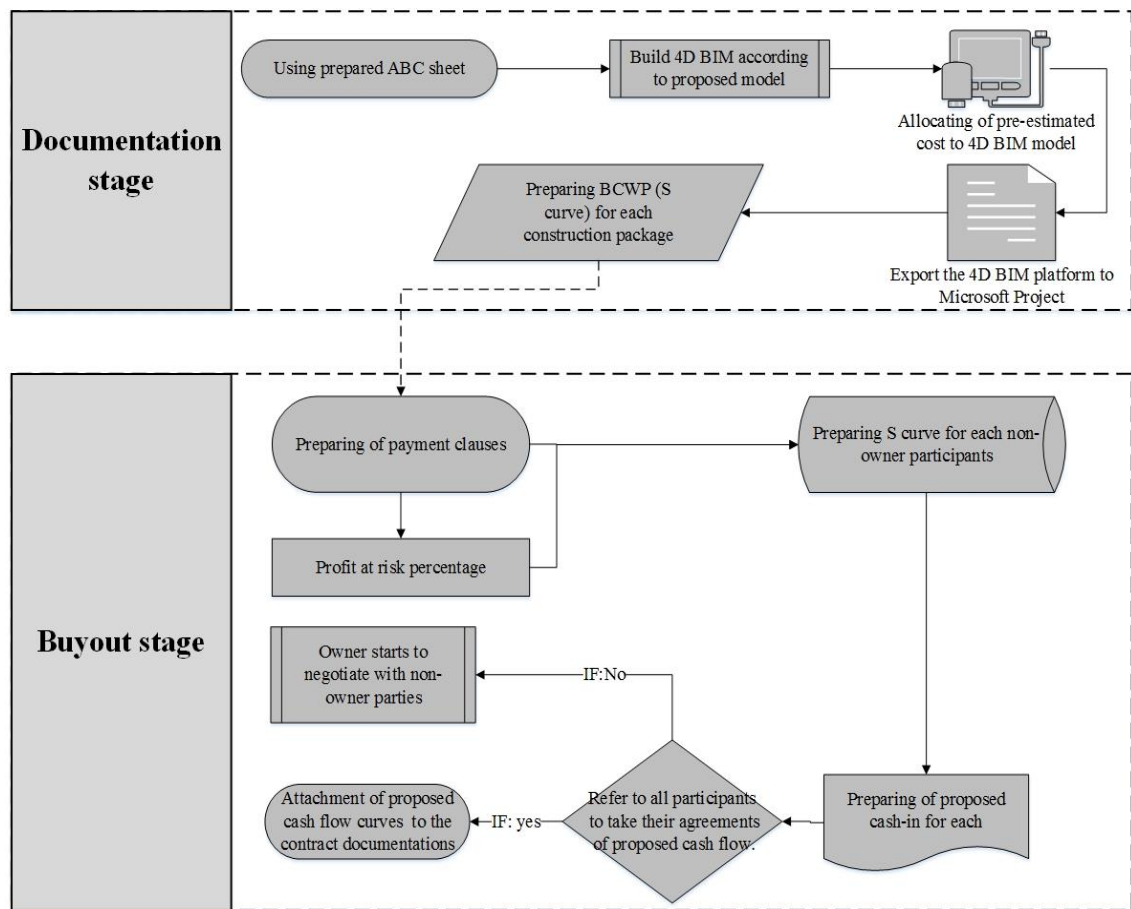


Figure 30.Data Flow within IPD Approach

6.5.2. Formulation of Cash-Flow Model

The cash-out (CO) for trade contractor i at specific period p , can be determined from the following model:

$$CO_{ip} = \sum_{(i,p)} ECoA_{ij} (LIMB\ 2)_{OA} \quad (6)$$

Where $ECoA_{ij}$ is Estimated Cost of Activities for trade package J which will be executed by contractor I .

While the cost of each activity can be determined as follows:

$$ECoA_{ij} = MC_{AP} + LC_{AP} + EqC_{AP} \quad (7)$$

Where MC_{AP} is the Material Cost for Activity A when needed for period P , LC_{AP} is the Labour Cost for Activity A when needed for period P , EqC_{AP} is the Equipment Cost for Activity A when needed for period P .

After determining the required resources for each activity, the ABC sheet will be filled by all cost data. Since ABC sheet is designed to include the Activity cost, not resource costing, therefore the inherent lack of integration between CBS and WBS has been sorted out in this method.

As aforementioned, the proposed Cash-in (CI) for trade contractor i at specific period p , can be determined as follows:

$$CI_{ip} = \sum_{(i,p)} ECoA_{ij} (LIMB\ 2)_{OA} \times (1 + P@R (LIMB\ 3)\%) \quad (8)$$

Where $P@R$ is Profit at Risk percentage

$$EP_{ij} = P@R\% \times \sum_{(i,p)} ECoA_{ij} \quad (9)$$

Where EP_{ij} is Estimated Profit for trade contractor I which will execute package J

Since the contractors need indications regarding the expected maximum/minimum cash in during the execution stage, therefore the following equations show the calculations of $EMnCI_{ij}$ and $EMCI_{ij}$.

$$EMnCI_{ij} = \sum_{(i,n)} ECoDA_{ij} \quad (10)$$

$$EMCI_{ij} = \sum_{(i,n)} ECoA (LIMB\ 2)_{ij} \times (1 + Entire\ P@R (LIMB\ 3)\%) \quad (11)$$

Where $EMnCI_{ij}$ is the Estimated Minimum Cash Inflow for trade contractor I which will execute package J , while $EMCI_{ij}$ is the Estimated Maximum Cash Inflow for trade contractor I which will execute package J .

Therefore, the Maximum Overdraft for trade contractor I which will execute package J , (MO_{ij}) can be calculated as follow equation 12.

$$MO_{ij} = EMCI_{ij} - EMnCI_{ij} \quad (12)$$

The below figure 31 shows that at each milestone n , the above equations (1 and 2) should be implemented for each participant i . the continuous S curve represents LIMB 2 which involves direct, indirect and overhead costs, and the periodic curve represents the LIMB2 plus profit at risk percentage. However, the below figure 31 assumes that the actual spent equals the planned, hence each cash-in instalment is located above cash-out curve. However, in other cases, such as the actual spent is more than planned and Budgeted Cost of Work Performed (BCWP), the movement of two curves will be completely different.

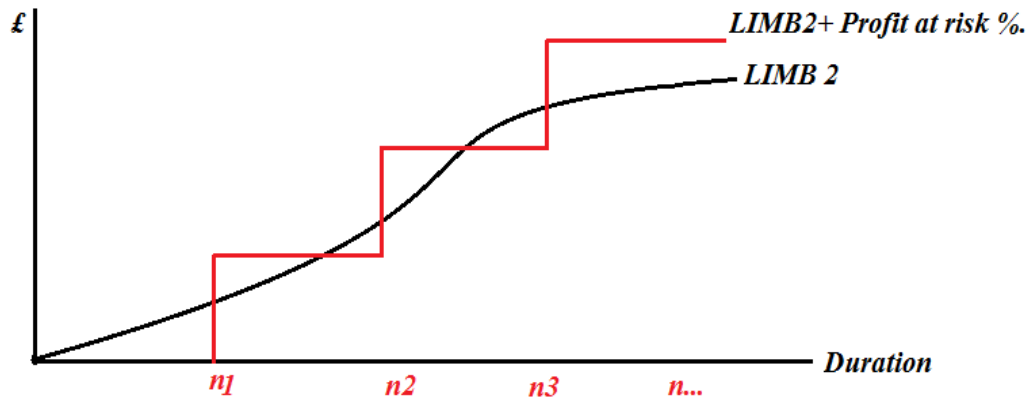


Figure 31.Proposed cash flow of IPD approach

6.5.3. Different IPD cash flow scenarios

Given that the payment under IPD approach relies on the achievement rate, there are different scenarios to address the relationship between cash in and cash out. The following scenarios show the most important cases that could take place while implementing IPD.

- (1) Figure 32 - Case 1: Cost has been achieved in accordance with the planned value
- (2) Figure 32 – Case 2: Expended cost is more than planned cost, which means that a part of profit at risk percentage has been used to cover the cost overrun issue
- (3) Figure 32 – Case 3: Expended cost exceeded the LIMB 3, which comprises the entire cost-plus profit at risk percentage, the cash in and cash out relationship is completely different from traditional approach. So that, the client is responsible only to pay the direct cost to the contractor

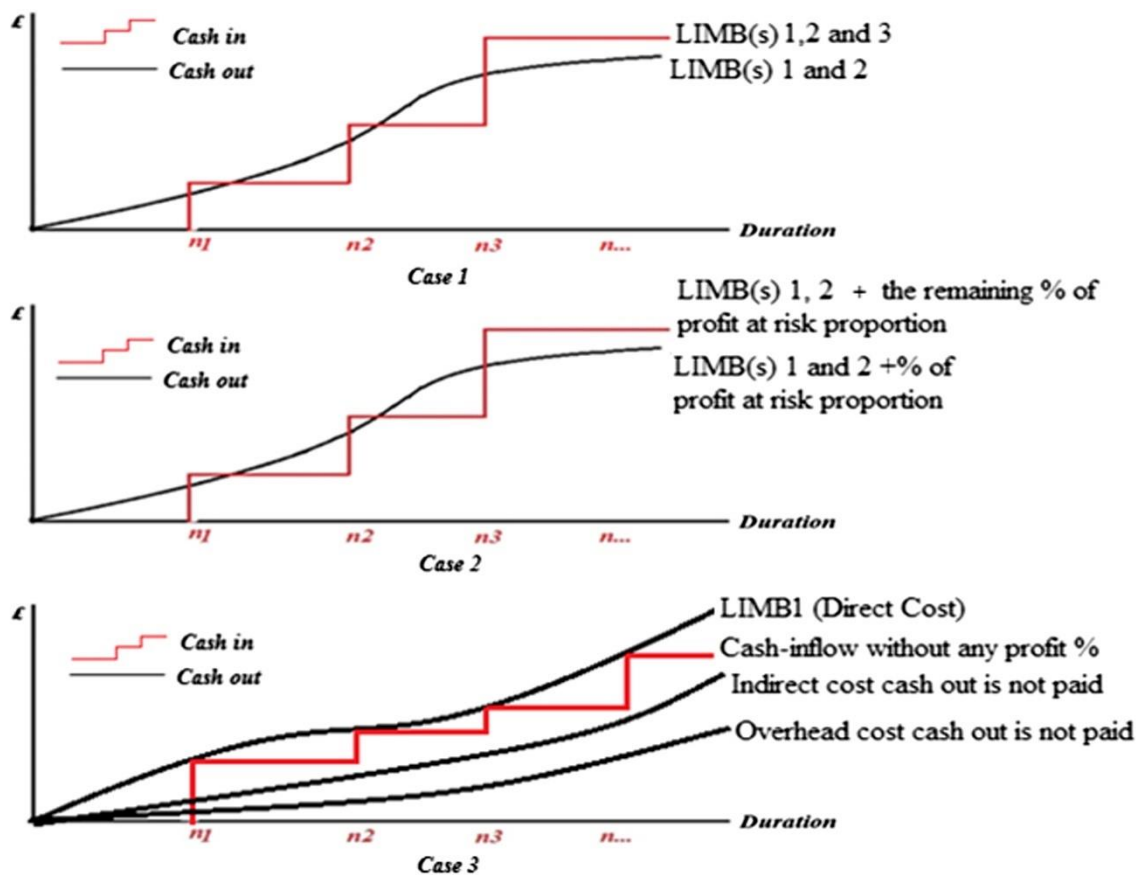


Figure 32.IPD Cash Flow Scenarios

6.5.4. BIM-Based Cash Flow

Since BIM and IPD are interrelated processes to lean construction process, Figure 33 shows the integration between schedule and cost within IPD approach using BIM capabilities. The model is divided into three steps, so that each step focuses on finishing the requirements of the following one until accomplishing the fully integrated cash flow for all participants. The developed model introduces a comprehensive solution for the fragmentation of WBS and CBS within using ABC, which deals with costs and schedule through a single hierarchy system.

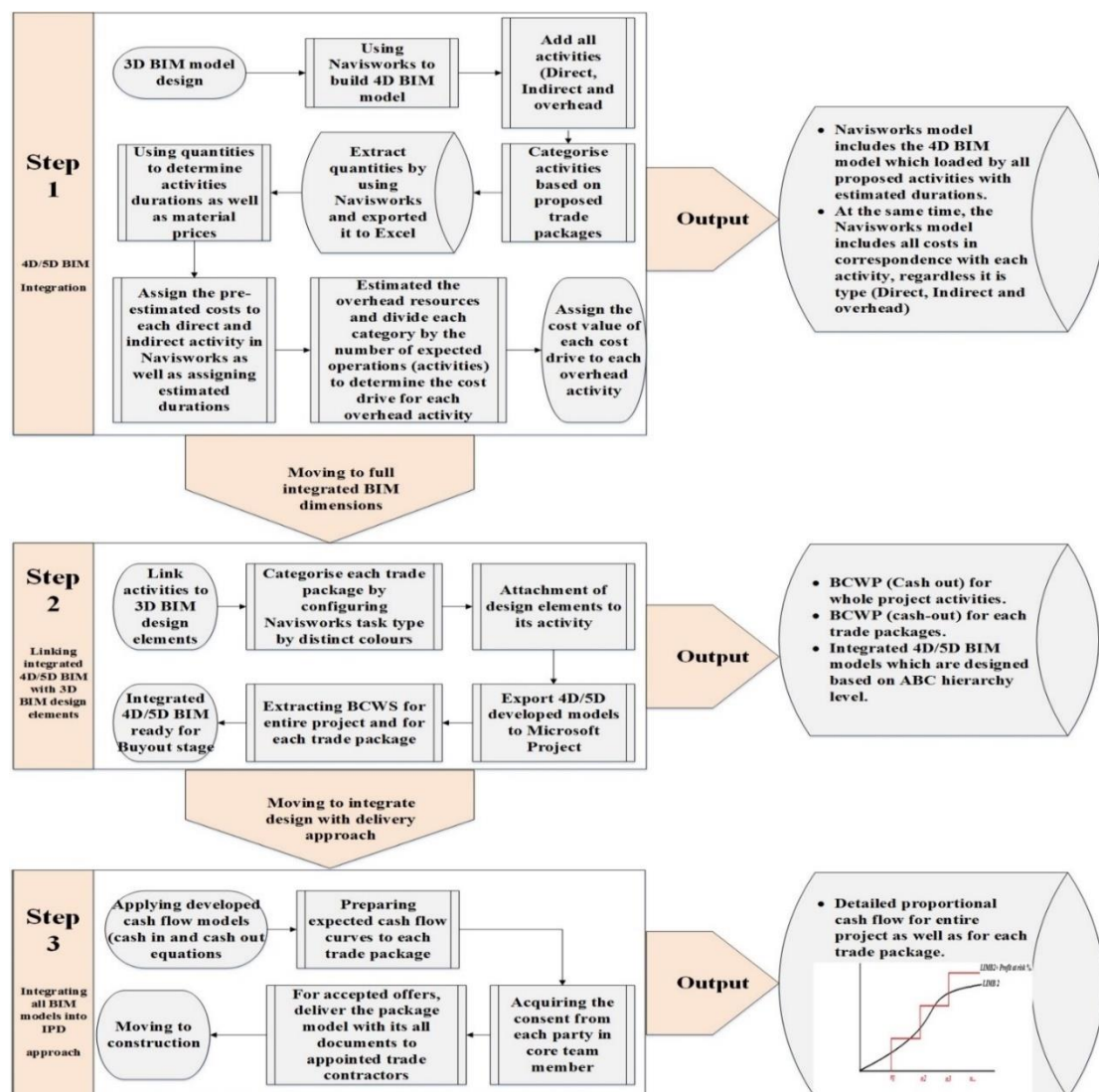


Figure 33. BIM and IPD Cash Flow Correlation

6.6.COST CONTROL AND RISK/REWARD SHARING SYSTEM

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.

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 25). Hence, the proposed framework involves an innovative risk/reward sharing method through integrating the ABC estimation method into EVM controlling technique. Figure 34 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.

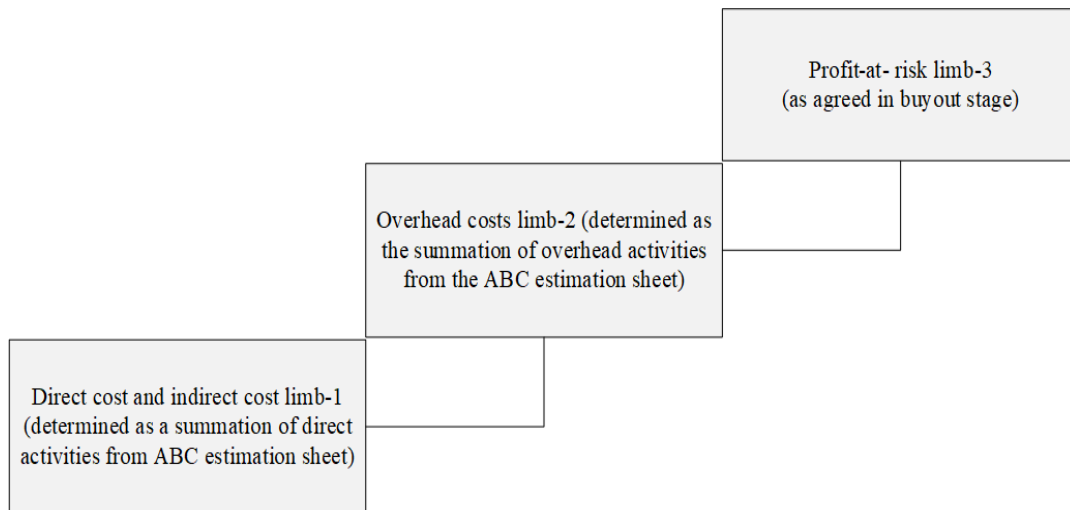


Figure 34. Compensation under the IPD approach using ABC estimation

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. 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 34.

6.6.1. 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 (a tool will be developed in the next chapter to enable estimating CPR and SPR and other EVM calculations automatically). 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 35 is used.

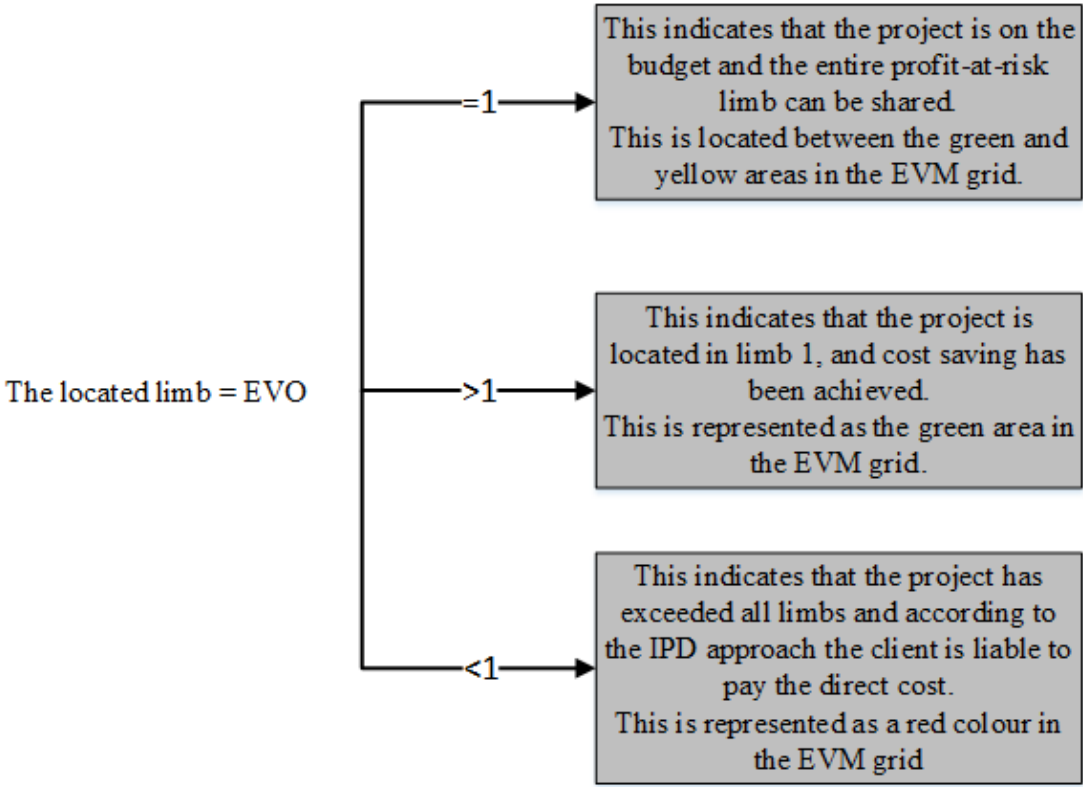


Figure 35.Function to assess the overall project situation and the limb location

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 10, where EVO represents the EVM grid output.

Table 10.Cases summary and required models

No of cases	Case	EVM values	output Equation(s)
1	On cost/schedule	$EVO = 1$	Equations 23 and 24 (Case 1)
2	Ahead of schedule and/or cost underrun	$EVO > 1$	Equations 21, 22, 23 and 24 (Case 2)
3	Behind schedule and/or cost overrun	$EVO < 1$	Equations 23 (Case 3)

5.1.1. Case 1

The first case occurs when a project is progressing on the schedule and within the budget. Equations 23 and 24 should be used to determine the risk/reward sharing among the project participants.

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 21 and 22 should be used to determine the cost savings' sharing among the project participants.

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 23. 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.

6.6.1.1. Developing the Risk/Reward Sharing Model Based ABC and EVM

The proposed models based EVM and ABC to provide the proper risk/reward sharing for the aforementioned three cases are presented in equations 13 to 24.

- Equations 13 shows the Earned Value Outcome (EVO) that represents the schedule and cost performances. Meanwhile, Equation 14 is the adjusted EVO with considering the P@R% since this shows whether the performance greater or less than the P@R%, subsequently, determine the project case. Equation 15 is another adjustment to decide whether there is a cost saving (Reward) or not. This equation is structured as conditional equation, so that if the Adjusted EVO ≥ 0 , the results will be the value of the adjusted EVO, otherwise, the value will be zero.
- After determining the project case, equations 16, 17 and 18 are developed to determine the value of achieved reward in the direct and indirect costs, equation 16 is developed to determine the total value of the reward in case that there is a cost saving in the direct and indirect costs. Then equations 17 and 18 are developed to calculate the proportions for owner and non-owner parties. The cost values of all LIMB (s) are designed according to the cost estimation framework based ABC and BIM as shown in section 6.3.
- Equations 19 and 20 are developed to determine the cost saving for overhead costs based ABC sheet. For more details about the cost estimation sheet for overhead cost see section 7.2.1.
- Equations 21 and 22 are developed to calculate the summation of the reward for owner and non-owner parties for direct, indirect and overhead costs.
- Equation 23 is to calculate the reimbursed costs according to the project case, therefore, it is designed as a conditional equation according to the EVO4Profit,

and two sub-equations are designed to determine the reimbursed costs if the $EVO4Profit > 0$ and another if $EVO4Profit < 0$.

- Equation 24 is developed to determine the profit as a conditional equation according to $EVO4Profit$ value against the $P@R\%$, inside this equations, two sub-equations are developed, one in case that the entire $LIMB-1$ (Profit) will be paid and another in case that a part of it has been consumed as a cost.

$$EVO = ([CPI] * [SPI]) \quad (13)$$

Where EVO represents Earned Value Outcome

$$Adjusted\ EVO = [P@R\ per] - (1 - [EVO]) \quad (14)$$

$$EVO4Profit = If([Adjusted\ EVO] \geq 0, [Adjusted\ EVO], 0) \quad (15)$$

Where $EVO4Profit$ is Earned Value Outcome for Profit

$$\begin{aligned} MV\ for\ R\ for\ each\ party\ (LIMB - 1) \\ = If([EVO4Profit] \\ > [P@R\ per], ([PLIMB - 1] - [Actual\ LIMB - 1]), 0) \end{aligned} \quad (16)$$

Where MV for R for each party ($LIMB-1$) represents Monetary Value for Reward for each owner and non-owner parties and $LIMB-1$ is the direct and indirect cost.

$$\begin{aligned} Reward\ For\ Owner\ (LIMB - 1) \\ = [MV\ for\ R\ for\ each\ party\ (LIMB - 1)] * [PoO] \end{aligned} \quad (17)$$

$$\begin{aligned} Reward\ For\ non - Owner\ (LIMB - 1) \\ = [MV\ for\ R\ for\ each\ party\ (LIMB - 1)] * [PoNO] \end{aligned} \quad (18)$$

Where $PoNO$ or PoO is The Proportion of sharing cost-saving for Non-Owner Parties/Owner

$$\begin{aligned} CSoOC\ for\ NO \\ = ([CSoOOA] + ([CSoOPA] * NoARP)) \end{aligned} \quad (19)$$

$$CSoOC \text{ for } O = ([CSoOPA] * [OARP]) \quad (20)$$

Where CSoOC for NO represents Cost Saving of Overhead Cost for Non-Owner parties, CSoOOA represents Cost Saving of Overhead Organisation Activities, CSoOPA represents Cost Saving of Overhead Project Activities and NoARP/ OARPis the Non-Owner/Owner Agreed Reward Percentage.

$$TR4O = ([Reward \text{ For Owner } (LIMB - 1)] + [CSoOC \text{ for } O]) \quad (21)$$

$$TR4NO = ([Reward \text{ For non - Owner parties } (LIMB - 1)] + [CSoOC \text{ for } NO]) \quad (22)$$

Where TR4O/TR4NO Total Reward for Owner/Non-Owner parties.

Reimbursed Cost

$$\begin{aligned} &= IIf \left([EVO4Profit] \right. \\ &> 0, ([TCS] \\ &- ([Profit] + [MV \text{ for } R \text{ or } RD \text{ for each party } (LIMB - 1)] \\ &+ [CSoOC \text{ for } NO] + [CSoOC \text{ for } O])), ([TCS] - [Profit]) \\ &\left. + [DC \text{ above } TCS]) \right) \end{aligned} \quad (23)$$

$$Profit = IIf([EVO4Profit] \geq [P@R \text{ per}], [LIMB - 3], ([EVO4Profit] * 10 * [LIMB - 3])) \quad (24)$$

Where TCS represents Total Compensation Structure

Figure 36 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.

EVM-Grid for IPD approach

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.

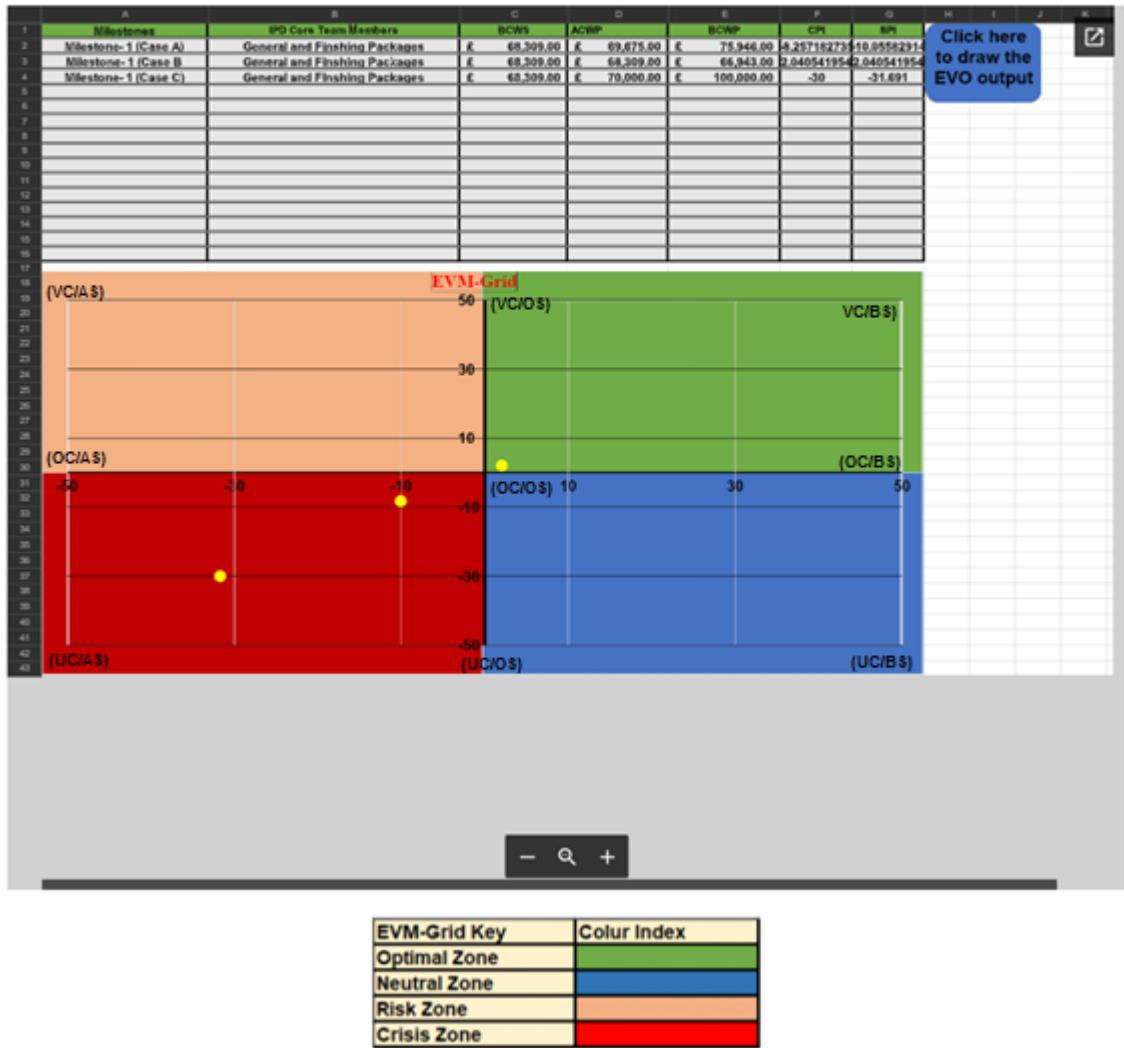


Figure 36. EVM-Based IPD with considering ABC estimating approach

Figure 37 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.

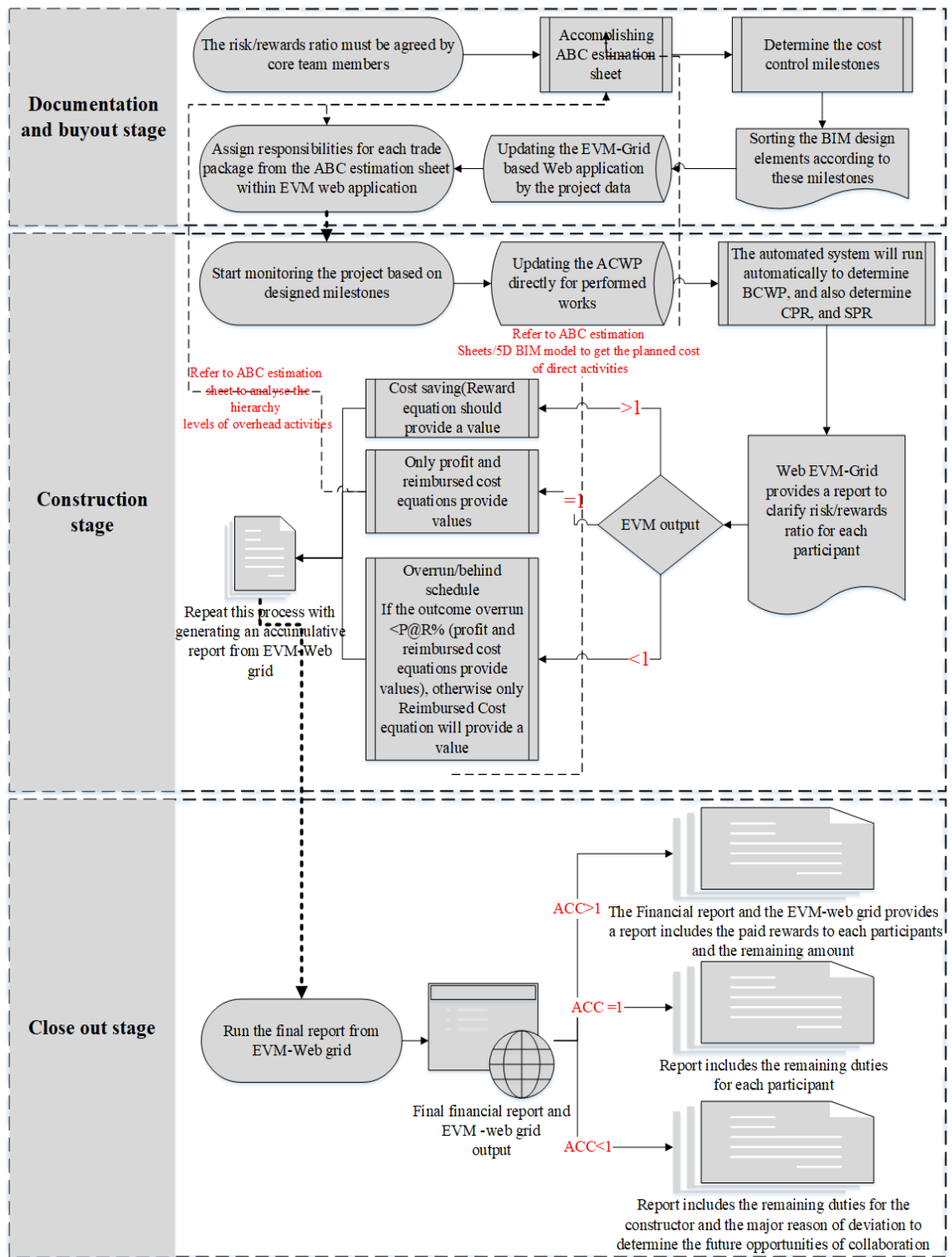


Figure 37.EVM-based IPD approach implementation flowchart

6.7.THE FRAMEWORK TASKS OVER IPD STAGES

Figure 38 summarises the tasks of cost management based CCMS framework, this figure works as a map to direct the potential users of the framework and the tools that will be developed such as the web-based management system to implement all tasks efficiently.

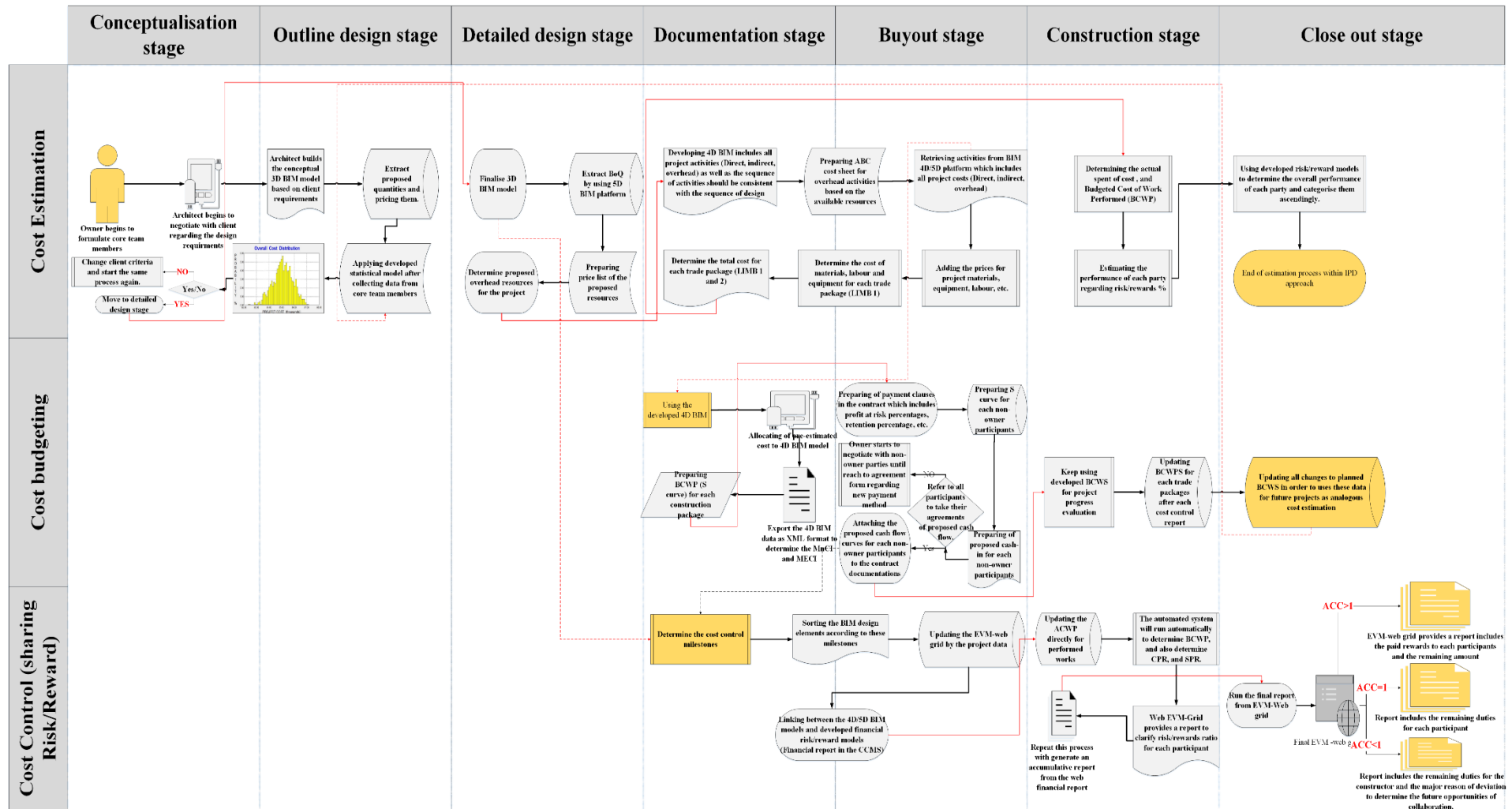


Figure 38. The summary of the framework tasks over the IPD stages

6.8.USING DLT TO SHARE AND VALIDATE THE RISK/REWARD SHARING DATA

This framework is developed to work whether as an independent solution to share risk/reward values among IPD core team members or receiving the data from the proposed CCMS framework and deploy it into the blockchain network. Therefore, the framework here is designed separately with showing how the three transaction (Reimbursed costs, Profit and cost saving) should be calculated under different cases—Scenarios.

The framework is divided into three main sections – following the three main phases of IPD, as discussed. The first section focuses on preparing the BCN before deploying it, this should be implemented throughout the IPD pre-construction stage. The second section is about developing a mechanism to manage all IPD transactions within the – IPD – construction stage, as well as, enabling parties who finished their agreed works at early stages of the project timeline to follow other contractors without the necessity to attend all meetings (see Figure 39). The third section, the close out stage, is different from traditional approaches in terms of determining the owed profit proportions for owners and non-owner parties.

This section of the framework is designed to integrate the triple processes of IPD, blockchain and BIM in visualising the flow of information. As for BIM, the framework provides the details of what BIM dimensions are utilised. This is to provide information that feeds the proposed IPD-blockchain system – using 4D to inform the payment schedule for all IPD core team members and 5D to provide cost data (see Figures 39).

Figure 39 shows the entire process of implementing permissioned blockchain, the hyperledger-fabric with the IPD stages. Every stage of IPD includes different types of

information and different tasks. Therefore, the framework aims at enabling potential users to implement it easily. It can be used to inform users of the input and outcome of each IPD stage, along with the progress of developing or utilising the blockchain network. Given each set of IPD stages have different levels of information and distinct characteristics, therefore, the BCN should be developed and used according to the characteristics of IPD stages, as follows.

6.8.1. Conceptualisation to Buyout

There are three major sections that form this stage. First, building the network components; each party in the IPD core team represents a peer node in the blockchain network. This peer node will carry its own ledgers in the deploying stage, as well as, other two peers: one to represent the ordering peer, while another peer is called orderer peer. Second, the endorsement policy that includes the path of transaction from one party to others for endorsing transactions: defining whom should endorse transactions proposed by one of the parties. This requires developing mathematical equations to enable determining the value of each transaction and proposing new terms in consistency with the blockchain technology. The third section covers the ordering policies, concerning the path of the transactions to be recorded in which peer (project party) through a channel.

Core team members in IPD should have the same level of information/details, therefore, any transaction by non-owner parties (including contractors, and consultant team) should be endorsed by the owner and consultant peers. Given that not all contractors finish their tasks at the same time, the time stamp is a part of the endorsement policy. Each contractor is limited to act in a specific period, extracted from the project timeline (4D BIM). Any proposed transaction sent – by a contractor – beyond the ranges specified will be invalid. The compensation approach of IPD relies on reimbursing all the cost below the specified profit at risk percentage (limb 3). This value will be coded for each party individually, so

that no party can exceed. Following Equation 1 shows how the IPD reimbursed costs are calculated.

$$RMVoT_i = \sum Limbs (1,2 \text{ and } 3) \leq PMVoLimbs \quad (24)$$

Where $RMVoT_i$ is the reimbursed monetary value of transaction for contractor I , and $PMVoLimbs$ is the planned monetary value of limbs for contractor I .

Other transactions must be also invoked by any non-owner party, these transactions should be profit/risks values and the achieved cost saving value. Equations 25 and 26 show the calculation mechanism of these two transactions when the total planned value of the compensation structure is greater than reimbursed costs.

$$T_{2p} = PMVoLimbs - RMVoT1 = \begin{cases} (+)Profit \\ (+)(Profit + Cost saving) \\ (-)Monetary value of risks \end{cases} \quad (25)$$

$$T_{3CS} = T_{2p} - Limb3 \quad (26)$$

Where T_{2p} is the second transaction for the profit values and the T_{3cs} is the third transaction for the cost saving values.

In case that the value of $RMVoT_i$ exceeds that of $PMVoLimbs$, the non-owner party should split the value into two transactions, Equation 27 presents the reimbursed costs as the whole compensation structure.

$$T_{1R} = PMVoLimbs \quad (27)$$

Another transaction (T_{2R}) should be implemented by the same contractor (i) and endorsed by the client, as it represents the direct costs of all works exceeding the planned values (see Equation (28)).

$$T_{2R} = \sum DCALimb3 \quad (28)$$

The value of transaction 2R should be assigned to all other peer nodes that carry stamp, which identify the trigger of the transaction and the time.

The interrelationships among project parties on the blockchain network should be drawn to identify the endorsement path. The proposed framework assumes that the owner is committed to endorse any transaction invoked by any non-owner party. For mistakes in any previous transaction by the client, the client can invoke a retrieved payment to receive money back – should be endorsed only by the payer non-owner party.

The IPD smart contract should include specific functions to record the proposed financial transactions presented in this section. There are three IPD financial functions to be coded: (1) reimbursed costs pool, (2) profit pool, (3) cost saving pool. Each function should include identifier parameters like sender, value, milestone and the trade package. Given that IPD agreement accepts adding new members anytime during the project stages, the smart contract can include a function for this purpose with specific parameters like the name, trade package and contacts. In order to maximise the transparency and security for IPD parties, the profit pool can be capped by a certain monetary value for each milestone, as well as accumulatively. The profit thus will be checked/endorsed automatically for any new transaction.

Ordering the process presents a main part of the hyperledger fabric network component. In the IPD context, the ordering policy refers to managing and controlling the relationships among project parties. That is, the movement of endorsed transactions should be pre-identified through nominating the channel for transferring the transaction data.

The ordering process in the present study is designed to follow the sequence of project timeline, as well as, the distinguished relationships among IPD project team members. To extend IPD characteristics in sharing all acquired data to all participants, the genotype of

each transaction should show: (1) the transaction number (i.e. 1, 2, etc.); (2) who the respondent is (owner and non-owner parties); (3) the endorsement status (which peer has accepted the transaction) – based on who has invoked the transaction, the endorsement policy defines which peers should endorse the transaction (see Figure 39).

In each payment milestone, all non-owner parties who are supposed to implement works based on the project timeline (4D BIM) should invoke three transactions according to the agreed endorsement policy. Once all the invoked transactions have been indorsed, the total reimbursed cost transaction should be gathered in a block (i.e. block 1 for the May payment milestone). Accordingly, this block should be shared with all parties' peers through a channel. Subsequently, the other two transactions that carry the profit and cost saving should be transferred to all parties' peers, to make sure all IPD core team members have the same amount of information that enables them to make the needed decision (see Figure 39). Therefore, any IPD project requires two main channels: the main channel to transfer the transactions among all parties and another individual channel among all non-owner parties and the owner, in case an error is revealed, so that the adverse transaction should be invoked by the owner to restore the amount paid.

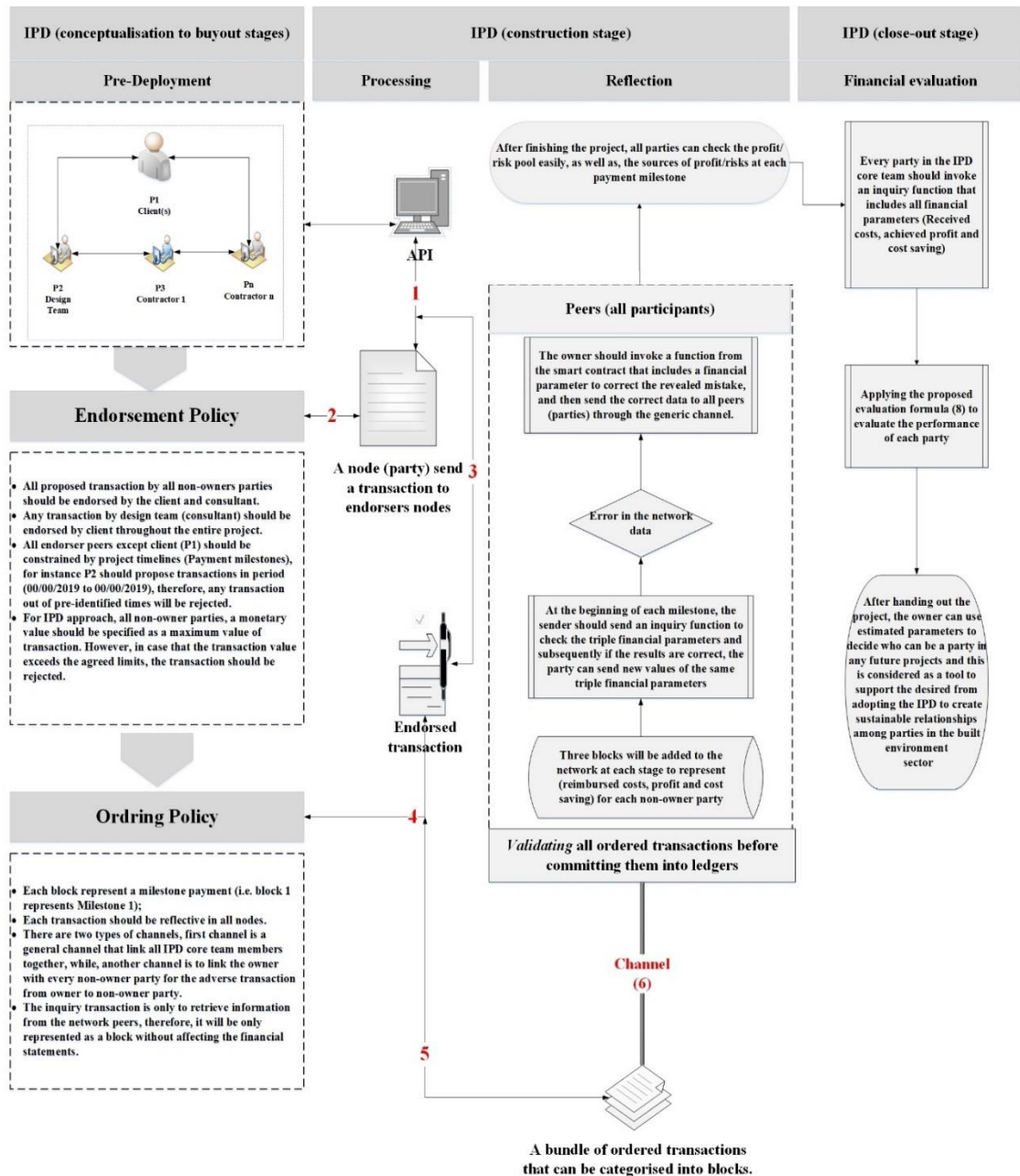


Figure 39.The framework: IPD-based hyperledger fabric

6.8.2. Construction Stage (Processing and Reflection)

The processing of a transaction in hyperledger fabric includes four major stages. These stages are tailored to fit into the BIM and IPD contexts. Therefore, all needed information from BIM models are identified, considering the characteristics of IPD. In addition, the related tasks with hyperledger fabric are also presented. These four stages are described below and highlighted in figure two using numerical indications from 1 to 5.

- Send a transaction proposal to specific peer nodes: according to the project timeline (4D BIM), non-owner parties who implemented works should initiate request transactions using an Application programming interface (API) to invoke the chaincode function. The framework relies on IBM blockchain and the IBM cloud offers API screen that can manage the blockchain network nodes, channels and peers. Every network member can use this API screen to log in and invoke any function to record new data in the hyperledger. As stated in the endorsement policy, the transaction should be sent for endorsement to other pre-identified peers (see Figure 39, processing and reflection sections).
- Endorsing proposed transactions: all transactions should meet the mentioned endorsement policies like the maximum value of each transaction and the planned time to invoke the transaction (see Figure 39, processing and reflection sections). Once a transaction has been endorsed, it returns back to the transaction sender to begin the ordering process.
- Ordering endorsed transaction: all endorsed transactions should be transferred to the ordering peer node for their signature to be double checked. Subsequently, transactions will be ordered chronologically. That is, there is an interrelationship between the transactions, as there is a precedence for each transaction, as planned in the 4D BIM) based on the agreed upon ordering policy in the pre-deployment stage. The architecture of chaincode hence represents the number of transactions, respondent, endorser (i.e. T1, Consultant, Owner) (see figure 39, processing and reflection sections). Accordingly, based on the timestamp, the transactions will be packaged into a block, to be sent to peers for commitment. The architecture of chaincode for the proposed three transactions (reimbursed costs, profit and cost saving) should be arranged, as illustrated in Figure 40, coded as function parameters in the IPD smart contract.

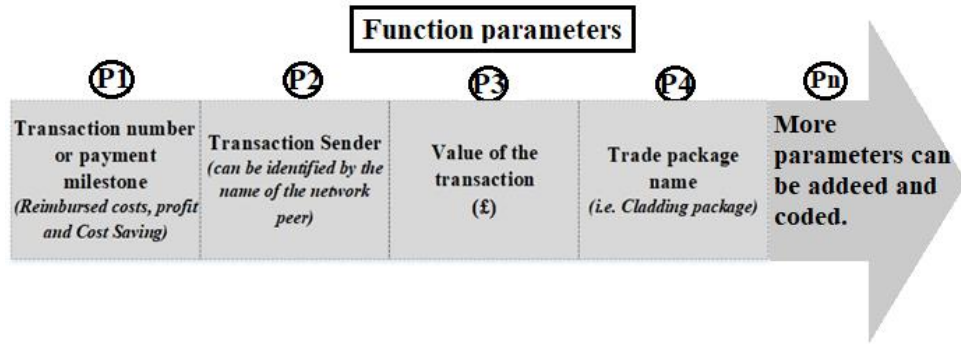


Figure 40. The architecture of the IPD-based smart contract transaction

- Committing transaction: all ordered and packaged transactions should be broadcasting to pre-identified peer nodes in ordering policy as stated in figure 39 (processing and reflection sections). For illustration, all ordered transactions proposed by non-owner parties should be broadcasting to all peer nodes through a channel using API. Additionally, the transaction that comes from the owner party in order to correct any revealed issue in previous financial statement (adverse transaction) should be transferred to all peers (project parties), to make them aware of any change in the final statements of the three main IPD transactions.

6.8.3. The Close-Out Stage

At each milestone, the same process should be repeated, however, the accumulative value of project profit should be checked through the ordering service. All profit transactions for each milestone should be gathered in a ledger, hence the profit node (profit pool) includes a bundle of ledgers. The summation of the profit requested by all non-owner parties should be presented in the ledger. Each profit ledger must be linked to the previous one to achieve the conditions, as formulated in Equation 29.

$$VAPT = \sum AVoPT_{(Ln,Pn)} \leq PLimb3_{(Mn,Ln)} \quad (29)$$

Where VAP is the valid accumulative profit transaction, $AVoPT_{(Ln, Pn)}$ is the accumulative value of profit transactions, stated in Ledger (n) for Party (p), $PLimb3_{(Mn, Ln)}$ is the planned monetary value of limb 3 for payment milestone (n), stated in ledger (n). As discussed, IPD supports sustainable relationships among owner and non-owner parties. Accordingly, a financial evaluation for all parties should be retrieved from the hyperledger-fabric network, with evaluation parameters as presented in Equation 30.

$$f(AFP_{ij}) = \begin{cases} C = ARC_{ij} - Planned\ Limbs\ (1\&\ 2) & (-) = C \geq 0 \\ P = APP_{ij} - Planned\ Limb\ 3 & P \leq 0 \\ CS = ACS_{ij}/Planned\ Limbs\ (1\&\ 2) & CS \geq 0 \end{cases} \quad (30)$$

Where C represents the paid cost, AFP_{ij} is the accumulative financial parameters for party (i) that is appointed to implement trade package (j) (£), P represents the profit parameter, ARC_{ij} is the accumulative reimbursed cost (£), APP_{ij} is the accumulative planned profit (£) CS represents the cost saving and ACS_{ij} is the accumulative cost saving (£).

As discussed, three parameters can articulate a performance indicator for the entire IPD financial progress. Table 11 illustrates how these parameters can be understood by core team members in IPD.

Table 11. The evaluation of financial parameters during the IPD close-out stage

Parameter	Value	Indication
C	Zero	The package has been implemented as planned and no cost saving has been achieved.
	(+)	A cost overrun has occurred and part of the profit proportion has been consumed.
	(-)	A cost saving has occurred equal to the estimated value from this parameter.
P	Zero	The estimated profit is achieved.
	(-)	A cost overrun has occurred and a proportion of the profit has been consumed as a cost.
CS	Zero	No cost saving has been achieved. This case is accompanied by the C equals zero parameter.

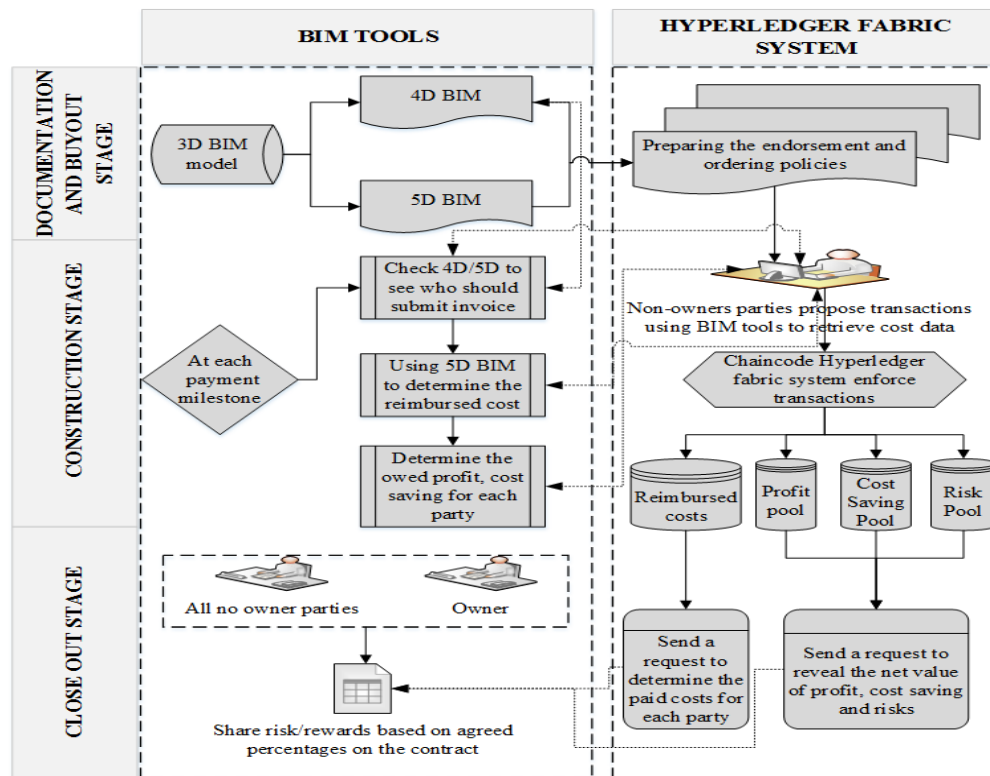
>Zero	A cost underrun has been achieved and the profit percentage has been completely achieved.
-------	---

Note: C = cost; CS = cost saving; P = profit

Therefore, an inquiry function is needed to be coded in the IPD smart contract to support collecting the needed information to undertake the proposed financial evaluation.

6.8.4. Interoperability among BIM, IPD and Blockchain

Figure 41 depicts the interrelationships between BIM tools and the chaincode hyperledger fabric within the IPD implementation stages. During the IPD pre-construction stages, particular documentation and buyout stages, BIM dimensions (3D, 4D (Scheduling) and 5D (Cost)) provide the needed information to develop the chaincode system. The needed information from BIM should be the dates of starting and finishing each trade package, in order to be coded in endoresement and ordering policies, the total cost for each package and maximum estimated profits for each non-owner party to be used in validiting the profit transactions per paymemt mnilestones and accumulativly at further milestones (see Figure 39). Simulationsly, the chaincode hyperledger fabric should be designed using the data provided from the BIM data, such as defining numbers of peers (peer per party), and the required functions to be written in IPD's smart contract format, as discussed next.



As

Figure 41. The interoperability among BIM, IPD and the chaincode system

shown in Figure 41, once the construction stage begins the non-owner parties who implemented works should invoke smart contract functions by retrieved values. This is from the 5D BIM (i.e. the spent financial resources to implement the agreed works, counting the remaining profit-at-risk percentage based on agreed values in the IPD buyout stage and determining whether there is achieved cost saving or not) through API. This process will be repetitive to reach the close out stage. Since all risks/reward should be shared during the close out stage, all parties can request the net amount of total profit, cost saving and the reimbuiresed costs. Subsequently, based on the agreed risk/reward proportions during the buyout stages, each party can get the owed proportion in each term – profit, cost saving and risks (Ashcraft, 2012, Teng et al., 2017). Then comes assessing the performance of each party, according to the achieved profit compared to the planned profit, using 5D BIM.

In contrast to the traditional accounting systems that record owed profit, cost saving and profits for each party, the chaincode hyperledger fabric prevents any party to amend

achieved percentages. Particularly, some parties leave construction site at early stages because their trade packages are scheduled to be finished at the these stages, therefore, they cannot track the progress in the site. This may create lack of trust among IPD core team members.

6.9.SUMMARY

This framework presented a comprehensive cost management solution for the IPD approach, the developed framework can be concluded as follows:

- The research introduced an innovative way for cost estimation, therefore, the estimation methods have been developed to be matched with IPD's characteristics. Since the early decision is vital to ensure successful management of IPD, the developed framework includes a model for an early estimation by exploiting the IPD's early involvement of all participants in order to collect reliable historical data and using these data to build a statistical model. The built model will be analysed by Monte Carlo Simulation in order to obtain the entire cost against a degree of certainty of the used cost data. The framework revolutionised the IPD cost structure through enhancing the overhead costs allocation, as well as, supporting the automation process of estimation.
- The framework presented a methodology framework to develop a cash flow approach using BIM tools. The framework adopts ABC, due to its ability to allocate different costs precisely to each construction process. Given that the BIM and IPD is recommended to achieve the best collaboration among project parties, the proposed framework proposed a detailed mechanism of integrating BIM tools/methods into the IPD stages.
- For the cost control and sharing risk/reward values among IPD core team members, the proposed model can provide accurate values of the three main

transactions (profit, cost saving and reimbursed costs) for the IPD approach. As, well as, the proposed model considered adopting BIM under the IPD approach. For the sharing in the cost savings, which represents as a significant barrier in implementing IPD, it managed this issue through adopting 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 the case of sharing of overhead cost saving for overhead resources, the source of this saving will be determined, which will minimise the conflicts among 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 the all processes will be automatically implemented with a minimal human interference.

- As the first of its kind, the blockchain technology is adopted in the present study, in developing a framework to propose utilising the blockchain technology in delivering IPD-based projects. The outcome enables IPD's core team members to execute all financial transactions automatically, through coding IPD's three main transactions – reimbursed costs, profit and cost saving – as functions of the IPD's smart contract.

The next chapter shows how the proposed tools in this framework such as the web-based management system including the EVM-grid and the automated financial system, as well as, the CCMS database are developed. The applicability of these tools will be validated using an illustrative case study.

CHAPTER SEVEN: PROTOTYPE DEVELOPMENT AND VALIDATION

7.1.INTRODUCTION

This chapter presents the development of the proposed tools in the framework, these tools help to implement the cost management process of the IPD approach according to the concepts of the framework. In order to validate the proposed tools in the framework, a prototypes is developed, which comprises of (1) an automated database system whether offline or online, (2) An EVM-grid for cost control visualisation, (3) interactive web-based management system. Moreover, developing a blockchain network and smart contract to test the proposed processes in the framework. An illustrative case study is also presented in this chapter to enable measuring the capacity, validity and reliability of the developed tools through applying multiple scenarios and compare the results.

7.2.PROTOTYPE DEVELOPMENT

The proposed tools to develop an IPD automated cost management system will be developed in this chapter as a prototype in accordance with the framework. The prototype is divided into two sections, the centralised system and the decentralised system to cover all proposed tools in the framework.

7.2.1. Centralised Cost Management System (CCMS) for IPD

The CCMS includes specific tools according to the IPD stage, as follows.

- Developing a cost estimation environment to fulfil the proposed estimation process in the framework section, this will be implemented using BIM 4D/5D platforms in integration with MS Access to build integrated tables and using Macros to automate the process.

- Using MS Excel to develop the proposed EVM-Grid (Coloured indications) to show the EVO data, the process will be automated using Macros to facilitate its implementation.
- Developing a web-based management system, this web will be the interface to visualise all the data automatically once it has been updated in the database (Access database). The main purpose of this web is to show the status of the project parties regarding their financial progress including the reimbursed costs, profits and cost-saving.

7.2.1.1. Developing a Database System for the CCMS

Figure 42 shows the tables that have been designed to show the data in specific sets, The output of 5D BIM will provide the LIMB-1 (Direct and indirect costs), see table-1 in figure 42, meanwhile, the proposed table to develop the overhead costs based ABC method is designed in three tables (see tables 2-A, 2-B and 2-C in figure 42), the calculations of the needed overhead resources will be executed using table 2-A, subsequently, the value of the overhead driver for each operation will be executed using table 2-B, finally, the ABC sheet is designed as can be seen in table 2-C to include all overhead activities for each package and trade contractor.

In order to facilitate filling and searching into these database, codes are designed to facilitate collecting data during the construction stage, the LIMB-2 will be automatically calculated for each party (i.e. General package) and for the entire project through programming the proposed equations in the framework (Equation 4). Subsequently, the IPD compensation structure is presented in a table entitled Package costs that includes the values of each limb for each party in the project (see table 3, figure 42). Given that LIMB-3 represents the Profit-at-Risk percentage, therefore, this limb will be automatically calculated by adding the equation 5 as an expression in the table design.

Since the framework includes a new way to present the data to enable parties making the decisions during the buyout stage whether continuing in the project before the construction stage or rejecting the offer. The data for two main metrics (EMnCI and EMCI) is sorted in a table, these data will be calculated automatically through linking the table with “Project Package Costs” and “Contract Financial Terms”, subsequently, and the maximum overdraft for each project party will be automatically calculated (see figure 42, table 4).

During the construction stage, the developed risk/reward sharing model (Equations 13 to 24) will be used to provide the three main financial transactions for each party (reimbursed cost, cost-saving for both overhead and direct cost, profit values), a table is developed and it is linked with the cost estimation and budgeting database, the developed risk/reward model is coded as expressions in this table to enable the automation in calculating the profit, cost-saving and reimbursed costs, this table is entitled “Financial report”, see table 5 in figure 42. Moreover, the output of the developed EVM-Grid such as “The generic case of the project” should be also presented.

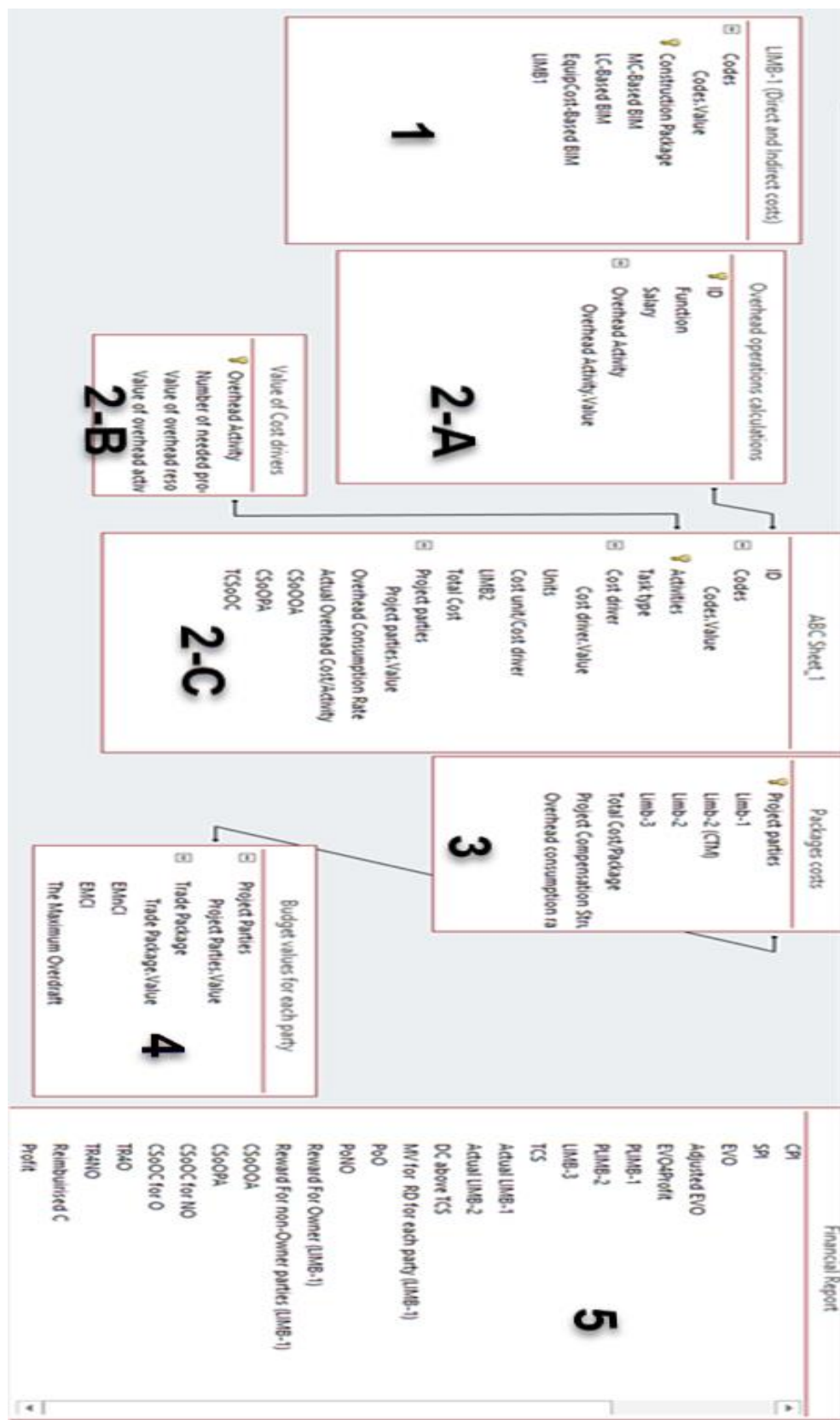


Figure 42.The Database structure of the CCMS

7.2.1.1.1. The Structure of the Tables

Figure 43 shows the structure of the tables that were designed to show how the cost/financial data is sorted, for example, the output of 5D BIM will provide the LIMB 1 —Direct and indirect costs— See table 1, in figure 43. The proposed table to develop the overhead costs based ABC method is designed using automatic codes to facilitate collecting data during the construction stage, the LIMB-2 will be automatically calculated for each party (i.e. General package) and for the entire project (see table 2 in figure 43). Given, LIMB-3 represents the Profit-at-Risk percentage, therefore, another table is designed to include the agreed financial terms during the buyout stage and it is linked with the project costs table to automate the calculation of LIMB-3 (see table 3 in figure 43). The structure of the financial report is also presented in figure 43, table 4.

Codes	Construction Package	MC-Based BIM	LC-Based BIM	EquipCost-Based BIM	LimB1
CMLMB-1	Ceiling Package	£2,140.20	£1,115.00	£0.00	£3,855.20
FMULMB-1	Finishing Package	£3,553.80	£1,334.40	£0.00	£4,888.20
GMULMB-1	General Package	£38,038.90	£21,318.90	£366.80	£59,724.60
LFMLMB-1	Lighting Fixture Package	£17,037.90	£296.50	£0.00	£17,334.40
NDMLMB-1	Windows and Doors Package	£31,913.10	£763.00	£0.00	£32,682.10
		£0.00	£0.00	£0.00	
Total		£92,689.90	£25,427.80		£118,484.50

(1) LimB1 is retrieved from the 5D BIM model

LimB-1	Overhead consumer	LimB-2 (CTM)	LimB-2	LimB-3	Total Cost/Package	Project Compensation Sh
£3,855.20	3.25%	£105.74	£11,519.20	3096.0276	£15,480.14	£18,576.17
£4,888.20	4.13%	£134.07	£15,403.80	4085.2944	£20,426.17	£24,511.41
£59,724.70	50.40%	£1,638.09	£27,557.60	17794.07622	£28,520.39	£106,704.47
£17,344.40	14.64%	£475.71	£7,134.60	4890.54024	£24,954.71	£29,945.65
£32,682.20	27.58%	£896.39	£7,134.60	8142.63732	£40,713.19	£48,655.62
£0.00			£0.00			
£118,484.80	100.00%	£3,250.00	£68,749.80	38098.92002	£190,494.60	£228,593.52

(3) LimB3 will be calculated automatically through adding its equation as an expression in the "Access Table design"

ID	Codes	Activities	Task type	Cost driver	Units	Cost unit(C	LimB2	Total Cost	Project parties	Overhead Const	Actual One	CS000A	CS00PA	TCS00C	Click to Add
1 010G	Setting out	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	
2 010G	Inspection of formworks	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	
3 010G	Inspection of rebar works	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	
4 020G	Inspection of foundation batch	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	
5 010G	Setting out walls	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	
6 020G	Inspection of masonry works	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	
7 010F	Setting out separation of rooms	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	£1,500.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	

(2) Automated ABC sheet to estimate the overhead cost

(4) Financial report that includes the outcome of all equations (1 to 12), these equations have been developed by integrating ABC into EVM to automate the determination of the main three IPD financial Transaction (Cost Saving, Profit and Reimbursed Costs)

WM for Rd for each party (LimB	POO	PONO	Reward for Owner (U	Reward for non-Owner parties (U)	CS000A	CS00PA	CS00C for NO	CS00C for O	TMAD	TMANO	Reimbursed C	Profit	CI
£1,719.40	50.00%	50.00%	£359.70	£359.70	£0.00	£1,013.00	£709.10	£303.90	£1,165.60	£1,568.80	£66,022.80	£13,751.04	
£0.00	0.00%	0.00%	£0.00	£0.00	£0.00	£0.00	£0.00	£0.00	£0.00	£0.00	£78,655.55	£3,850.29	
£0.00	0.00%	0.00%	£0.00	£0.00	£0.00	£0.00	£0.00	£0.00	£0.00	£0.00	£82,506.24	£0.00	
*	0.00%	0.00%			£0.00	£0.00							

Figure 43. The structure of the database tables of the CCMS

7.2.1.1.2. Developing Data Entry Forms

In order to facilitate the data entry for potential users, a set of forms is designed, for all main database as shown in the figure 44, for the five main tasks, namely, Limb-1 (Direct and indirect costs), ABC sheet (LIMB-2), Compensation Structure, budget metrics and financial report. Figure 44 depicts the data entry forms for all table to make it user-friendly, as well as, it is featured by a button to print all data in case that the party wants to get the data from the server not from the web interface. The user can only fill the required terms to determine the outcome automatically, for example, in the financial report, only the terms of CPI, SPI, Project compensation structure and contractual terms should be filled and automatically the risk/reward values for owner/non-owner parties will be calculated automatically on the table (see table 5 in figure 44). Similarly, all tables are designed by the same way to minimise the human interference in the calculations, which maximise the trust among project team members. The calculations are executed according to the developed mathematical equations for cost estimation, budgeting and risk/reward sharing based EVM outcome as proposed in the framework.

Table 1 in figure 44 includes the cost data from the 5D BIM—LIMB-1— (i.e. the Autodesk Navisworks platform is utilised to export the automated BoQ as XML, then adding the prices allowances to develop the cost of material, other costs such as equipment and labour is determined using automated spreadsheet after importing the needed data from the 4D/5D BIM model). The limb-2 should be ready from table 2 in figure 44. LIMB 3 will be calculated through retrieving the P@R% from a designed table in the database (see figure 43). Then the compensation structure will be calculated automatically after the three LIMB(s) are calculated, see table 3 in figure 44.

Tables 4 and 5 in the figure 44 shows the cost budget and the financial report forms. It can be seen that from table 4 in figure 44, the EMnCI and EMCI should be entered after

developing them using the proposed model (Equations 10, 11 and 12), and the maximum overdraft will be calculated automatically. Moreover, Table 5 in figure 44 shows the cells that should be entered in order to determine the three main financial transactions (Profit, cost saving and reimbursed costs).

IPD Cost Estimation

LIMB-1

ABC Sheet

Construction Package

MC-Based BIM

LC-Based BIM

LIMB1

Codes

£0.00

£0.00

Codes

Units

Cost unit/Cost driver

Total Cost

LIMB2

Project parties

Overhead Consumpti

Actual Overhead Cos

CSOOOA

CSOOPA

TCSOOC

£18,576.17

IPD Cost Estimation

Budget values for each party

Project Parties

EMInCI

EMCI

The Maximum Overdraft

Trade Package

£0.00

£0.00

Financial Report

Payment Milestones

Construction Package

Project Case

NOARP

OARP

P@R per

CPI

SPI

Actual LIMB-1

0

0.00%

0.00%

0.00%

0.00%

0.00%

£0.00

Actual LIMB-2

PLIMB-1

PLIMB-2

PoO

PoNO

CSOOOA

CSOOPA

£0.00

£0.00

£0.00

0.00%

0.00%

0.00%

£0.00

IPD Cost Estimation

Packages costs

Construction Package

Limb-1

Limb-2

Limb-3

Total Cost/Package

Project Compensation Structure

Project parties

£3,855.20

£11,519.20

£3,096.03

£15,480.14

£18,576.17

Ceiling Works Cc

1

2

3

4

5

Figure 44.The entry form of the CCMS

7.2.1.1.3. The Home Page of the CCMS

Given that the user interface enables users to find the needed tool easily, therefore, a user interface is developed and automated using a Macro for the process of each task, set of messages have been added to direct the user regarding the next step, see figures 45 and 46. A sample of a written micro for the ABC sheet is shown in figure 46. the micro includes three main processes, (1) open the form to enable recording the data, (2) Auto-Save for all inserted data, (3) displaying a message to show what you have done and the next step that should be proceeded, this will help the user, particularly as the IPD based cost management process is still not widely familiar.

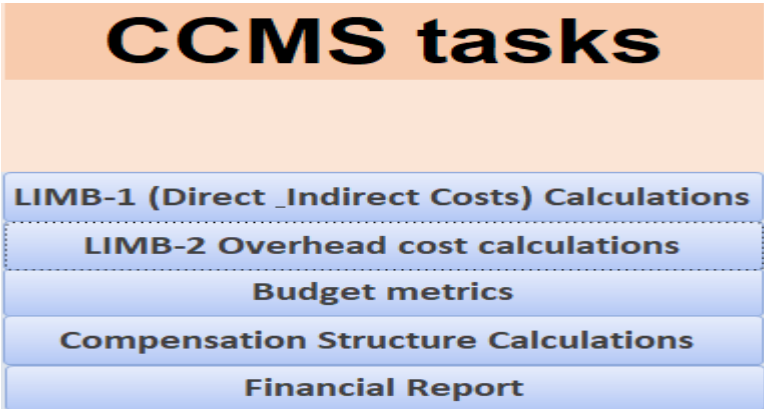


Figure 45.The user interface of the CCMS

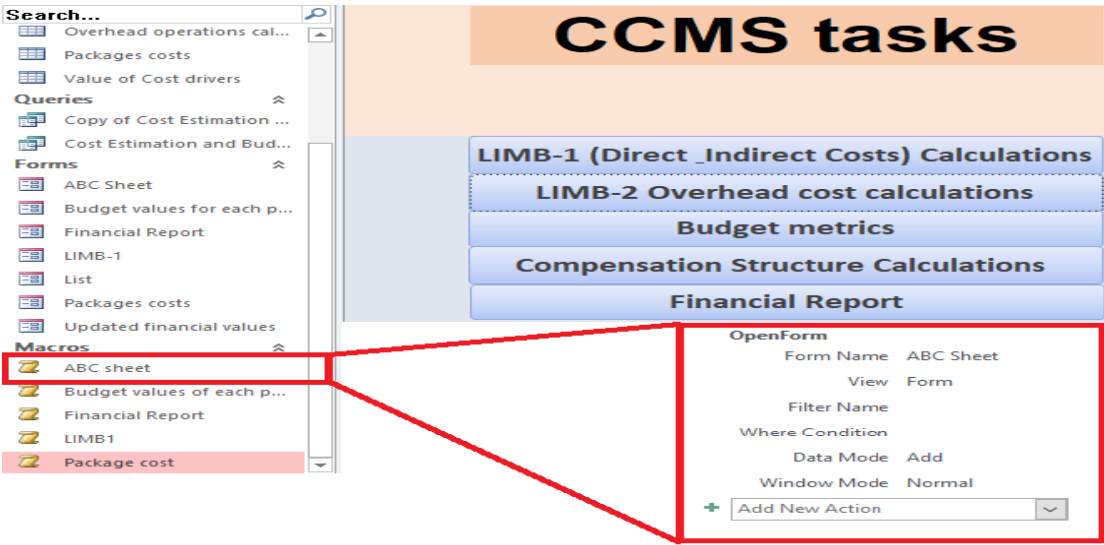


Figure 46.Snapshot of the Macro and a sample of added message to direct the users

7.2.2. Developing an Interactive Web Interface to Display the Project Data — CCMS4IPD.

The web-based management system is developed as six pages as seen in figure 47, home page includes information about the purpose and the mechanism of this platform, “about” page is designed to include information from the framework to show how the cost estimation, budgeting and control tasks are executed in the CCMS, this explanation is provided to guide IPD core team members, therefore, a source of knowledge about all the cost management tasks including the proposed risk/reward models are presented to increase the transparency and the trust among the IPD core team members.

Given that the IPD core team members can be increased such as adding new members while the project is progressing and other members could finish their works at an early stage in the construction phase, therefore, the profile of all members should be updated to facilitate the contact among project parties (see figure 47). Moreover, this will be a source of knowledge for the future collaboration since building a sustainable relationships is one of the objectives to adopt the IPD approach. The mentioned three pages are not functional pages, however, they are designed to help the users.

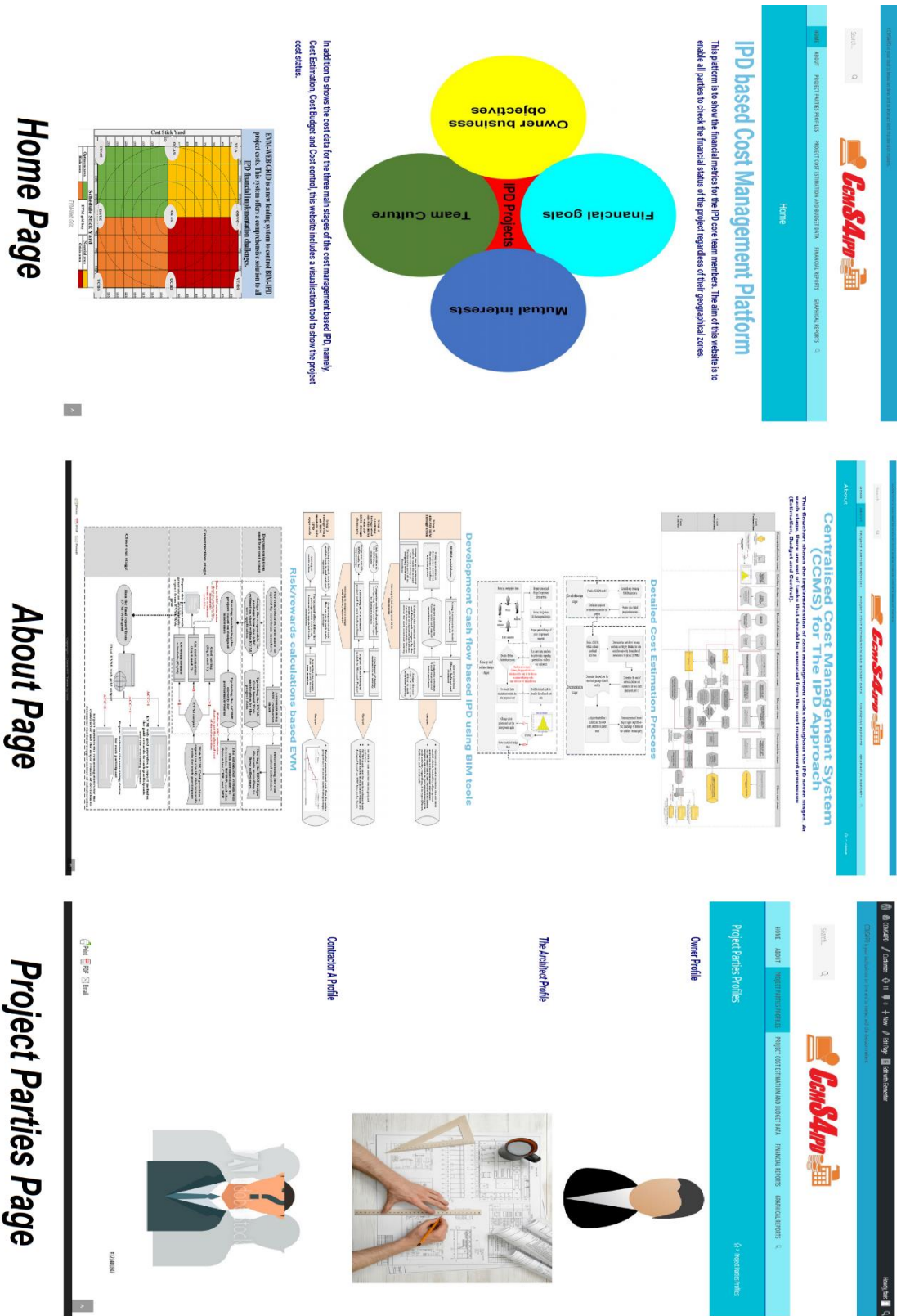


Figure 47.The CCMS4IPD non-data pages

7.2.2.1. Develop an Online Database for the CCMS4IPD

The developed database in the Microsoft Access should be linked with an online server in order to share these data as a set of web pages. Similar to the database structure in the access database (see figure 48), the similar structure is presented on the online database as seen in figure 42. Six tables are presented in figure 48, these tables represents three main processes (Cost estimation, budgeting and risk/reward sharing), these database will be only updated according to the database in the server, this means that there are no any relationships or calculated fields in the online database, it is a platform to reflect the database in the system.

Material Cost	ABC Sheet	Package costs	Financial Report
<ul style="list-style-type: none"> ID BIM_element Quantity Unit CostUnit TCFU 	<ul style="list-style-type: none"> ID Codes Activities Task_type Cost_driver Units Cost_UnitCost_driver LIIM2 Total_Cost Project_parties Overhead_Consumption_Rate Actual_Overhead_CostActivity CS9000A CS900PA TCS900C 	<ul style="list-style-type: none"> Project_parties Limit1 Overhead_consumption_rate_of_the Limit2_CTM Limit2 Limit3 Total_CostPackage Project_Compensation_Structure 	<ul style="list-style-type: none"> Entity_type CPI SPI EVO Adjusted EVO EVOProfit Actual_LIIMB1 Actual_LIIMB2 LIIMB1 LIIMB2 LIIMB3 TCS DCaboveTCS INV_for_R_or_PD_for_each_party_U P00 P010 Reward_For_Owner_LIIMB1 Reward_For_nonOwner_parties_LIIMB CS9000A CS900PA CS900C_for_NO CS900C_for_O TRA0 TRAND Reimbursed_C Profit

Figure 48. The structure of the CCMS4IPD based web system

These tables are converted as web pages in order to be embedded in the proposed web system to enable project parties to access to the data anytime with ensuring a high level of security through hiding these data from any person who does not have the authentication information, see figure 49.

Name	Records	Size	Last M
ABC_Sheet	31	48 KB	
Budget_values_for_each_party	5	16 KB	
Demo_Users	2	96 KB	
Financial_Report	3	32 KB	11
Financial_terms	0	0 Bytes	
LIMB1_Direct_and_indirect_costs	5	32 KB	
Material_Cost	0	0 Bytes	
Overhead_operations_calculations	8	32 KB	
Packages_costs	5	32 KB	04
Report	0	0 Bytes	
Updated_financial_values	0	0 Bytes	
Value_of_Cost_drivers	4	32 KB	

Converting the database to web pages to enable sharing and searching the needed data

Name	Data Source	Authentication	Deployed	Last Modified
ABC_Sheet Search and Report	ABC_Sheet	Demo - Admin Login	Enabled	08 Nov 2019 09:01 PM
Budget_values_for_each_party Search and Report	Budget_values_for_e:	Demo - Admin Login	Enabled	09 Nov 2019 10:56 PM
Financial_Report Search and Report	Financial_Report	Demo - Admin Login	Enabled	08 Nov 2019 09:01 PM
LIMB1_Direct_and_indirect_costs Search and Report	LIMB1_Direct_and_In	Demo - Admin Login	Enabled	08 Nov 2019 09:01 PM
Packages_costs Chart	Packages_costs	Demo - Admin Login	Enabled	10 Nov 2019 11:14 AM

Figure 49.The database tables and web-pages

7.2.2.2.Functional Pages of the CCMS4IPD

There are three functional pages to display and manage the cost management data including cost estimation, budget and the risk/reward for each party based the EVM outcome. The data is stored on a server (MS Access database, see figures 42 and 43) and it is linked as web pages through using a platform called (Casipo), then the data is embedded as HTML into the web page, this enables the automated update for all data without any human interference.

7.2.2.2.1. Cost Estimation and Budgeting Page-Based IPD

Figure 50 shows a snapshot of the compensation structure that presented in three forms, namely, Limb-1, ABC sheet (Limb-2), Limb-3 (P@R%). The web page is designed to enable searching in the database using different parameters such as the construction package for Limb-1, the code and project parties for Limb-2, the project parties for the Limb-3. This will enable all parties to get the data they want in a quick and organised way, regardless of their attendance to the regular IPD core team members meeting, as well as, the readability of the data is considered to allow any party from various background to understand the structure of the data. In order to ensure the privacy and credential to such sensitive data like cost/financial data, authentication information (Username and password) is required before displaying any data (See figure 50), the usernames and passwords will be similar to all members and will be given by the server demonstrator, subsequently, the user can search using one of the parameters to get the data.

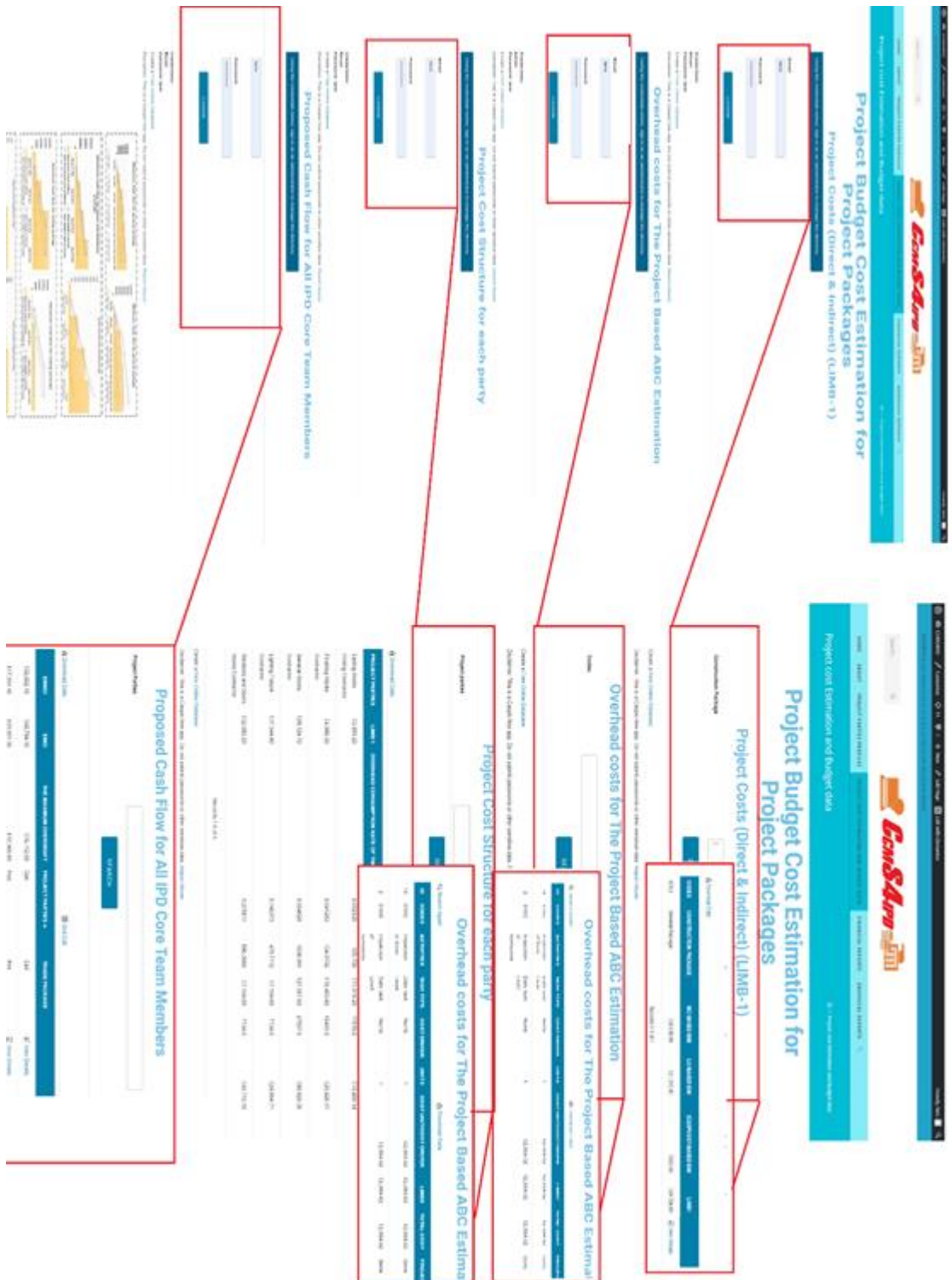


Figure 50. The cost management contents of CCMS4IPD

7.2.2.2.2. Financial reports (Sharing risk/reward) pages

Figure 51 depicts the web pages of the financial metrics of the CCMS4IPD with showing the 4D/5D BIM data. Each party can search using the name of the “Package” (i.e. General Package) to get the financial metrics for different payment milestones. The financial metrics show three main transactions (Reimbursed Costs, Cost Saving and Profit).

Given that the profit/risk should be shared regardless of the individual performance, therefore, the achieved values of the three financial transactions will be presented individually to maximise the trust and collaboration among IPD core team members without needing to attend the regular meetings and the generic values of the three transaction will be also presented to show the progress of the project, the proposed equations by Integrating ABC into EVM to develop risk/reward sharing models of the IPD are presented in the CCMS (See figure 51). The report can be retrieved after the party log-in using the shared username and password by the server manager, then the party should use the agreed packages’ names to see all achieved financial metrics for both individual parties and the accumulative of all achieved works. The parties can share their report with their employees through using the embedded feature in the webpage footer which is to email the data on the page to anyone without needing to have the authentication information.

Given, the IPD core team members come from different backgrounds, therefore, the visualisation of data could enhance the collaboration and understanding among the team. Therefore, Figure 51 shows a snapshot of the web-data page of the EVM-grid with showing the data that are used in the calculation. To ensure the security of the data, the party will be asked to provide the given username and password in order to open this web-data page. Similar to the financial report, parties are able to share the data with their employees.

The presented six web-data pages works as IPD big room that is recommended by the IPD developers to facilitate the collaboration/coordination for the large size team, particularly, when the decision is not dominant such as the IPD case. All the data regarding the cost, risk/reward values will be updated directly once it is ready, as well as, the web-based management system is designed to serve in different stages of the IPD. During the Buyout and documentation stages, the web page “Project Cost Estimation and Buyout Data”, presents the required data to make the decisions.

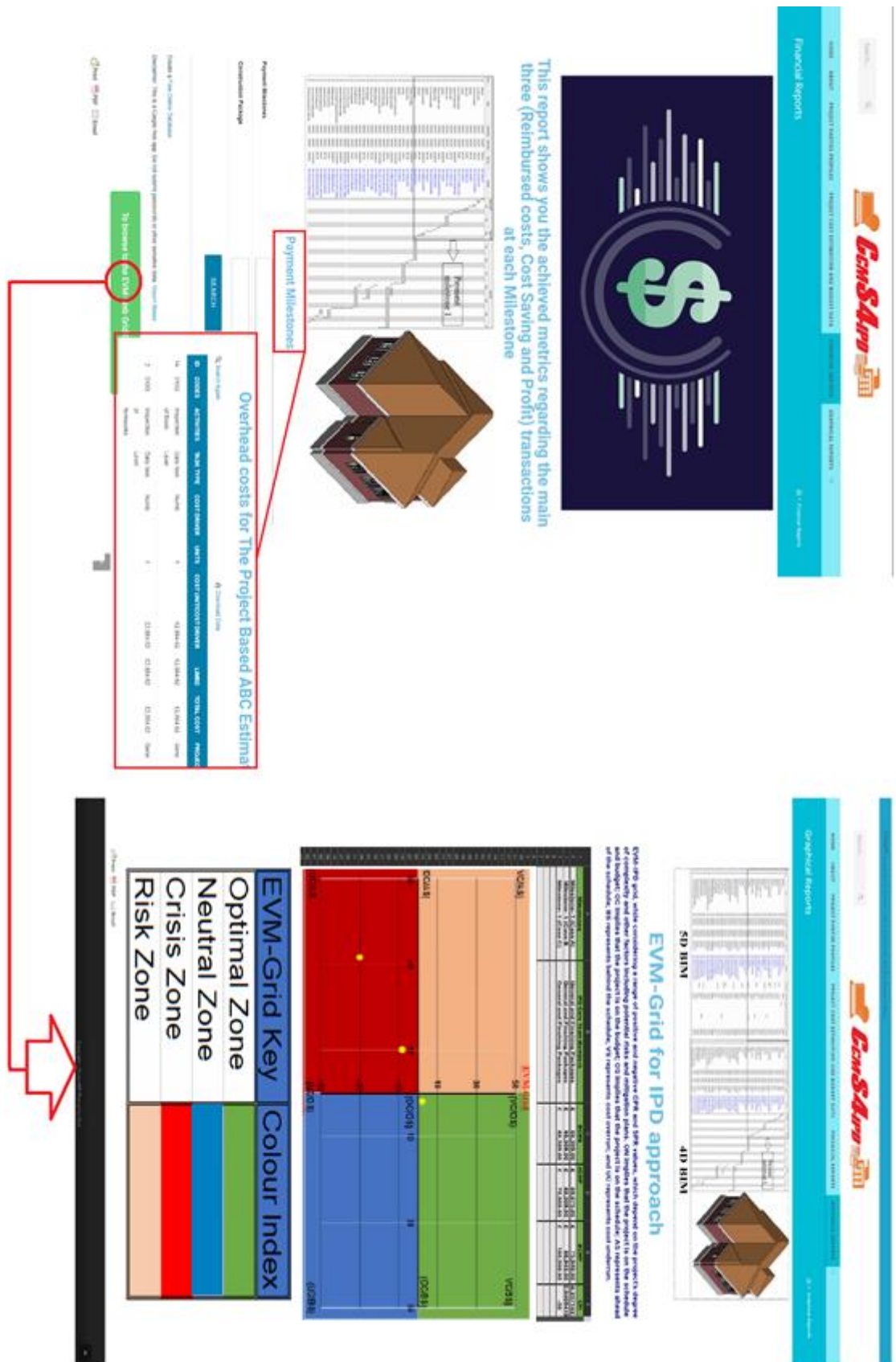


Figure 51. The financial report pages

7.2.3. Model Integration and Flow of Data through the CCMS and IPD Stages

Figure 52 shows the path of creating/sharing the data through the CCMS, the server operator has an important role to collect data from the consultancy team and utilise the designed tools such as MS Access database forms, MS Excel spreadsheets, retrieve data from 4D/5D BIM model —Determine the direct costs using 5D BIM model and the cost budget through integrating 4D/5D BIM models—, managing the data in the web-based management system, as well as, facilitating the interaction among the IPD core team members.

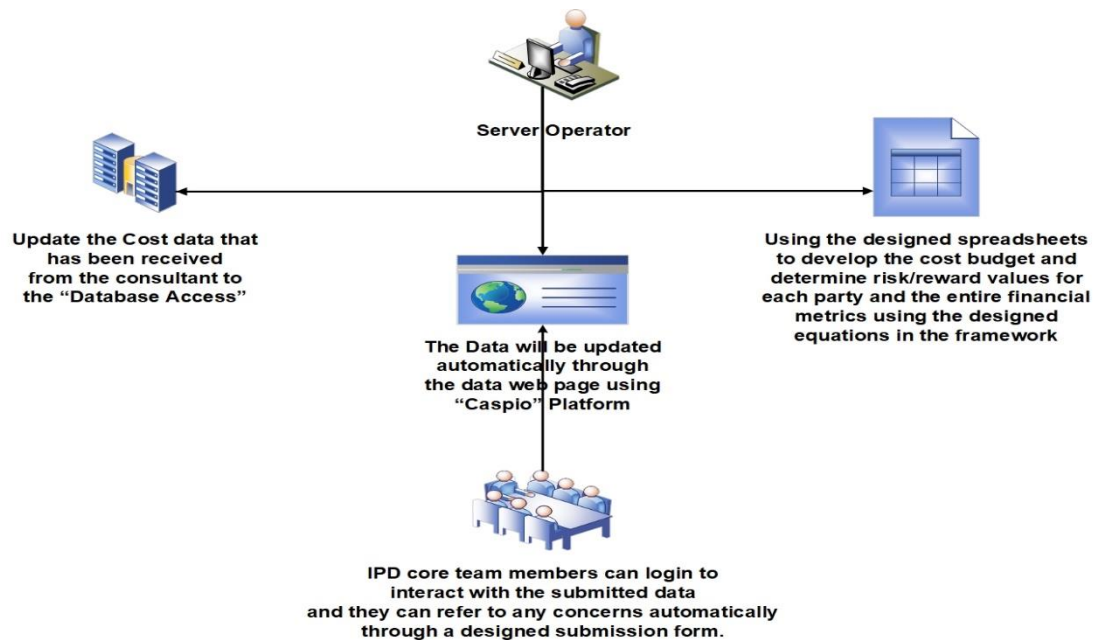


Figure 52. The path of creating data within the CCMS

The flow of data in the proposed model will be from the documentation and the buyout stage to the closeout 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 51. The steps, shown in Figure 50 and 51, 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 scheduled (BCWS). Afterwards, the progress data will be updated on the server and lively used in generating the milestone report (See Figure 51).
- For the closeout 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 closeout stage.

7.2.4. The Decentralised Cost Management System (DCMS) of IPD using the Blockchain Technology

7.2.4.1. The Permissioned Blockchain Web-Based IPD

In developing the proof of concept, Figure 53 illustrates the main ten steps to create a blockchain network using IBM blockchain platform Beta 2 – released recently. This IBM Beta platform can enable enterprises to develop and extend their networks, when the enterprise intends to use the network as an ongoing practice. The IPD-based blockchain proof of concept is developed based on the hyperledger fabric as discussed – mentioned in the development of the framework section. The hyperledger fabric includes specific components: Certificate Authorisation (CA), Member Service Provider (MSP), peers and channels, where each peer (project party) needs to have a CA as well as MSP to identify its presence in the network. The channel role is to move the information (transaction) to a set of peers (project parties) according to an agreed endorsement policy. For instance, a client should have all the information regarding reimbursed cost, profit and cost saving for all participants. And the client peer should be selected when instantiating the smart contract. The architect team is responsible to develop the network and then all other participants (i.e. contractors and trade contractors) can join the network. Figure 53 represents a map to direct developing a blockchain network to automate financial transactions in the construction industry, all processes are accompanied by adequate details to clarify the nature of each step and who the responsible party is for each one.

Smart contracts should be written in specific algorithms. The IBM VSCode extension for blockchain is used to write all proposed functions. Therefore, each party should invoke the three transactions and each payment milestone to update the hyperledger fabric network.

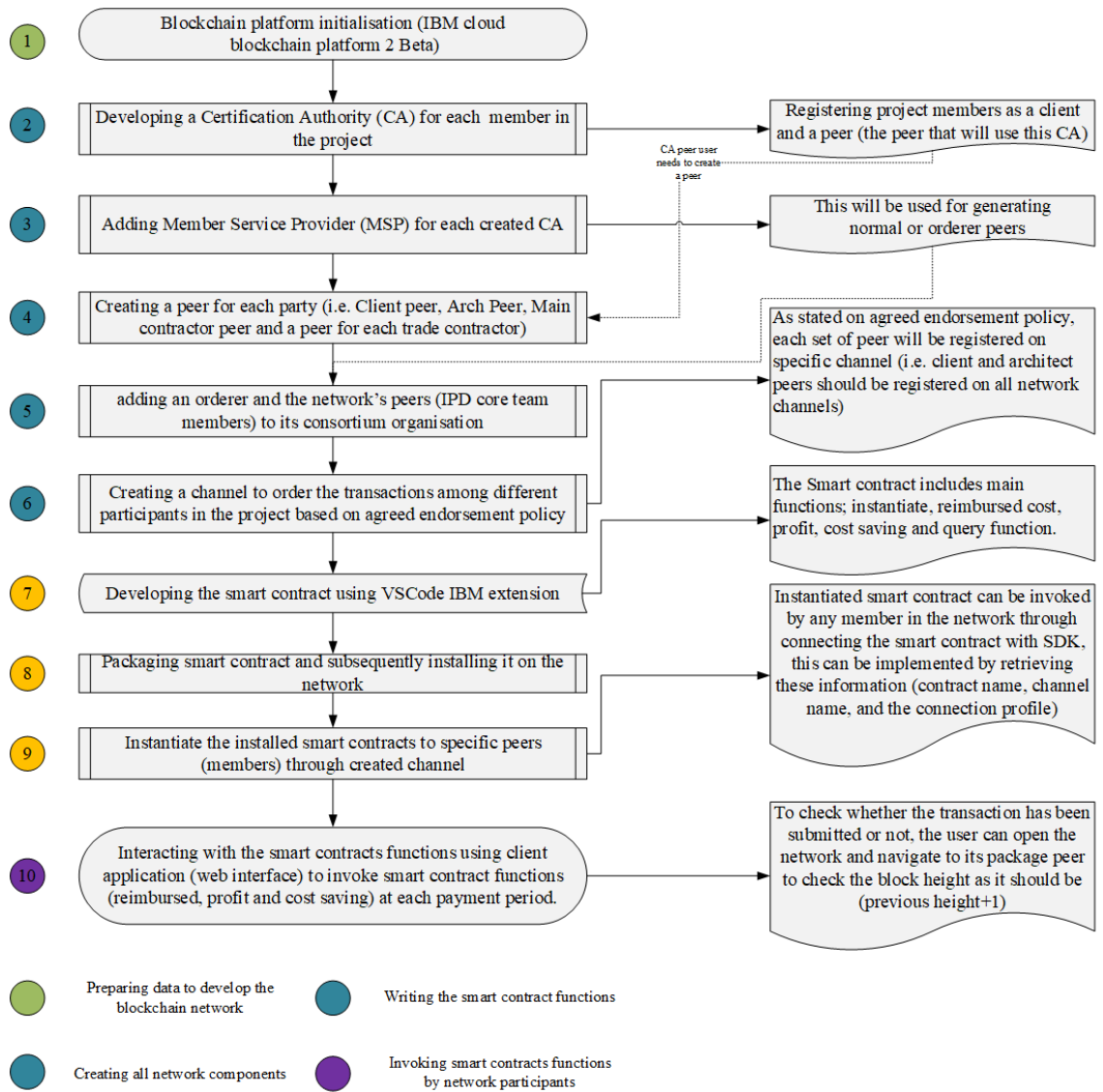


Figure 53. The logic of the proposed “Proof of Concept” blockchain based IPD framework

7.2.4.2. A Case Study to build a blockchain network (More Details for the Case Study is presented in Section 7.3)

A property development company decides to build a compound of 100 identical houses. The specification of each house is as follows: (1) the gross floor area is about 192 m²; (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 robe room, three bedrooms, large living room, kitchen, dining room, another bathroom, family room and utility room.

The project works are categorised into five trade packages (general works, ceiling, lighting fixture, finishing, and doors and windows). The client intends to use IPD for delivering the project. In forming the core project team, an architectural firm and five trade contractors are appointed to create the project's core group, those trade contractors are also involved in the core group to obtain the required information during kick-off meetings. The blockchain network should include all IPD core team members (Client, five contractors and the consultant).

7.2.4.3.The Blockchain Network: IBM Blockchain Beta 2

As illustrated in Figure 54, there are seven participants in the case project and those will be network members, subsequently each party should be represented by a peer. In order to create a peer, two main components should be created beforehand, these components are Certification Authority (CA) and Member Service Provider (MSP). Figure 54 shows a CA for each party and one for the orderer peer. This network is developed for a project that includes seven members in its core team: client, architect, main contractor, and other four trade contractors (doors and windows, finishing works, ceiling works, and lighting fixture works).

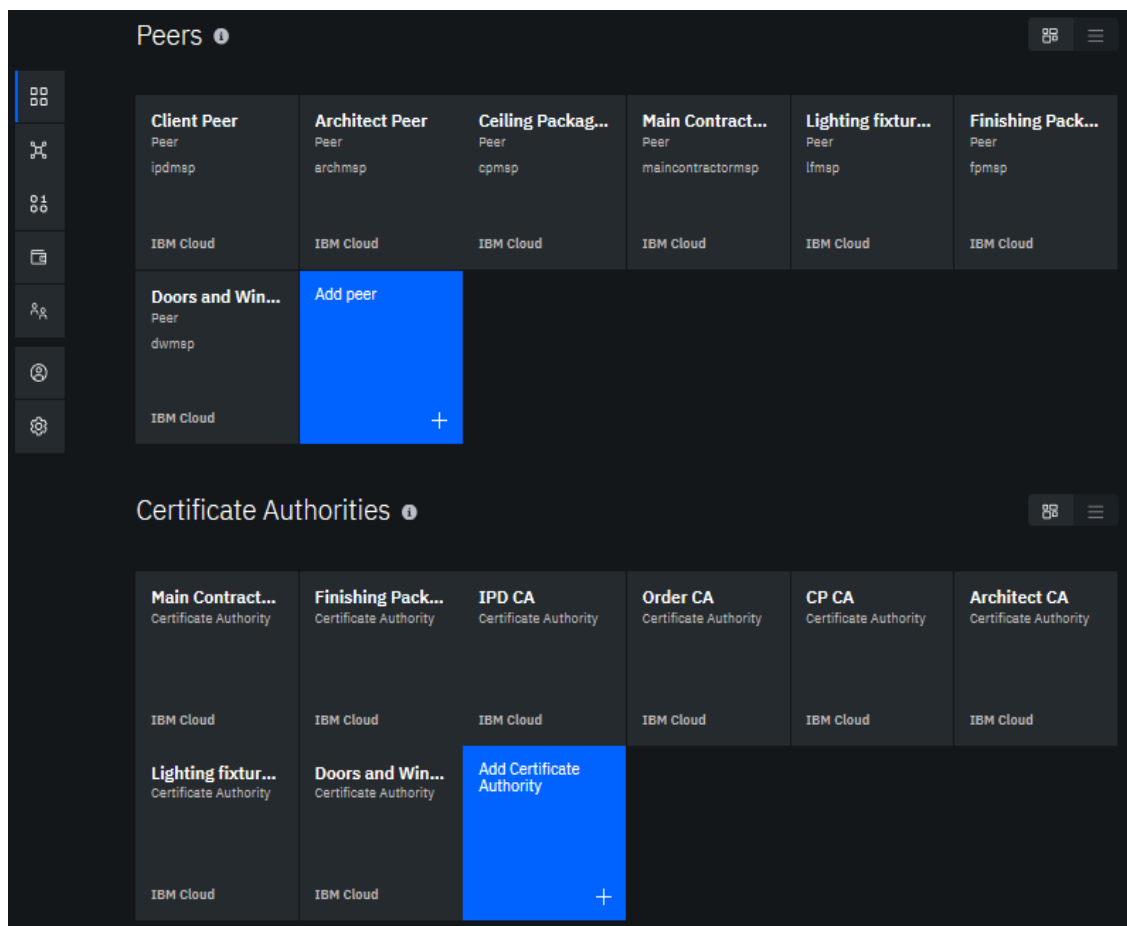


Figure 54.The developed blockchain network based on IPD

Figure 55 illustrates the IPD core team's organisations, where each participant is identified by a distinct MSP. This is also used to validate the identity of network members. That is, when data are sent from any party to others, the receivers are identified through

their MSP as shown in Figure 55 for the presented case project. The orderer here works as a node in the network, therefore, a MSP should be presented in the organisation list (see Figure 55).

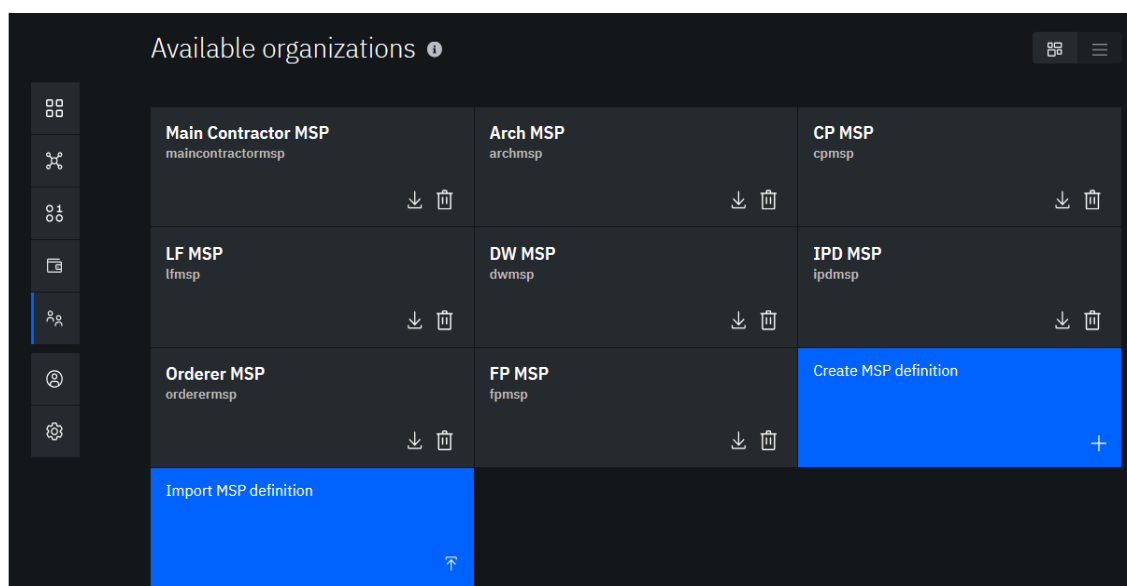


Figure 55.The MSP for the organisation members

As discussed, channel is a main part in the blockchain network, used to move the data between network parties. Figure 56 shows the channel for an IPD project case which is called “ipdchannel” and its members is provided in order to identify the path of the data when any function is invoked to record any new data on the network, as well as, specifying which parties should receive this data. In IPD projects, all core team members should receive the same amount of data in the same sequence. Therefore, all parties should be listed, as illustrated in Figure 56.

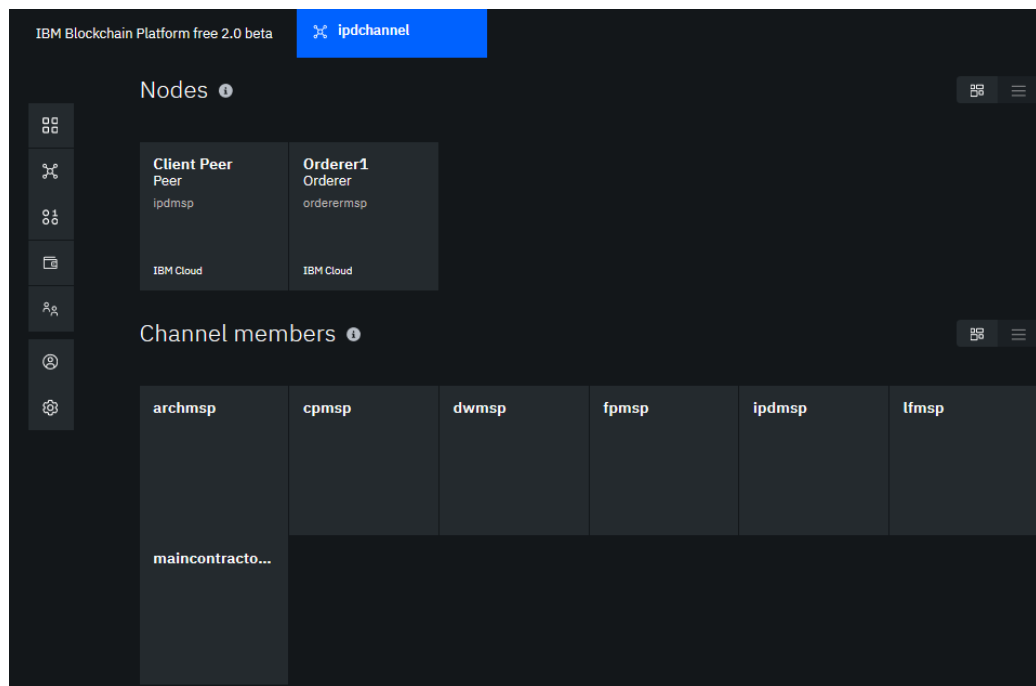


Figure 56.Creating a channel to assign the data to the network participants

7.2.4.4.The Smart Contract Based On IPD Financial Terms

As discussed, the IBM VSCode extension is used in building smart contract (chaincode) functions, packaging it and subsequently, installing and instantiating it to the specific channel and peer. As proposed in the framework (see Figure 39), the chaincode should include substantial functions such as instantiate and query function. The user can add more functions to govern the purpose of the chaincode.

In the prototype presented here, four functions are added to perform the proposed purpose of the framework – recording all project transactions and keeping it from any possible amendments. Figure 9 shows the used functions: (1) the add participants; (2) cost saving; (3) reimbursed costs; (4) profit.

All financial transactions are defined through specific parameters like who the sender is, the trade package, payment milestone and the value of this transaction (see Figure 57).

```

project1 > lib > JS my-contract.js > ...
1  'use strict';
2
3  const { Contract } = require('fabric-contract-api');
4
5  class MyContract extends Contract {
6
7      //update ledger with a greeting
8      async instantiate(ctx) {
9          let greeting = { text: 'Instantiate was called!' };
10         await ctx.stub.putState('GREETING', Buffer.from(JSON.stringify(greeting)));
11     }
12
13     //add a member along with their email, name, address, and number
14     async addMember(ctx, email, name, address, phoneNumber) {
15         let member = {
16             name: name,
17             address: address,
18             number: phoneNumber,
19             email: email
20         };
21         await ctx.stub.putState(email, Buffer.from(JSON.stringify(member)));
22         return JSON.stringify(member);
23     }
24
25     async Reimbursedcosts(ctx, sender, milestone, value, package) {
26         let member = {
27             sender: sender,
28             milestone: milestone,
29             value: value,
30             package: package
31         };
32         await ctx.stub.putState(sender, Buffer.from(JSON.stringify(member)));
33         return JSON.stringify(member);
34     }
35
36     async profit(ctx, sender, milestone, value, package) {
37         let member = {
38             sender: sender,
39             milestone: milestone,
40             value: value,
41             package: package
42         };
43         await ctx.stub.putState(sender, Buffer.from(JSON.stringify(member)));
44         return JSON.stringify(member);
45     }
46     // look up data by key
47     async costsaving(ctx, sender, milestone, value, package) {
48         let member = {
49             sender: sender,
50             milestone: milestone,
51             value: value,
52             package: package
53         };
54         await ctx.stub.putState(sender, Buffer.from(JSON.stringify(member)));
55         return JSON.stringify(member);
56     }
57
58     // look up data by key
59     async query(ctx, key) {
60         console.info('querying for key: ' + key );
61         let returnAsBytes = await ctx.stub.getState(key);
62         let result = JSON.parse(returnAsBytes);
63         return JSON.stringify(result);
64     }
65 }
66
67 module.exports = MyContract;

```

Figure 57. Snapshot of the developed chaincode based on IPD financial transactions

7.2.4.5.Smart Contracts on the Blockchain Network

After developing the chaincode, any party can invoke one of the transactions in accordance with the agreed upon endorsement policies. Figure 58 illustrates the installed smart contract that includes the proposed functions. The smart contract should be uploaded to the smart contract panel in the network and the endorsement policies as stated in the development of framework section, subsequently, the uploaded smart contract should be installed and instantiated in all peers (project parties). Subsequently, project parties can invoke the four main functions (reimbursed costs, profit, saving, and query) at each payment milestone. The invoking can be executed through a web-based application for providing easy access for all participants, regardless of their technical skills and capabilities.

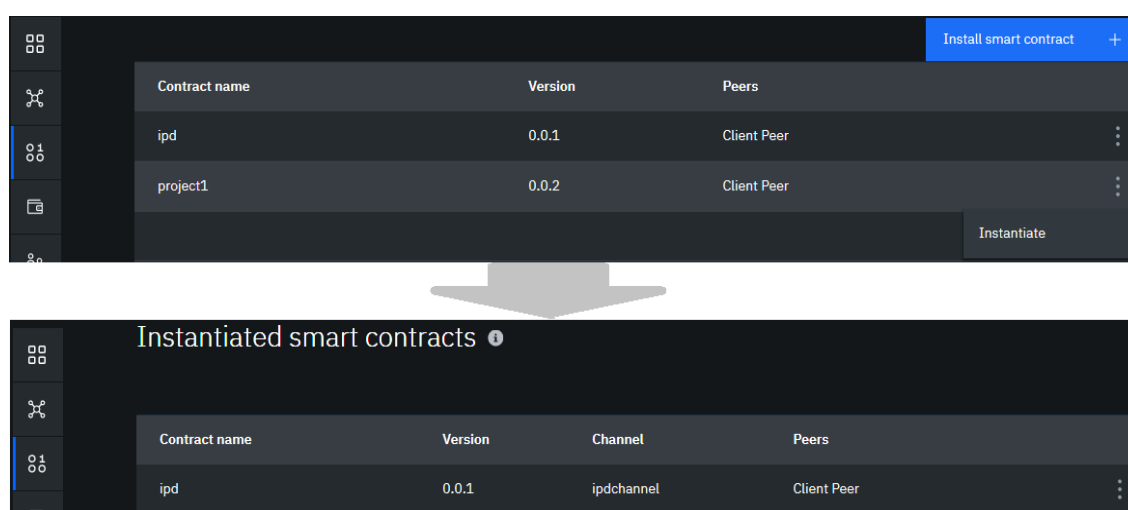


Figure 58.Snapshot of installing and instantiating smart contracts on blockchain-IPD network

By the end of IPD project, any party can invoke the query function in order to estimate the recorded amount of money in each pool (reimbursed cost, profit and cost saving). This can facilitate the rate of IPD adoption, given that the main barrier is the lack of trust in sharing risk/reward. This will be addressed with implementing blockchain, particularly

hyperledger fabric – the blockchain for business networks. With this, all participants can have the equal opportunity to track all financial transactions, regardless of their geographical locations.

7.3.A PRACTICAL CASE—AN ILLUSTRATIVE CASE STUDY

A property development company decides to build a compound of 100 identical houses. The specification of each house is as follows: (1) the gross floor area is about 192 m²; (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 robe room, three bedrooms, large living room, kitchen, dining room, another bathroom, family room and utility room (See appendix E for more information about the 3D BIM model of a sample house and extracted lists of schedules).

The project works are categorised into five trade packages (general works, and ceiling, lighting fixture, finishing, and doors and windows packages). The client intends to use IPD for delivering the project. In forming the core project team, an architectural firm and five trade contractors are appointed to build the project's core group, as well as involving trade contractors to obtain the required information during kick-off meetings. As discussed, the IPD approach relies on sharing the benefits and risks; hence, it is important to determine all expenses and costs and assign them to specific activities.

Given that the company decided to deliver the project using IPD and BIM. Since the tender stage is not applied in IPD approach, therefore, it is replaced by buyout stage, which relies on open pricing technique. Thereby, the cash flow analysis should be designed for this purpose, the estimated cash flow, especially cash-in should be presented as estimated maximum curve, which is the LIMB 3 limit and estimated minimum curve, which is the LIMB 1 limit. Since the literature review justified that BIM tools are necessary for successful delivery of projects within IPD approach, 4D/5D BIM data will be utilised in this case study.

During documentation and buyout stage, the BIM team is responsible to develop 4D/5D BIM to prepare the project budget before emerging project parties' negotiation regarding

profit at risk percentage and the decision in IPD approach is individual as the relationships are direct among all core team members.

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, existing IPD model the owner does not get any proportion from P@R%, however, 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 was £ 228,581.9.

The proposed cost management system will be applied to this case study, all calculations will be presented for a house since they are identical 100 houses as mentioned.

7.3.1. Cost Estimation

7.3.1.1. Initial Cost Estimation at Outline Design Stage

The graphs in Figure 59 illustrate the total material and labour costs and were prepared by a Monte Carlo simulation after the cost data were collected by the IPD core team's quantity surveyor, with beta distribution used to distribute these cost elements. The output from this process is the total costs graph, showing how the total cost corresponds to a specific certainty percentage. Moreover, the sensitivity analysis charts reveal the impacts of each cost element in the project, thus determining each element's importance in the detailed design stage and the execution process. The client makes decisions based on these outputs and, if the client accepts the solution, the project progresses to the detailed design stage. If the client does not accept the solution, the client/quantity surveyor can alter the requirements by changing the cost elements and repeating the process.

In the case project, the decision-making scope reveals that the cost will be almost £103,000, while the actual case study states that the direct and indirect costs total £118,484. The deviation between the decision-making scope and the precise cost estimation is about 12%: this level of deviation is more acceptable at the feasibility study and budget authorisation stages, in accordance with class 3 of the cost estimate classification matrix developed by Amos (2004), with this class accepting a deviation below detailed estimation of from -10% to -20%.

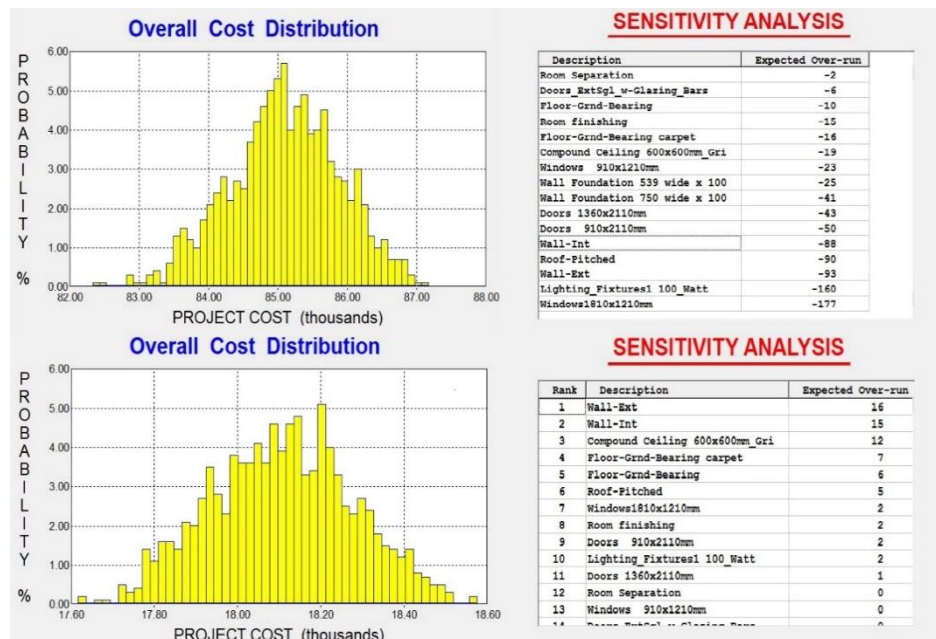


Figure 59.Total material and labour costs prepared by Monte Carlo simulation

7.3.1.2. Cost Estimation during Detailed Design Stage

After finalising the 3D BIM model, the estimator begins to use this model for detailed cost estimation by importing it to a 5D BIM platform to extract the quantities and move to the pricing stage. Based on the agreed-upon length of the contract, the overhead resources are determined to enable the costing process. The proposed resources and those resources needed to perform each activity are presented in figure 60, it is a snapshot from the CCMS.

	ID	Function	Salary	Overhead Activity
+	1	Quantity Surveyor	£12,000.00	Cost control
+	2	Quality control engineer	£9,000.00	Inspection
+	3	Quality assurance engin	£9,000.00	Inspection
+	4	Accountant	£7,500.00	Cost control
+	5	Project manager	£12,000.00	Inspection
+	6	Site engineer	£9,000.00	Setting out
+	7	Supervisor	£7,500.00	Inspection
+	8	Warehouse manager	£6,000.00	Mobilising
*	(New)		£0.00	
	Total		£72,000.00	

Figure 60.Organisation overhead costs (ABC estimation)

Therefore, the cost drivers can be determined as the total cost of each operation is divided by the number of operations (activities) in the project (see figure 61 below for details, it is a snapshot from the CCMS).

Overhead Activity ▾	Number of needed processes ▾	Value of overhead resources ▾	Value of overhead activity ▾
⊕ Cost control	6	£19,500.00	£3,250.00
⊕ Inspection	13	£37,500.00	£2,884.62
⊕ Mobilising	6	£6,000.00	£1,000.00
⊕ Setting out	6	£9,000.00	£1,500.00
*	0	£0.00	

Figure 61.Cost drivers of overhead operations

- Calculations of cost drivers/ cost units

The inspection process requires a quality control engineer, quality assurance engineer, supervisor and a project manager. In total, 13 inspection activities are needed during the project. The mobilisation process occurs six times during the project, with the warehouse manager assigned this responsibility. Cost control needs a quantity surveyor and an accountant and is run six times during project execution. Setting out is run six times during the project, with the site engineer having responsibility for its implementation. The outcome of the ABC sheet from the CCMS is presented in figure 62.

ID	Codes	Activities	Task type	Cost driver	Units	Cost unit	LMB2	Total Cost	Project parties	Overhead Costs	Actual One	CS00A	CS00PA	TCS00C	OTCS00C
+	1 010G	Setting out	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	2 010G	Inspection of formworks	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	3 010G	Inspection of rebar works	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	4 020G	Inspection of foundation batch	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	5 010G	Setting out walls	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	6 020G	Inspection of masonry works	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	7 010F	Setting out separation of rooms	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	8 020F	Mobilese material	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	9 010F	Inspection of separation of rooms	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	10 020G	Mobilese roof material	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	11 010G	Setting-out	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	12 020G	Inspection roof package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	13 010G	Setting out of floors	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	14 010G	Inspection of floors	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	15 030G	Cost control report for general works	Package Level	Proportion of the Pack	1	£3,250.00	£3,250.00	£3,250.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	16 020MD	Mobilese windows and doors	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Windows & Doors Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	17 020MD	Inspection of D&V package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Windows & Doors Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	18 030MD	Cost control report for D&V works	Core Team Level	Proportion of the Pack	1	£3,250.00	£3,250.00	£3,250.00	Windows & Doors Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	19 020C	Mobilese ceiling material	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	20 010C	Setting out of ceiling	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	21 010C	Inspection of the ceiling grids	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	22 020LF	Mobilese lighting fixtures	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Lighting Fixture Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	23 020LF	Inspection of the ceiling package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Lighting Fixture Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	24 030C	Cost control report for ceiling works	Core Team Level	Proportion of the Pack	1	£3,250.00	£3,250.00	£3,250.00	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	25 020LF	Inspection of the lighting fixture package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Lighting Fixture Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	26 030LF	Cost control report for lighting and fixture w	Core Team Level	Proportion of the Pack	1	£3,250.00	£3,250.00	£3,250.00	Lighting Fixture Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	27 020F	Mobilese finishing works	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	28 010F	Inspection of the floor carpet	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	29 010F	Inspection of the paint work	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	30 030F	Cost control report for finishing package	Core Team Level	Proportion of the Pack	1	£3,250.00	£3,250.00	£3,250.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	31 40	Final cost control report for the entire work	Core Team Level	Number of Reports	1	£3,250.00	£3,250.00	£3,250.00	Architect/Consultant Ceiling Pack	0	£0.00	£0.00	£0.00	£0.00	£0.00
+	(New)				0	£0.00				0					
+	Total					£72,000.00	£72,000.00	£72,000.00			£0.00	£0.00	£0.00	£0.00	£0.00

Figure 62.The ABC cost structure of the case study

7.3.1.3.Integrated Project Delivery (IPD) Cost Structure

With the extracted quantities priced, material costs are ready and the summary of each trade package's materials are presented, as illustrated in Table 12. Moreover, other labour and equipment resources are determined using the same MS Excel spreadsheet, as summarised in Table 12. Limb 1 is thus ready and the estimator should move to Limb 2 which pertains to overhead costs. Table 12 summarises both the cost estimation approaches, namely, the traditional costing system and the use of ABC estimation to validate the significance of the developed framework in presenting reliable cost estimation in the detailed design stage. The outcome from the CCMS of the compensation structure is presented in appendix f.

Table 12.Compensation structure components

Table sections	Construction packages	General £	Ceiling £	Lighting fixture £	Finishing £	Doors and windows £
Limb 1 for traditional and proposed estimation methods	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

Limbs 2 and 3 for traditional cost estimation	Total direct and indirect costs (Limb 1)	59,724.7	3,855.2	17,334.4	4,888.3	32,682.2
	Proportion of overhead costs	0.533	0.031	0.138	0.039	0.260
	Total overhead/pack age (Limb 2)	38,377	2,206	9,919	2,797	18,701
	Total costs	98,102	6,061	27,253	7,685	51,383
Limbs 2 and 3 for the proposed ABC estimation method	Profit-at-risk limit (Limb 3)	19,620.4	1212.2	5450.6	1537	10276.6
	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

With the cost of each package as shown in Table 13, the total project cost is £190,484. The overhead costs represent about 37.8% of the total costs: this requires a very precise allocation so the actual target cost for each package can be determined and the package can be sold to the buyer at a fair price. Moreover, when the project is completed, the project parties need to know whether each package has achieved cost savings or not, and to be able to determine the percentage of cost savings so the reward can be allocated fairly between the project parties. Each package includes various activities which have different expenditure on overhead costs from one package to the next. For instance, the concrete package needs to be inspected three times: after the formwork, the rebar and the concreting. In contrast, the doors and windows package only needs one inspection to ensure that the installation is according to the requirements and so the package can be delivered to the main contractor. Moreover, if any other package depends on the completion of this specific package, a delivery inspection is also needed.

- **Comparison between IPD estimation based ABC and traditional estimation**

As can be seen in Figure 63, Limb 1 is similar in both the traditional method and ABC estimation. However, the overhead cost differs between these two methods. The fluctuation percentage between ABC estimation and traditional cost estimation is higher than 100% in the finishing package due to this package requires many overhead activities to be executed, given that the case study project is relatively small with a limited number of activities, with the lowest level being 8% fluctuation in the lighting fixture package.

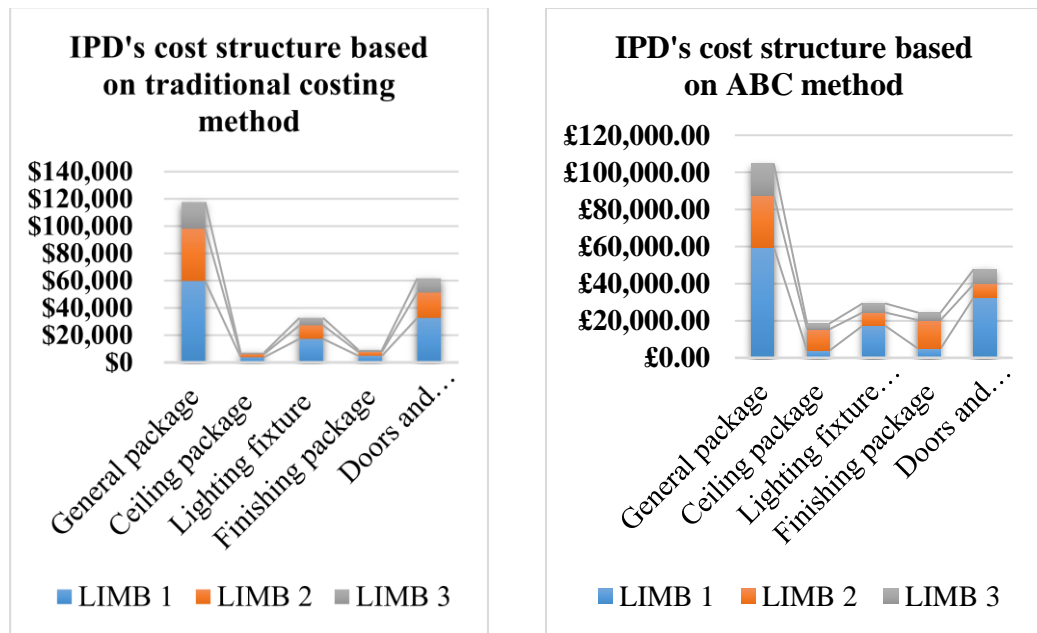


Figure 63.IPD cost structure using two costing methods

Figure 64 illustrates all deviations between using ABC estimation and traditional cost estimation for each package. To validate the significance of integrating ABC into IPD using BIM capabilities, Figure 64 reveals that the deviation for Limb 3 values (the profit-at-risk percentage) has been elevated by £2521.42 for the finishing package, which is more than twice the value in the traditional method. However, other packages have decreased in value, such as the doors and windows package which is 22% lower than when traditional cost estimation was used.

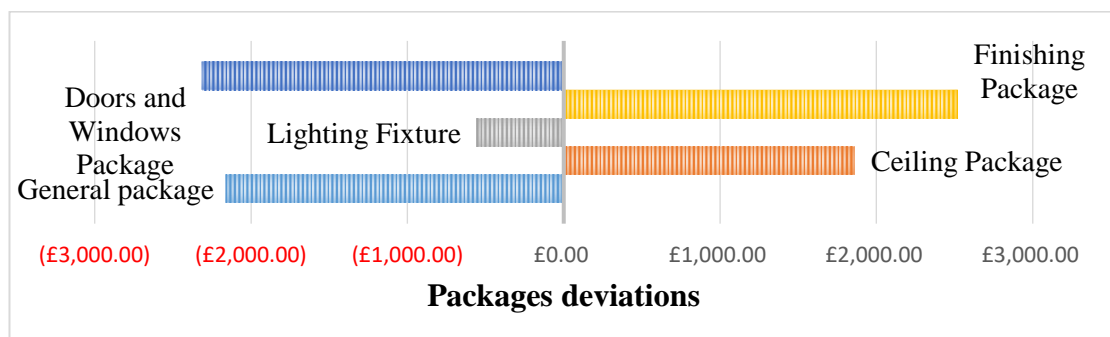


Figure 64.Deviations between ABC estimation and traditional estimation for each package

In their study, Ballard et al. (2015b) set out to identify the factors leading to the failure of risks/reward sharing, with this research undertaken as a case study that comprised a 250,000 ft² patient care pavilion. The findings referred to cost overrun as the main reason, with the completed project having a cost overrun of almost 6.4% more than what had been planned; subsequently, the risk pool firms did not receive any profit. To reflect that case study's conclusion in the findings of the current research, the scrutiny of continuous cost estimation is vital to reveal any potential cost overrun at an early stage. If this is done, the source of the overrun can be defined with appropriate corrective action taken. Accurate cost estimation, as well as better allocation of resources among core project team members, can improve project implementation, thus preparing high-level evidence to prove any increase or reduction in cost. This requires a cost estimation method that can distinguish between all the different elements in the cost structure (i.e. direct, indirect and overhead costs).

- **The level of contribution based on the ABC hierarchy level:**

The below table 13 shows the percentage of contribution to each overhead hierarchy level from the core team member to the daily task level.

Table 13.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 figure 65, daily task level represents the maximum contribution by 37.5%, this reflect the importance of 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-contractors management.

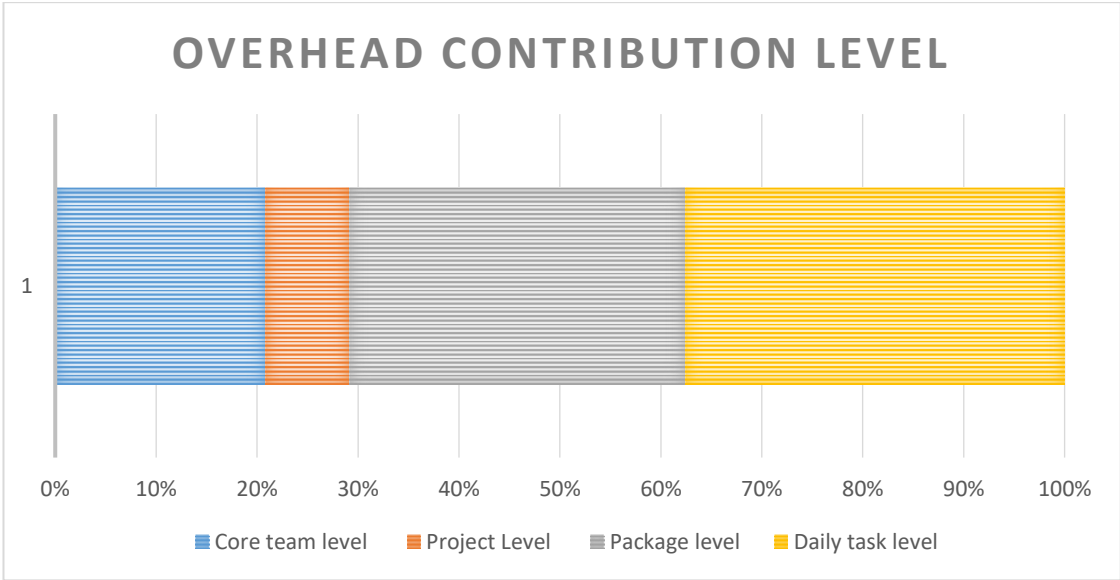


Figure 65.The overhead contribution level between all participants

7.3.1.4.Web-Applications of the Cost Estimation Based CCMS4IPD

Figure 66 shows snapshots of retrieving cost data from the CCMS4IPD web system. To enable parties to understand how the compensation structure is articulated properly, the system allows to them to search data for each limb separately, for example, the first snapshot in figure 66 depicts the direct and indirect cost of the general works package (LIMB-1), the second snapshot shows the overhead costs for the code ‘010G’, which, means the overhead activities of general works package, particularly, the daily task level (LIMB-2). The third snapshot shows the compensation structure of the project five

packages. All the data can be shared and printed by clicking on ‘view details’ button. As well as, the entire data in the page can be emailed using an embedded features on the bottom of the each web page.

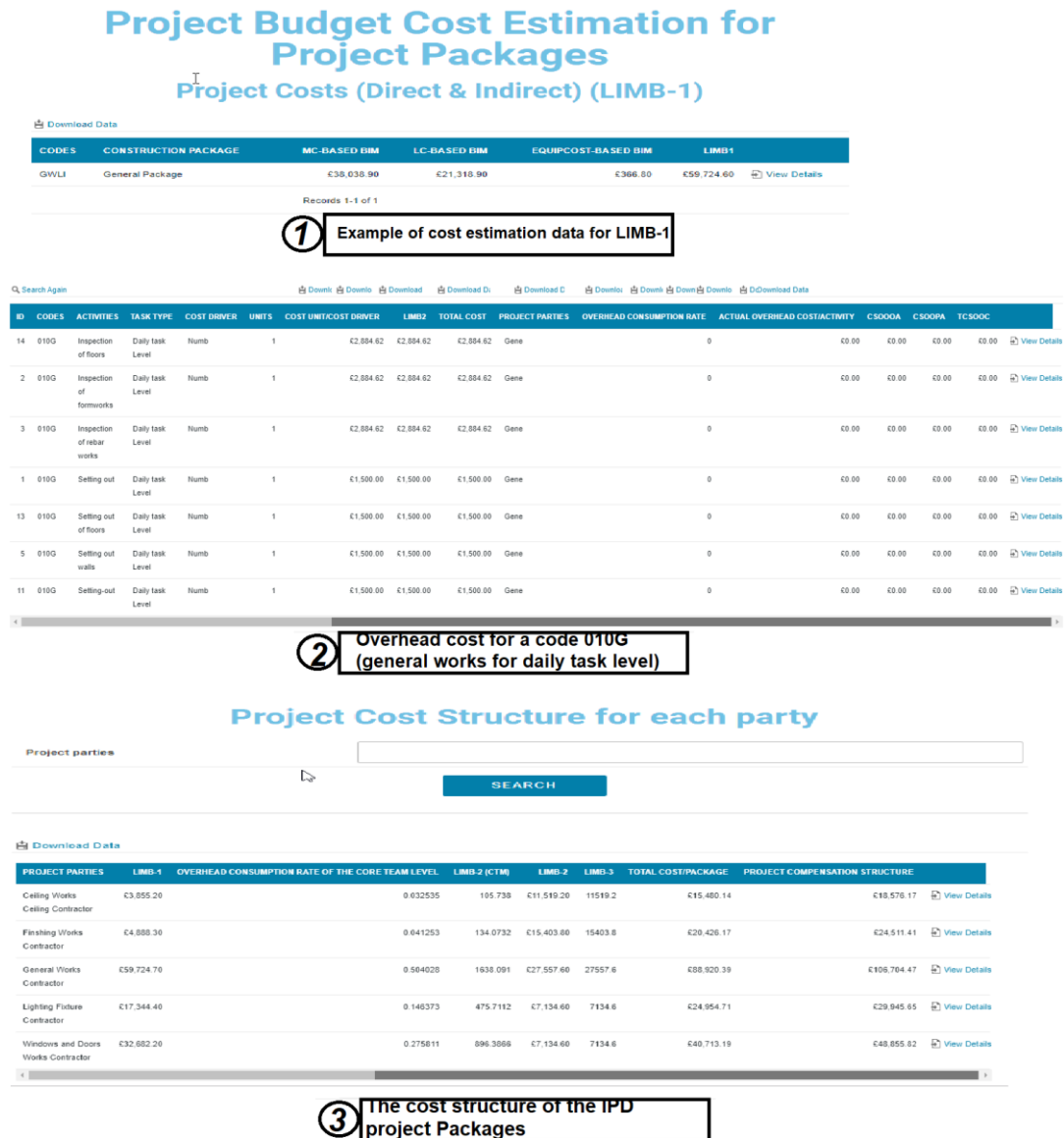


Figure 66. Snapshots of the cost estimation data from the CCMS4IPD web system

7.3.2. Buyout Stage (Cash Flow)

Refer to the framework part that discussed the integration of 4D and 5D BIM to develop a cost budget plan for the IPD approach, in this sub-section, the applicability of the proposed methodology framework is presented using the same case study context.

7.3.2.1.Step 1: 4D/5D Creation and Integration

As aforementioned, the 4D/5D BIM model should be developed at documentation stage. Figure 67 illustrates the project timeline, which was developed using BIM Navisworks platform, and to support the interoperability, a 5D BIM model was developed using the same platform. Figure 68 displays the allocation of project costs such as; material, labour, equipment, and subcontractor costs. As the ABC has been chosen to estimate project costs, the costs have been assigned to the project activities, and the developed timeline included overhead activities for each trade packages to ensure the cost structure of each package is properly estimated before emerging buyout stage. As stated in the literature review, the traditional cost estimation does not comply with IPD structure, as it relies on proportional overhead allocation, which could cause cost structure distortion and lead to misleading project pricing.

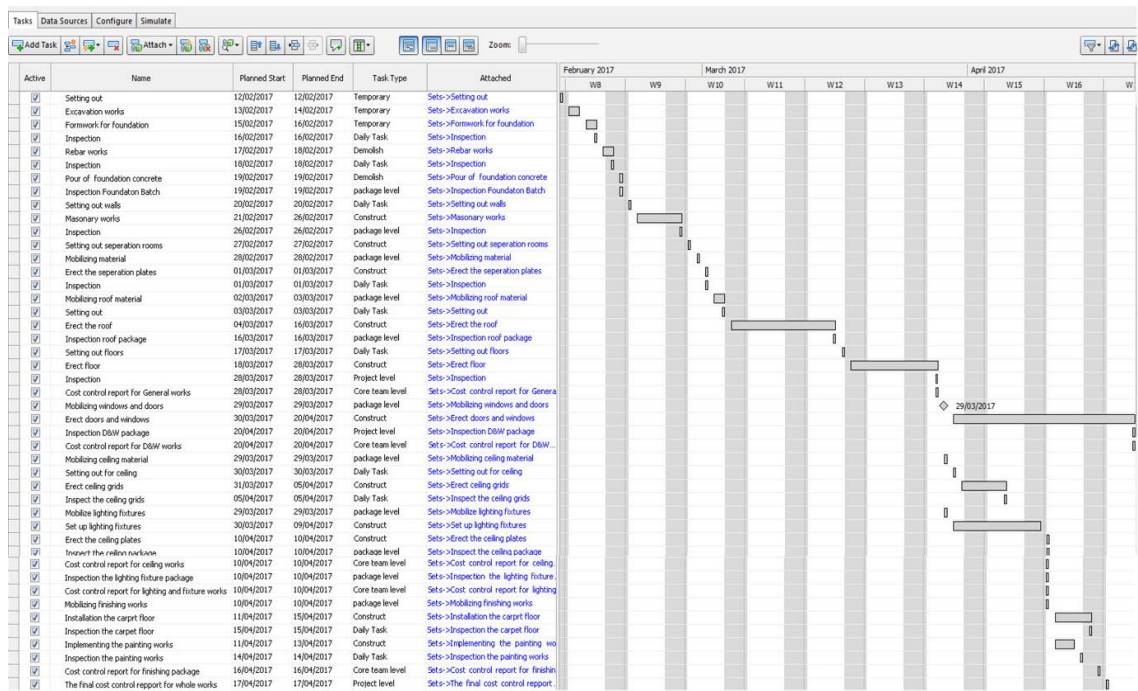


Figure 67.4D BIM - Navisworks Platform

Active	Name	Status	Planned Start	Planned End	Task Type	Attached	Material Cost	Labor Cost	Equipment Cost	Subcontractor Cost	Total Cost
<input checked="" type="checkbox"/>	Setting out		12/02/2017	12/02/2017	Temporary	Sets->Setting out		1,500.00			1,500.00
<input checked="" type="checkbox"/>	Excavation works		13/02/2017	14/02/2017	Temporary	Sets->Excavation works			366.81		366.81
<input checked="" type="checkbox"/>	Formwork for Foundation		15/02/2017	16/02/2017	Temporary	Sets->Formwork for Foundation	770.62	2,371.89			3,142.52
<input checked="" type="checkbox"/>	Inspection		16/02/2017	16/02/2017	Daily Task	Sets->Inspection		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Rebar works		17/02/2017	18/02/2017	Demolish	Sets->Rebar works	4,623.73	3,162.53			7,786.26
<input checked="" type="checkbox"/>	Inspection		18/02/2017	18/02/2017	Daily Task	Sets->Inspection		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Pour of Foundation concrete		19/02/2017	19/02/2017	Demolish	Sets->Pour of Foundation concrete	2,311.87	2,371.89			4,683.76
<input checked="" type="checkbox"/>	Inspection Foundation Batch		19/02/2017	19/02/2017	package level	Sets->Inspection Foundation Batch	00.00	2,884.62			2,884.62
<input checked="" type="checkbox"/>	Setting out walls		20/02/2017	20/02/2017	Daily Task	Sets->Setting out walls		1,500.00		00.00	1,500.00
<input checked="" type="checkbox"/>	Masonry works		21/02/2017	26/02/2017	Construct	Sets->Masonry works	19,466.88	4,751.43			24,218.31
<input checked="" type="checkbox"/>	Inspection		26/02/2017	26/02/2017	package level	Sets->Inspection		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Setting out seperation rooms		27/02/2017	27/02/2017	Construct	Sets->Setting out seperation rooms		1,500.00			1,500.00
<input checked="" type="checkbox"/>	Mobilizing material		28/02/2017	28/02/2017	package level	Sets->Mobilizing material		1,000.00			1,000.00
<input checked="" type="checkbox"/>	Erect the seperation plates		01/03/2017	01/03/2017	Construct	Sets->Erect the seperation plates	278.02	54.12			332.15
<input checked="" type="checkbox"/>	Inspection		01/03/2017	01/03/2017	Daily Task	Sets->Inspection		2,884.62		00.00	2,884.62
<input checked="" type="checkbox"/>	Mobilizing roof material		02/03/2017	03/03/2017	package level	Sets->Mobilizing roof material		1,000.00			1,000.00
<input checked="" type="checkbox"/>	Setting out		03/03/2017	03/03/2017	Daily Task	Sets->Setting out		1,500.00			1,500.00
<input checked="" type="checkbox"/>	Erect the roof		04/03/2017	16/03/2017	Construct	Sets->Erect the roof	9,696.12	00.00		7,710.72	17,406.84
<input checked="" type="checkbox"/>	Inspection roof package		16/03/2017	16/03/2017	package level	Sets->Inspection roof package		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Setting out floors		17/03/2017	17/03/2017	Daily Task	Sets->Setting out floors		1,500.00			1,500.00
<input checked="" type="checkbox"/>	Erect floor		18/03/2017	28/03/2017	Construct	Sets->Erect floor	1,169.71	950.54			2,120.25
<input checked="" type="checkbox"/>	Inspection		28/03/2017	28/03/2017	Project level	Sets->Inspection		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Cost control report for General works		28/03/2017	28/03/2017	Core team level	Sets->Cost control report for Genera...		3,250.00			3,250.00
<input checked="" type="checkbox"/>	Mobilizing windows and doors		29/03/2017	29/03/2017	package level	Sets->Mobilizing windows and doors		1,000.00			1,000.00
<input checked="" type="checkbox"/>	Erect doors and windows		30/03/2017	20/04/2017	Construct	Sets->Erect doors and windows	31,919.10	763.00			32,682.10
<input checked="" type="checkbox"/>	Inspection D&W package		20/04/2017	20/04/2017	Project level	Sets->Inspection D&W package		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Cost control report for D&W works		20/04/2017	20/04/2017	Core team level	Sets->Cost control report for D&W...		3,250.00			3,250.00
<input checked="" type="checkbox"/>	Mobilizing ceiling material		29/03/2017	29/03/2017	package level	Sets->Mobilizing ceiling material		1,000.00			1,000.00
<input checked="" type="checkbox"/>	Setting out for ceiling		30/03/2017	30/03/2017	Daily Task	Sets->Setting out for ceiling	00.00	1,500.00			1,500.00
<input checked="" type="checkbox"/>	Erect ceiling grids		31/03/2017	05/04/2017	Construct	Sets->Erect ceiling grids	2,140.26	1,200.52			3,340.79
<input checked="" type="checkbox"/>	Inspect the ceiling grids		05/04/2017	05/04/2017	Daily Task	Sets->Inspect the ceiling grids		2,884.62		00.00	2,884.62
<input checked="" type="checkbox"/>	Mobilize lighting fixtures		29/03/2017	29/03/2017	package level	Sets->Mobilize lighting fixtures		1,000.00			1,000.00
<input checked="" type="checkbox"/>	Set up lighting fixtures		30/03/2017	09/04/2017	Construct	Sets->Set up lighting fixtures	17,037.93	296.48			17,334.41
<input checked="" type="checkbox"/>	Erect the ceiling plates		10/04/2017	10/04/2017	Construct	Sets->Erect the ceiling plates		514.51			514.51
<input checked="" type="checkbox"/>	Inspect the ceiling package		10/04/2017	10/04/2017	package level	Sets->Inspect the ceiling package		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Cost control report for ceiling works		10/04/2017	10/04/2017	Core team level	Sets->Cost control report for ceiling...		3,250.00			3,250.00
<input checked="" type="checkbox"/>	Inspection the lighting fixture package		10/04/2017	10/04/2017	package level	Sets->Inspection the lighting fixture...		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Cost control report for lighting and fixture works		10/04/2017	10/04/2017	Core team level	Sets->Cost control report for lighting...		3,250.00			3,250.00
<input checked="" type="checkbox"/>	Mobilizing finishing works		10/04/2017	10/04/2017	package level	Sets->Mobilizing finishing works		1,000.00			1,000.00
<input checked="" type="checkbox"/>	Installation the carpet floor		11/04/2017	15/04/2017	Construct	Sets->Installation the carpet floor	1,640.38	1,024.52			2,664.90
<input checked="" type="checkbox"/>	Inspection the carpet floor		15/04/2017	15/04/2017	Daily Task	Sets->Inspection the carpet floor		2,884.62		00.00	2,884.62
<input checked="" type="checkbox"/>	Implementing the painting works		11/04/2017	13/04/2017	Construct	Sets->Implementing the painting wo...	1,635.48	255.79			1,891.28
<input checked="" type="checkbox"/>	Inspection the painting works		14/04/2017	14/04/2017	Daily Task	Sets->Inspection the painting works		2,884.62			2,884.62
<input checked="" type="checkbox"/>	Cost control report for finishing package		16/04/2017	16/04/2017	Core team level	Sets->Cost control report for finish...		3,250.00			3,250.00
<input checked="" type="checkbox"/>	The final cost control report for whole works		17/04/2017	17/04/2017	Project level	Sets->The final cost control report...		3,250.00			3,250.00

Figure 68.5D BIM model - Navisworks Platform

7.3.2.2.Step2: Development of Cash Flow

After developing 4D/5D BIM models, in which its activities are linked with its design elements, the project budget should be developed at this stage. Notably, the budget should be developed separately for each trade package to enable negotiation at buyout stage. Table 14 shows the different packages along with their colour indices. Table 15 shows all values for each trade package as assigned to project timeline. By applying equation 6 and Table 15 illustrates the BCWS for LIMB 1, which is the direct cost which in IPD, it represents the minimum expected return in case of the actual cost exceeded the agreed profit at risk percentage. Likewise, it shows the BCWS of the overhead cost individually in case that there will be cost saving in the project, and IPD approach recommends sharing the achieved cost saving. The accumulative BCWS for all costs structure (i.e. direct, indirect and overhead costs) is computed based on equations 6 and 7. And the estimated cash in using Equation 8.

Table 15 illustrates the estimated maximum and minimum cash inflow for each trade package, therefore, the trade contractor should be able to identify the expected profit as well as the maximum overdraft that could happen during the project implementation. After applying equations 10, and 11 with considering IR equals zero and using the agreed profit at risk percentage (20%), the maximum cash in-flow for general package was £106,817.7, and the estimated minimum was £ 57,224.8. Hence the difference between those represents the profit at risk percentage plus the overhead cost, which was £ 49,592.91, and this only happens in case that the actual cost exceeded the planned LIMB 3. Without using ABC method, this kind of analysis to the cost structure could not be achieved, and the project parties will encounter the scarcity of cost index data. The estimated minimum and maximum cash inflow for all other packages are detailed in Table 15.

Table 14. Cost Packages

NO	Package	Colour index
1	General Package (GP)	
2	Doors and Windows Package (DWP)	
3	Ceiling Package (CP)	
4	Lighting fixture Package (LP)	
5	Finishing Package (FP)	

Table 15. Estimated Cash Flow Distribution

Package	Cash flow parameters	£ W2	Feb W3	£ W4	Feb	£ W1	March W2	£ W3	£ W4	March	£ W1	April W2	£ W3	April
	Accumulative BCWS					5,716.8	5,716.8	5,716.8	5,716.8	5,716.8		16,509. 2	20,418. 9	
	Accumulative BCWS for overhead					5,384.6	5,384.6	5,384.6	5,384.6	5,384.6		12,153. 9	15,530. 6	
(GP)	Accumulative Direct Cost					332.2	332.2	332.2	332.2	332.2		4,355.4	4,888.3	
	Maximum Cash inflow					6,860.1	6,860.1	6,860.1	6,860.1	6,860.1		19,811. 1	24,502. 7	
	Minimum Cash Inflow					332.2	332.2	332.2	332.2	332.2		4,355.4	4,888.3	

(DWP)	Accumulative BCWS		1,866.8	26,133	54,736.	63,038.	73,192.	79,875.	89,014.
					1	4	4	7	7
	Accumulative BCWS		1,500.0	10,154	14,538.	17,038.	19,538.	23,923.	31,790.
	for overhead				5	5	5	1	0
	Accumulative Direct		366.8	15,979	40,197.	45,999.	53,653.	55,952.	57,224.
(CP)	Cost				7	9	9	6	8
	Maximum Cash inflow		2,240.2	31,359	65,683.	75,646.	87,830.	95,850.	106,81
					4	1	9	8	8
	Minimum Cash inflow		366.8	15,979	40,197.	45,999.	53,653.	55,952.	57,224.
					7	9	9	6	8
(CP)	Accumulative BCWS								
								15,706.	27,145.
								4,268.2	40,661.
(CP)								9	7
	Accumulative BCWS								
	for overhead							1000.0	7,979.6

(LP)	Accumulative Direct		14,706.	26,145.	32,682.
	Cost	3,268.2	9	7	1
	Maximum Cash inflow		18,848.	32,574.	48,794.
		5,121.9	3	8	1
	Minimum Cash inflow		14,706.	26,145.	32,682.
		32,68.2	9	7	1
	Accumulative BCWS			15,475.	15,475.
		3,056.8	8,725.4	3	3
(LP)	Accumulative BCWS			11,620.	11,620.
	for overhead	2,500.0	5,384.6	0	0
	Accumulative Direct				
	Cost	556.8	3,340.8	3,855.3	3,855.3
(LP)	Maximum Cash inflow				
		3,668.1	10,470.	18,570.	18,570.
(LP)			5	3	3

Minimum Cash Inflow		556.8	3,340.8	3,855.3	3,855.3
(FP)	Accumulative BCWS	4,466.9	16,600.	24,917.	24,917.
			9	5	5
	Accumulative BCWS for overhead	1000.0	1000.0	7,583.1	7,583.1
	Accumulative Direct Cost	3,466.9	15,600.	17,334.	17,334.
			9	4	4
	Maximum Cash inflow	5,360.3	19,921.	29,901.	29,901.
			1	0	0
	Minimum Cash Inflow	3,466.9	15,600.	17,334.	17,334.
			9	4	4

In buyout stage, the architect requires to show the completed budget plan to all project parties. As stated in the framework development section, the contractor will take the decision based on the expected maximum and minimum cash inflow. Figure 69 shows the estimated overdraft per package. That said, the overdraft implication is completely different from traditional delivery approaches, as the contractor, at the worst case, will be reimbursed the direct costs. In case that the actual values of project costs are located between the total cost and profit at risk values, this means the overdraft equals zero. In case of the actual project cost is located above LIMB 3, this means that overdraft equals the value of overhead costs, whether completely or partly. The way of presenting cash flow information warns contractors through minimising the project overhead by optimising the project schedule to implement more overhead activities at the same time, and accordingly minimise the number of cost drivers that will maximise the estimated minimum cash inflow. For instance, the overdraft in the finishing package, shown in Figure 69, is high due to the overhead costs are high. Using ABC enabled the estimators to precisely distinguish and identify the overhead costs to analyse the cost structure.

Since the IPD approach requires a trust environment throughout the project stages, the developed framework supports this by showing the maximum overdrafts could happen if the actual cost exceeded the profit at risk percentages (LIMB 3). Figure 69 shows the estimated overdraft values for each trade package and with integrating ABC into 4D/5D BIM models, the overdraft is precisely determined using equation 15.

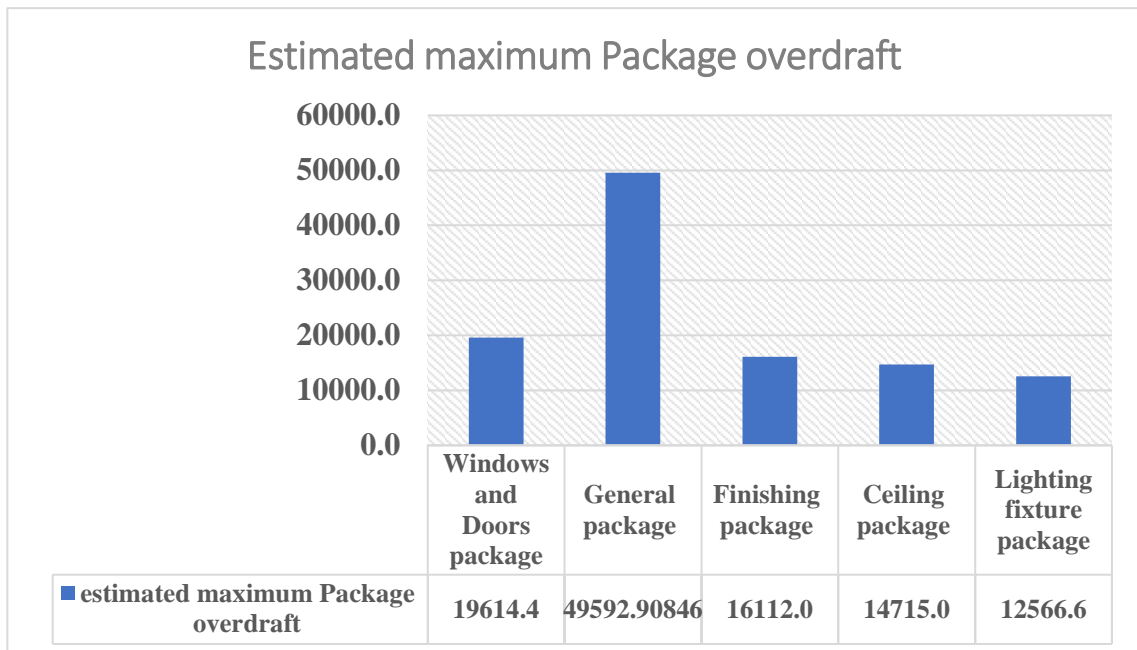


Figure 69. Estimated overdraft of each Package

Figure 70 illustrates that the maximum cash in deviations may occur in windows, doors, and packages by 80%, 80%, and 79% respectively. This is due to the value of overhead costs which are high comparing to other packages such as finishing and lighting fixture packages by 33% and 42% respectively. Accordingly, the contractors will be completely aware regarding the maximum deviations which would happen in case of poor performance. In case that all displayed analysis will be presented during the IPD's buyout stage, this can ensure the successful project implementation since all the project parties are fully aware about all financial consequences. Even though these deviations were determined based on the planned direct and total cost, however these deviations indicate the expected gap if the trade contractor exceeds LIMB 3 limit. Figure 70 illustrates deviations of all packages—the outcome of the CCMS for the budgeting data is presented in appendix (f), similarly, figure 71 illustrates the proposed cash flow plans for all packages, as well as estimated maximum required budget from the client, to be used for

decision making during the buyout stage. Contrary to BIM-based cash flow, which has been developed by Lu, Won and Cheng (2016).

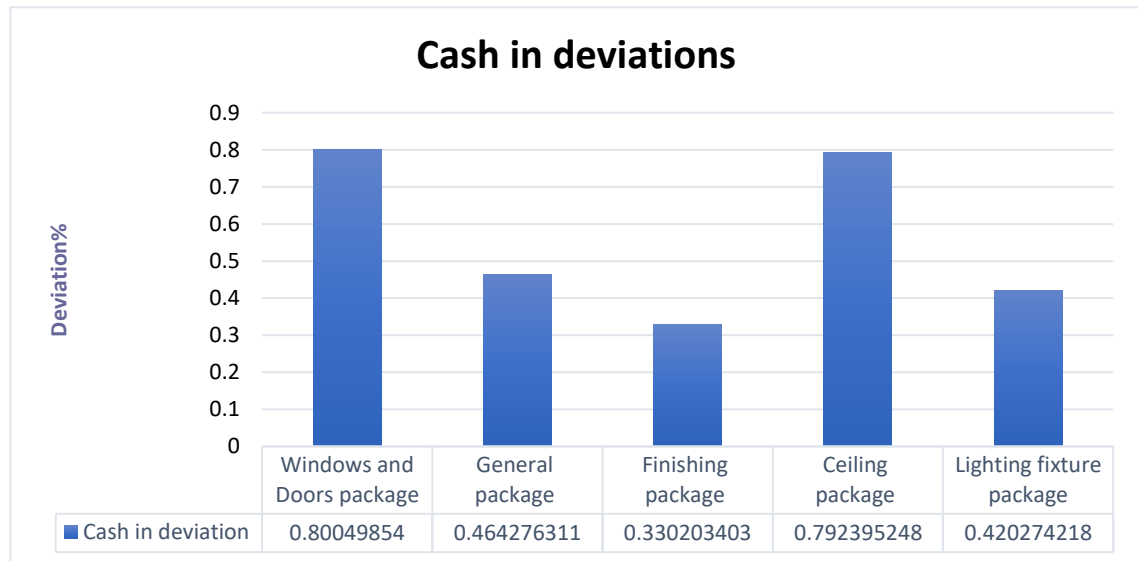


Figure 70.Packages cash in deviations’ percentage

7.3.2.2.1. Cost Budget based CCMS4IPD Web System

Figure 71 illustrates a snapshot from the CCMS4IPD web system regarding the cost budget data for each trade package, therefore, any party can access using given authentication information and check the cost budget details whether from the table or graphically from the cost budget chart. All cash flow data for all trade packages and the data is presented, whether using estimated maximum/minimum cash inflow, which include all cost elements (direct, indirect and overhead) are presented as S curve. Therefore, the contractors and client requirements to identify direct cost of the activities at the buyout stage, since the client is liable to pay the actual cost of direct activities, in case that the actual cost exceeds Limb 3. Therefore, the monetary value for minimum estimated cash inflow indicates the planned cost for direct activities and it enables project parties to track these activities during the execution stage, in order to determine the actual value. The deviation between estimated maximum/minimum cash inflow gives an indication to restructure the cost estimation in case overhead and indirect costs are larger than direct cost. Without using ABC, the filtering of direct, indirect, and overhead

activities could not be attainable, therefore, the developed cash flow will not be reliable and representable to the nature of the project. The embedded data in figure 71 should be displayed on the IPD's big room to enable all participants to manage their cash flow, particularly the costs is only reimbursed, and profits will be shared after all works will be accomplished by all participants.

Proposed Cash Flow for All IPD Core Team Members

Project Parties

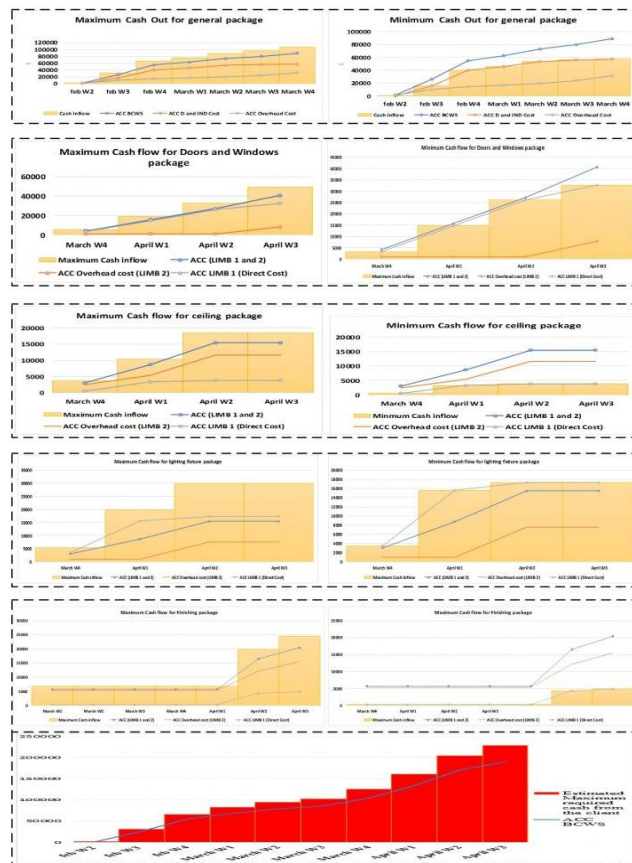
SEARCH

Download Data

Grid Edit

PROJECT PARTIES	EMNCI	EMCI	THE MAXIMUM OVERDRAFT
Ceiling Package	£32,682.10	£48,794.10	£16,112.00 View Details
Finishing Package	£17,334.40	£29,901.00	£12,566.60 View Details
General Package	£57,224.80	£106,818.00	£49,593.20 View Details
Lighting fixture Package	£3,855.30	£18,570.30	£14,715.00 View Details
Windows and Doors W & D Package	£4,888.30	£24,502.70	£19,614.40 View Details

Records 1-5 of 5



Print PDF Email

Figure 71. Cost budget data based CCMS4IPD web system

7.3.3. Construction Stage (Cost Control and Sharing Risk/Reward)

The detailed cost estimation was prepared by package for the three limbs, as shown in figure 72 (it is a snapshot from the CCMS) 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.

Project parties	Limb-1	Overhead α	Limb-2 (CTV)	Limb-2	Limb-3	Total Cost/Package	Project Compensation St
Ceiling Works Contractor	£3,855.20	3.25%	£105.74	£11,519.20	3096.0276	£15,480.14	£18,576.17
Finishing Works Contractor	£4,888.30	4.13%	£134.07	£15,403.80	4085.23464	£20,426.17	£24,511.41
General Works Contractor	£59,724.70	50.40%	£1,638.09	£27,557.60	17784.07822	£88,920.39	£106,704.47
Lighting Fixture Contractor	£17,344.40	14.64%	£475.71	£7,134.60	4990.94224	£24,954.71	£29,945.65
Windows and Doors Works Contractor	£32,682.20	27.58%	£896.39	£7,134.60	8142.63732	£40,713.19	£48,855.82
*	£0.00			£0.00			
Total	£118,494.80	100.00%	£3,250.00	£68,749.80	38098	£190,494.60	£228,593.52

Figure 72.The IPD cost structure

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.

7.3.3.1.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 16.

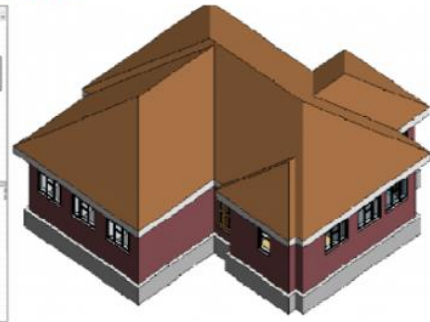
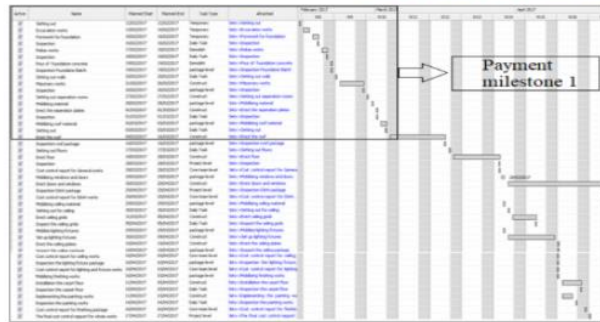
Table 16.Monthly cost data – Scenario 1

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	65,000	69,675

BCWP	2,362	62,740	72,000	75,946
CPR	0.91	0.91	0.902	0.92
SPR	0.79	0.83	0.781	0.90

Figure 73 summarises the above-mentioned scenarios steps and results of implementing the framework for both owner and non-owner parties. The figure 73 shows the cost and profit for contractors. Given the project is located in the risk area, therefore, there is no a reward for both owner and non-owner parties.

This report shows you the achieved metrics regarding the main three (Reimbursed costs, Cost Saving and Profit) transactions at each Milestone



Payment Milestones

Report	
Payment Milestones	1
Construction Package	Gene and Fini
Project Case	Crisis Case
NOARP	0.7
OARP	0.3
P@R per	0.2
CPI	0.92
SPI	0.9
EVO	0.82
Adjusted EVO	0.028
EVO4Profit	0.028
Actual LIMB-1	£0.00
Actual LIMB-2	£0.00
PLIMB-1	£46,332.10
PLIMB-2	£22,423.10
LIMB-3	£13,751.04
TCS	£82,506.24
MV for R or RD for each party (LIMB-1)	£0.00
PoO	0
PoNO	0
Reward For Owner (LIMB-1)	£0.00
Reward For non-Owner parties (LIMB-1)	£0.00
CSoOOA	0
CSoOPA	0
CSoOC for NO	0
CSoOC for O	0
TR4O	£0.00
TR4NO	0
Reimbursed C	£78,655.95
Profit	£3,850.29
BACK	

To browse to the EVM-Web Grid Click Here

Figure 73. The risk/reward report for scenario 1

7.3.3.2.Scenario 2 and 3

Scenario 2 shows how the cost saving are 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 17.

Table 17.Monthly cost data - Scenario 2 and 3

Scenarios	Activities	Feb W2	Feb W3	Feb W4	Mar W1
Budget data	BCWS	1,867	49,985	4,385	12,073
	Cumulative	1,867	51,852	56,236	68,309
	BCWS				
	ACWP	1,680	51,852	50,613	68,309
Scenario 2	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
	ACWP	2,147	57,037	60,000	70,000
Scenario 3	BCWP	2,362	62,740	70,000	100,000
	CPR	0.91	0.91	0.857	0.7
	SPR	0.79	0.83	0.803	0.6838

Figure 74 shows the outcome of the other two scenarios; for the second scenario, the CPI and SPI are 1.02 and 1.02 respectively, and the EVO output was 104%, located in the green area, implying an optimum situation due to the considerable positive deviation from

the planned values. Therefore, three transactions should be presented — reimbursed cost, profit and cost saving. The only reimbursed cost will be paid to non-owner parties; however, profit and cost saving will be kept in profit and cost saving pools until all project works will be performed (see figure 7, image 1). Regarding the third scenario, the EVO was 0.49 due to CPI and SPI were 0.7 and 0.7 respectively, therefore, only the reimbursed cost is presented in image 2, figure 7. Although the reimbursed cost is more than planned, this should be paid to the trade contractor according to IPD principles and this additional cost can be covered from the profit and cost saving pools as long as the needed additional cost is available in these pools, otherwise, the owner should pay the direct cost.

Report		
Payment Milestones		
Construction Package	Gene and Finl	1.1
Project Case	Optimal Case	
NOARP	0.7	
OARP	0.3	
P@R per	0.2	
CPI	1.02	
SPI	1.02	
EVO	1.04	
Adjusted EVO	0.2404	
EVO4Profit	0.2404	
Actual LIMB-1	£44,612.70	
Actual LIMB-2	£1,013.00	
PLIMB-1	£46,332.10	
PLIMB-2	£22,423.10	
LIMB-3	£13,751.04	
TCS	£82,506.24	
MV for R or RD for each party (LIMB-1)	£1,719.40	
PoO	0.5	
PoNO	0.5	
Reward For Owner (LIMB-1)	£859.70	
Reward For non-Owner parties (LIMB-1)	£859.70	
CSOOA	0	
CSOOPA	1013	
CSOC for NO	709.1	
CSOC for O	303.9	
TRAO	£1,163.60	
TRANO	1366.2	
Reimbursed C	£66,225.40	
Profit	£13,751.04	

BACK

Scenario-2

Report		
Payment Milestones		
Construction Package	Gene and Finl	1.2
Project Case	Crisis Case	
NOARP	0.7	
OARP	0.3	
P@R per	0.2	
CPI	0.7	
SPI	0.7	
EVO	0.49	
Adjusted EVO	-0.31	
EVO4Profit	0	
Actual LIMB-1	£0.00	
Actual LIMB-2	£0.00	
PLIMB-1	£46,332.10	
PLIMB-2	£22,423.10	
LIMB-3	£13,751.04	
TCS	£82,506.24	
MV for R or RD for each party (LIMB-1)	£0.00	
PoO	0	
PoNO	0	
Reward For Owner (LIMB-1)	£0.00	
Reward For non-Owner parties (LIMB-1)	£0.00	
CSOOA	0	
CSOOPA	0	
CSOC for NO	0	
CSOC for O	0	
TRAO	£0.00	
TRANO	0	
Reimbursed C	£82,506.24	
Profit	£0.00	

BACK

Scenario-3

Figure 74.The risk/reward report for scenario 2 and 3.

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 scenario 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. For 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 (2014) developed models capable of differentiating overhead cost levels such as corporate and project levels. These model 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 features, 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 to integrated models proposed in previous studies.

7.3.3.3.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 the three scenario, are illustrated in Figure 75.

Figure 75 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 75) 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 reward 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 yellow coloured circle 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 75). 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 (Roy et al., 2018, Allison et al., 2018).

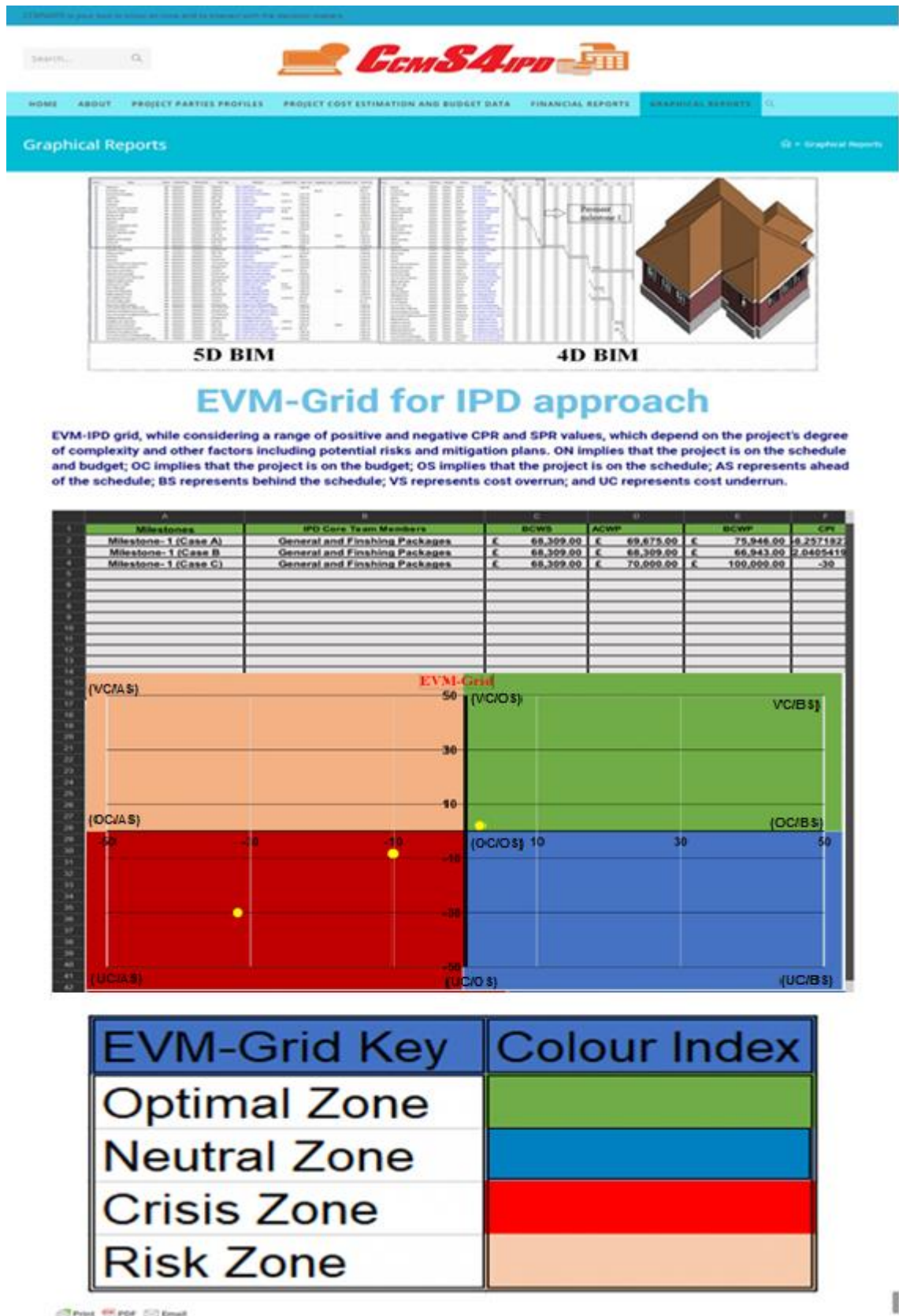


Figure 75.Result analysis of displaying risk/reward values on EVM-web system

7.4.Summary

This chapter presented how the prototype is developed including the three main tools—CCMS database system, EVM grid, Web-based management system (CCMS4IPD) and the blockchain network—the applicability of these tools are validated using an illustrative case study, the findings proves that the proposed tools are user-friendly. The system is tested under different scenarios to ensure its applicability to provide the needed data, for example, the risk/reward sharing system is tested using three scenarios—Profit and reward, Profit, no profit—the system showed its ability to provide accurate results for all scenarios. This can raise the trust and maximise the collaboration among project parties. The developed blockchain network and smart contract in integration with the CCMS4IPD web system works as an automated/integrated cost management system for the IPD projects.

CHAPTER EIGHT: THE RESEARCH FINDINGS VALIDATION

8.1.INTRODUCTION

This chapter presents the validation process of the developed framework and prototype, the interviews were conducted as a virtual/video interview method. Seven interviewees accepted to take a part in this evaluation, the procedures of conducting the interview were seeking for their consent through sending an email, subsequently, sending the video that includes a summary of the revealed gap and explanations of the framework, as well as, using the real tools to conduct different tasks, and questions to be answered after watching the video. In case that the interviewees need more clarifications, a phone call was offered. The characteristics of interviewees, data analysis and findings are presented in this chapter to evaluate the reliability and validity of the research findings.

8.2.THE CHARACTERISTICS OF INTERVIEWEES

This evaluation is to assess the findings of the research through seeking industry practitioners, as well as, academic staff views about the efficiency of the developed framework and the prototype tools. The inclusion criteria of the interviewees are the level of understanding the IPD approach, the level of experience that should not be less than six years and the interviewees to be familiar with BIM theoretical and practical knowledge. A scale from 1 to 5 was given to interviewees to evaluate their level of understanding regarding IPD mechanism, as well as, their level of the overall experience is categorised to meet the selection criteria. Regarding the knowledge of BIM, from the interviewees' profiles, their knowledge level has been determined whether by holding BIM degrees or having professional experience. Below table 18 shows the characteristic of participants.

Table 18.The characteristic of interviewees

IDs	Job	Range of Experience	IPD experience	Familiar with BIM	Education background
P1	Senior lecturer in Construction Management	6-10	4	yes	PhD
P2	Project Manager	15+	4	yes	PhD
P3	Senior Quantity Surveyor	15+	4	yes	MSc
P4	Lean lead	15+	4	yes	PhD
P5	Assistant Professor in Construction Management	6 to 10	5	yes	PhD
P6	Contract Manager	6 to 10	5	yes	PhD
P7	Senior lecturer in Construction Management (Lean construction)	6 to 10	4	yes	PhD

Figure 76 shows that five interviewees selected the scale 4 to represent their level of understanding regarding the IPD approach, meanwhile, other two interviewees selected

the maximum scale, which is 5 to represent their expertise in IPD approach. Therefore, this met the inclusion criteria to be able to assess the outcome of this research.

What is your degree of understanding of IPD approach?

7 responses

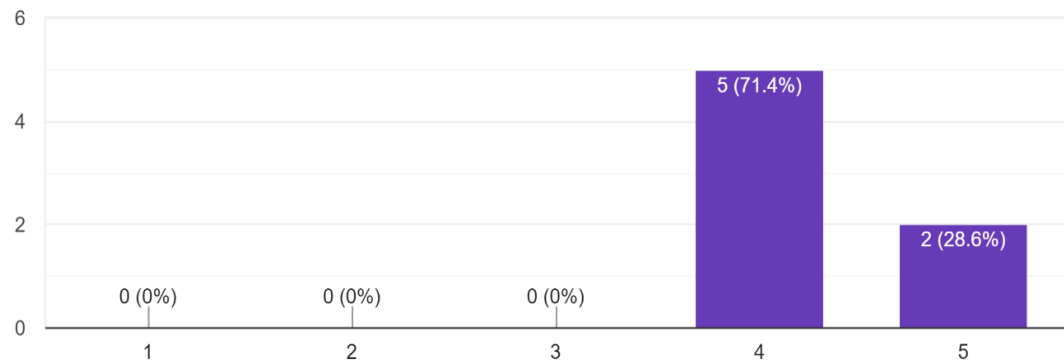


Figure 76.The respondents' level of understanding IPD approach

8.3.ENGAGING WITH PARTICIPANTS

The interview was conducted online as a virtual interview, Kisin et al. (2009) defined the virtual interview as a digital (video) interview that can be conducted either one-way through sending the video and list of questions, or two way through using the video conference technology (i.e. skype) to interact with the interviewee. In this study, both ways were used since some of interviewees asked for more explanations before answering the questions.

The video is structured as follows:

1. Presenting the revealed challenged (knowledge gap) by reviewing the literature, as well as, the exploratory questionnaire.
2. Giving a detailed explanation for all developed models and tools regarding cost estimation, budgeting and risk/reward sharing.

3. Going through the developed prototype with showing how it works through using an illustrative case study.

The length of the video was 50 minutes, the video was sent out to interviewee through the email, accompanied with the questions that were written using google form. After the interviewees watch the video, the researcher should get in touch with them to make sure everything is clear before the interviewees answering the questions.

Given that the objectives behind conducting this interview are (1) validating the proposed new concepts of managing risk/reward among IPD core team members, (2) Examining whether the presented cost management challenges of IPD are solved using CCMS4IPD, (3) Measuring the applicability of the developed tools such as CCMS database, EVM-Grid and CCMS4IPD web system, (4) Validating the applicability of utilising blockchain and smart contract to enhance the collaboration and trust among project parties. The questions were divided into two categories, namely, framework synergies and processes evaluation against presented cost management challenges of IPD, Evaluation of CCMS4IPD including database system and interactive web-based management system and the evaluation of the applicability of the developed IPD smart contract, as well as blockchain network.

The interview consists of eight open-ended questions, they were mainly to assess the developed tools (CCMS and the blockchain), and in addition, a question was asked to evaluate the reliability of the developed framework through all IPD stages, followed by another question to enable interviewees to directly propose ideas to enhance the applicability of the framework. After that, specific questions to assess the functions of the CCMS and DCMS such as the automated financial report to show the achieved risk/reward value for IPD parties. The final question was to give the interviewees the opportunity to summarise their views.

8.4.INTERVIEW ANALYSIS AND FINDINGS

The interview results were analysed using NVivo. Ten codes were identified to describe the interviewee's responses as seen from figure 77. Additionally, a mind map is developed to link between these codes, as well as, creating hierarchies to support the thematic analysis of the interviews' contents, see figure 77.

Name	Files	References	Created On	Created By	Modified On	Modified By	
The framework processes		1	8/03/2019 10:51	FA	06/12/2019 20:41	FA	
Potential improvements		1	5/03/2019 10:53	FA	06/12/2019 20:43	FA	
Practical implications		1	4/03/2019 10:45	FA	06/12/2019 12:20	FA	
Applicability of financial report		1	6/03/2019 10:58	FA	06/12/2019 20:45	FA	
Applicability of the blockchain based IPD approach		1	6/03/2019 11:03	FA	06/12/2019 20:45	FA	
Enhance trust among IPD members		1	4/03/2019 10:48	FA	06/12/2019 20:42	FA	
Web-based management system (CCMS4IPD)		1	6/03/2019 10:55	FA	06/12/2019 20:45	FA	
Completely satisfied		1	3/03/2019 10:54	FA	06/12/2019 12:27	FA	
General consent		1	34/03/2019 11:07	FA	06/12/2019 20:44	FA	
Comprehensive view		1	4/03/2019 11:04	FA	06/12/2019 12:29	FA	

Figure 77.The generated codes according to interviewee's responses

Figure 78 shows the map of linking the interview codes in order to facilitate the thematic and content analysis of the interviewee's responses.

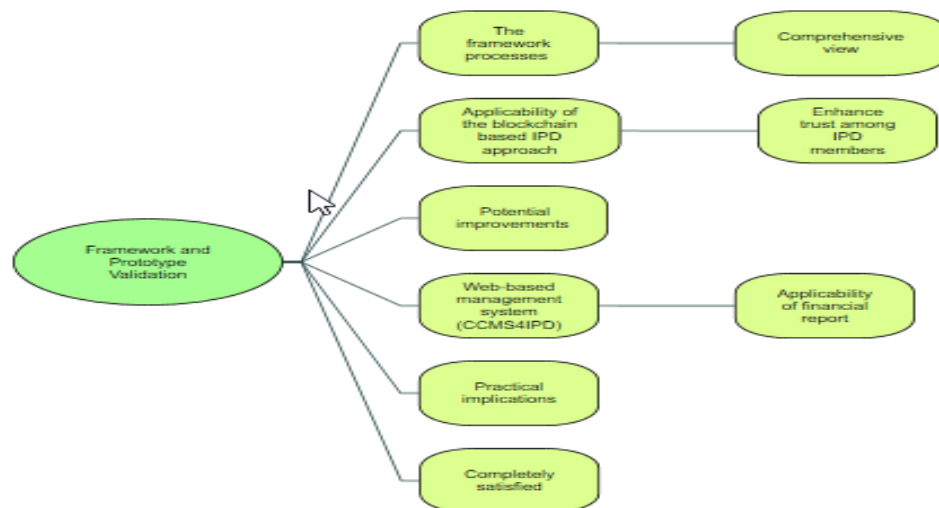


Figure 78.The mind map of the interview codes

8.4.1. The Evaluation of the Framework Processes and Tasks

The analysis of the interviewees' responses confirms that the developed tools and processes to manage the costs during all IPD stages. The responses can be summarised as (1) the framework captures all details and requirements for delivering an advanced cost management practices, (2) the ability of the presented estimation mechanism to consider all cost structure elements, which, prevents hide any profit into the overhead costs, (3) The presented cost estimation/budgeting methodologies can enable the practitioners to enhance their practices, indeed, the first interviewee (P1) said that *"CCMS can be a step towards changing practices in the industry"*, moreover, the fifth participants (P5) give a comprehensive comment *"Integrated project delivery (IPD) is seen by many practitioners and in the academia as the most effective delivery approach to implement BIM effectively. Despite that, IPD is rarely implemented in its pure form worldwide due to many technical, financial and legal challenges. One of the challenges upon these is the absence of tender stage. This framework has a significant contribution toward overcoming such challenge"*. Given that the framework adopted the ABC method to enhance the cost management process for the IPD approach, the fifth interviewee mentioned that *"Very helpful. Moving to Activity Based Modelling is much needed in construction particularly with the aid of CCMS, DCMS and BIM information management and instant rendering and analysis tools. This will increase transparency, collaboration and shift attention to Value rather than cost."*

8.4.2. The Applicability of the CCMS Tools (The Database and CCMS4IPD Web System)

The conclusion of the participants evaluation regarding the usability, validity and reliability of the integrated CCMS pertains to several aspects, namely, enabling all parties to reach the needed cost data anywhere while data maintain concealed from any unauthorised parties, the level of details is high since the second interviewee mentioned that *“It provides a real-time cost analysis information and reports which keeps all parties in IPD contract informed and involved”*, increasing transparency and trust among IPD core team members. Furthermore, the fourth interviewee (P4) who is expertise in the lean construction, particularly using IPD and BIM, commented that *“It is useful because of the absence of such systematic framework and tool for cost management in BIM-based project using IPD as a delivery approach. Moreover, having a web-based management system that is accessible by different stakeholders will enhance the collaboration, trust and integration between the project stakeholders”*. Figure 79 shows the most repeated word in this code, it can be seen that the words ‘Collaboration’, ‘trust’, ‘transparency’, ‘accessible’ and ‘BIM’ are the most repeated, this confirms that the participants agreed that the proposed system fulfilled the desired/planned objectives.

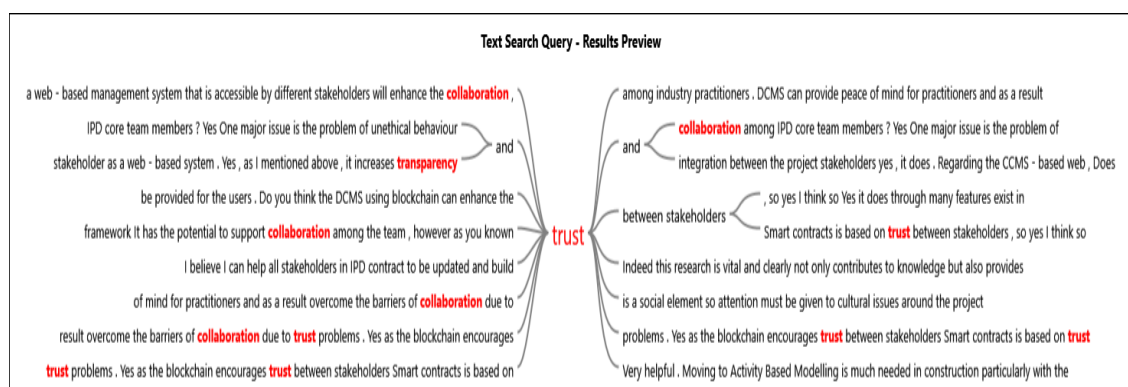


Figure 79. The outcome of words relationships search for words (Trust, collaboration, transparency).

8.4.3. The Practical Implications of the Proposed Tools (CCMS4IPD and Blockchain/Smart Contract Tools)

From the answers of Seven interviewees, the potential practical implications of the developed tools are coded under a single code (Practical implications) to enable summarise their views. All interviewees asserted that the developed tools—CCMS4IPD and blockchain/smart contracts—are very capable to create positive/rapid changes in the industry practices, as well as, fostering the implementation of the IPD. There are four implications mentioned by interviewees, namely, providing a real-life solution for the risk/reward sharing among IPD members through the automated financial information reports, CCMS4IPD works as a real-time shared cost information platform, the entire developed framework provides a significant contribution toward overcoming the existing challenges of cost management for IPD, the visualisation of financial data will raise the level of understand between all stakeholders. Figure 80 depicts the word three for “information” word to show how it appeared throughout the texts and the relevant sentences, this word is the most repeated one in this code, therefore, it has been selected to query the word relationships. The sixth interviewee (P6) commented on the entire system by saying that *“The tool provided in the research drastically enhances the project controls departments in actively managing their projects. Furthermore it provides the stakeholders with realistic indicators for their project in terms of schedule, budget and scope. The author has done a great job in translating the framework into a web-based tool that can be globally used by different stakeholders while managing their projects”*. Moreover, the fourth interviewee (P4) gave a comprehensive evaluation of the potential impact of the proposed tools by commenting that *“The system is practical and smart and I believe I can help all stakeholders in IPD contract to be updated and build trust, indeed this research is vital and clearly not only contributes to knowledge but also provides a*

tool for industrial practices. It provides comprehensive approach to share risks/reward with the support of BIM Capabilities. It also assist with automated reporting and fosters the collaboration aspects between partners. Further, it enables partners to focus on driving value through more accurate approach rather than the current estimated approaches that generates more hard feelings and reinforces blame culture...” Therefore, this tree reflects the mentioned practical implications of the ability of the proposed tools to manage the cost information throughout the different IPD stages.

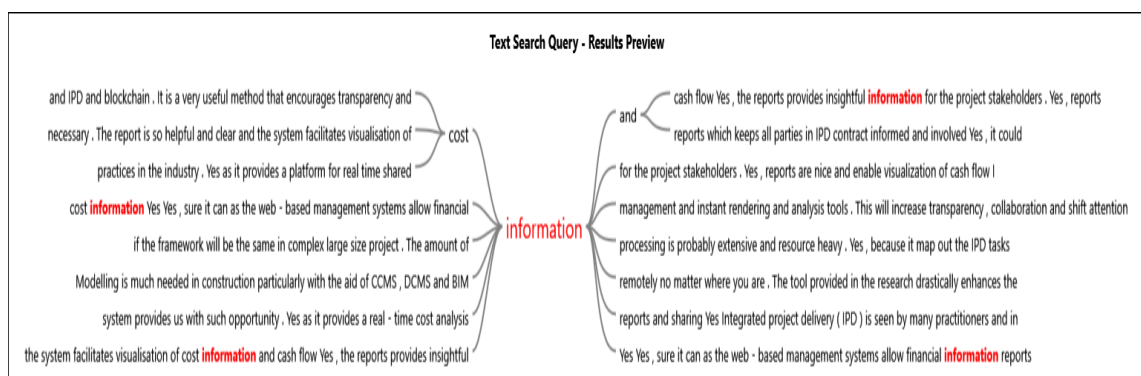


Figure 80.The outcome of words relationships search for words (Information)

8.4.4. The Interviewees Recommendations for Additional Features

Four out of seven interviewees did not ask for any change in the framework or adding new features to the developed tools, for instance, the fifth interviewee (P6) answered that “No, this framework is a good stepping up”. Meanwhile, other three interviewees recommended some improvements, the first interviewees recommended to develop an adoption steps to help the industry practitioners to implement the framework, he said that “I would introduce it to the industry in several steps to avoid confusion. The framework has many details which might be difficult for practitioner to digest in one go”. Additionally, the fourth interviewee recommended to highlight the tasks that BIM will be used to execute it to avoid any duplications in the processes since the three BIM dimensions (3D, 4D and 5D) are utilised over the IPD stages. The third interviewee recommended added new feature to the CCMS4IPD, which is considering the impact of

claims, she commented that *“I would add if there is any pending claims with financial implications to make all aware of possible risk or loss”*. However, IPD as a process targets to minimise the claims since the management of the project is shared, therefore, there is no a dominant party. Given that this research proposed a new set of tools such as the CCMS, as well as using the blockchain/smart contract. The seventh interviewee (P7) said that *“It has the potential to support IPD-based cost management. However, however some training has to be provided for the users.”* Therefore, the future research should include real implementations on some companies to measure the applicability of the CCMS4IPD system, as well as, the smart contract-based IPD. Figure 81 shows the word tree for the ‘Framework’, it can be seen that the content of the three indicates that the interviewees agreed the ability of the framework to overcome the endemic challenges of implementing the IPD approach, particularly, the challenges related to the cost management process (sharing risk/reward and the transparency in sharing the financial information).

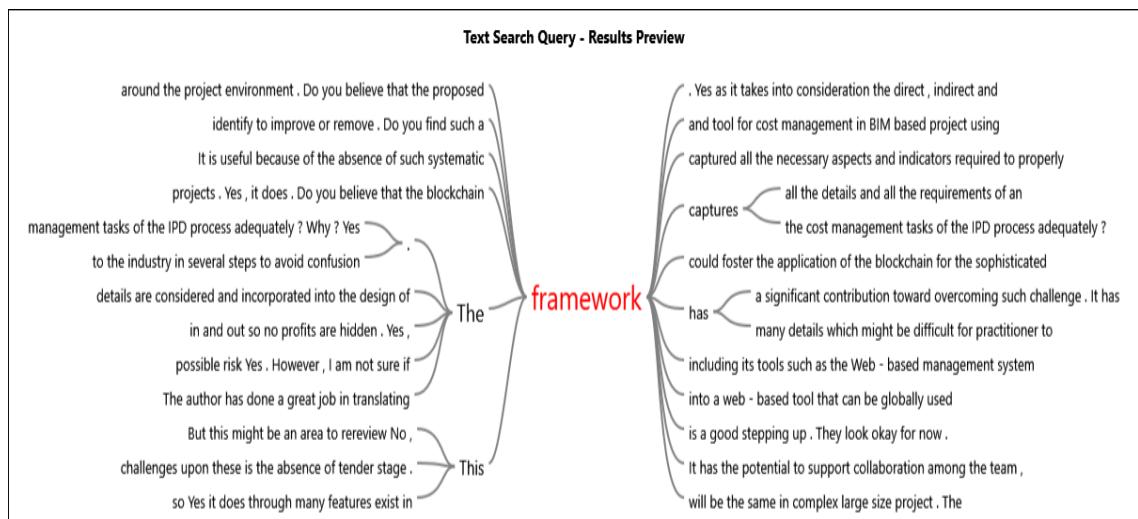


Figure 81. The outcome of words relationships search for words (framework)

8.4.5. The Implications of Blockchain and Smart Contracts

Given that blockchain technology is not widely implemented in the AEC industry, therefore, the researcher elaborate in this point in the virtual interview with providing in-

depth explanations to interviewees, as well as, displaying the developed real blockchain network and smart contract with focusing on the smart contract functions that should be evaluated. The interviewees' responses reflect their consents regarding the applicability of the proposed smart contract functions to enhance the trust among IPD core team members, for instance, the first interviewee (P1) commented that *"Absolutely, we need more use cases of blockchain on the construction industry and this one presents an ideal use case for the industry. Blockchain can be the future of contracts and finance management on projects. This work showcases the possibilities of blockchain"*. Indeed, the fifth interviewee (P5) mentioned that *"yes it does, due to different features such as the existence of risk and reward calculator"*. Even though, all participants confirmed the feasibility of blockchain/smart contract-based IPD framework to enhance the trust among project parties, however, the seventh interviewee highlighted that *"It has the potential to support collaboration among the team, however as you know trust is a social element so attention must be given to cultural issues around the project environment."* Figure 82 confirms the consent of the interviewees regarding the applicability and validity of the developed smart contract-based IPD.

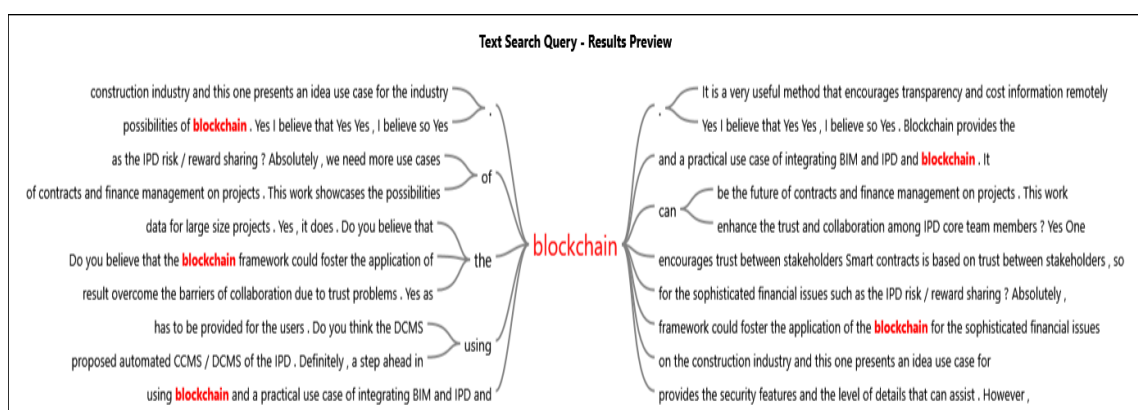


Figure 82. The outcome of words relationships search for words (blockchain).

8.4.6. The Degree of Satisfaction of the Framework and Prototype

Given most of the questions were asked to retrieve the participant's views, with asking for the reasons behind saying yes or no. Figure 83 shows the words three of word 'Yes' that has been repeated in all interviewee responses, which reflects their general satisfaction.

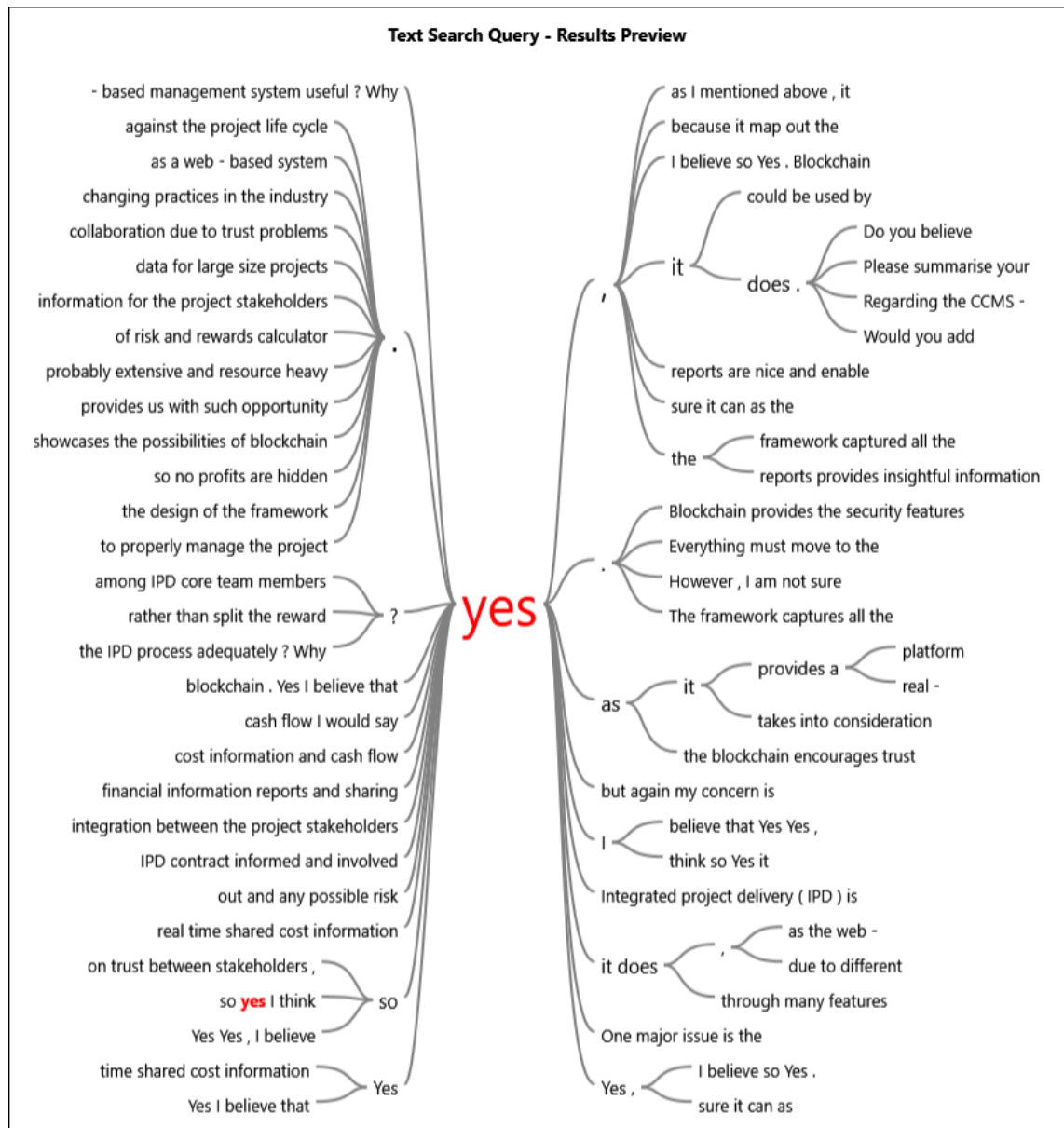


Figure 83.The outcome of words relationships search for words (Yes)

8.5.SUMMARY

This chapter presented the validation of the research findings, the content and systematic analysis of interviewees' responses confirm the validity of the research findings to bridge the revealed gap. The outcome of the analysis of interviews can be concluded as follows:

- The developed cost management system can works efficiently to deliver a proper cost management tasks over the entire IPD stages, to be more specific, CCMS can help to automate all calculations of cost estimation, budget and risk/reward values, as well as, sharing all data through smart web-based management system to enable all parties to access these data regardless of their geographical zones.
- The interviewees confirm the usability, flexibility and applicability of the developed ICT tools such as the web-based management system (CCMS4IPD) and the blockchain/smart contract.
- Some of the participants recommended this research to be introduced to the industry through steps of implementations to enable the practitioners to adopt its sophisticated tools and tasks. In other words, the research findings needs to be presented as technical reports for end users.
- Moreover, adding new features such as the impact of the claims, however, this was not in the scope of the research. Therefore, this will be considered in the future research as the same developed methodology of adopting blockchain to automate payment process can be reflected on other delivery approaches such as design and build approach.

CHAPTER NINE: CONCLUSION, RECOMMENDATION AND FUTURE WORKS

9.1.INTRODUCTION

This chapter summarises the research findings for each objective. The chapter includes three main sections, (1) the achievement of research objectives, (2) research limitations and future works, (3) the practical implications of the research. The achievement of the first three objectives develop the CCMS for the IPD approach, meanwhile, the fourth objective including two secondary objectives develop the DCMS using the blockchain network. The research limitations pertain to both framework development and the prototype tools are presented. All limitations that are subjected to future works such as enhancing the integration between the developed CCMS4IPD web system and the BIM models are introduced. The practical implications of the research, as well as, for each sub-process in the developed cost management system is presented to maximise the benefits of this research.

9.2.ACHIEVEMENT OF RESEARCH OBJECTIVES

Objective 1: To explore the existing cost management practices for the IPD approach, as well as, identifying the deficiencies in the existing practices.

The literature review was used to explore the cost management practices that have been mentioned in relevant research. In addition, a survey was conducted in order to explore the practices from industry perspectives. By reviewing the literature, a set of bad practices regarding estimation, budgeting and control (sharing risk/reward calculations) were revealed such as the misallocation of overhead costs that distorts the compensation structure of the IPD parties, the lack of utilising BIM to develop a cost budget plan using 4D and 5D BIM models, the lack of integration between the cost tasks that does not enable a proper cost control and there is no an automated system that enables determining

risk/reward to enhance the trust and collaboration among IPD core team members. The survey highlighted that the new characteristics of IPD such as there is no a tender stage and the pricing is open-book, the early involvement of participants and risk/reward sharing requires a new cost management system that can provide the required data through the entire IPD stages. The survey is also revealed that there is a lack in 5D BIM as existing to work as a platform for the IPD approach, particularly, it does not consider the entire cost structure element (Direct, indirect and overhead costs). Some improvements are required to enhance utilising 4D and 5D BIM, particularly for developing the S curve (Cost budget). The challenges of the cost managements of IPD were identified and the second objective is to explore how the existing methods can be integrated/extended to deal with such revealed challenges.

Objective 2: To explore and verify the capabilities of the existing tools that can enhance the cost management process for the IPD approach.

By comparing the revealed challenges from the first objective with a set of methods and tools, reviewing the literature shows that integrating the ABC method into 5D BIM could enhance the calculations of the IPD compensation structure. Additionally, integrating ABC into EVM could develop mathematical models to link between the outcome of the project performance and the risk/reward proportion for owner and non-owner parties. The survey highlighted that there are ten improvements as a result of (1) integrating ABC and EVM to enhance the cost management practices for IPD such as developing an automated model to show the duo payment for all parties based on their achievement against planned value and Providing an EVM grid to locate the Cost Performance Ratio (CPR) and Schedule Performance Ratio (SPR) to determine the holistic view of project progress. (2) Integrating Monte Carlo simulation into 5D BIM is proven as a solution to provide continuous cost estimation feedback in order to enhance the conceptual cost estimation

for TVD within IPD pre detailed design stages, (3) Utilising the ICT order to enhance the collaboration and trust among IPD core team members as it is highly recommended by both literature review and industry practitioners, two ICT applications have been identified, namely, web-based management system and blockchain technology.

Objective 3: To develop a framework that deals with identified key challenges of cost management practices with implementing the IPD approach. Given, the cost management process comprises of three main processes, therefore, the framework will be divided as follows:

- *To revolutionise the cost structure of IPD through integrating Activity Based Costing into BIM.*

Exploiting the full potential of BIM, IPD and non-traditional cost estimation approaches, such as TVD, requires solutions that draw upon each approach's capabilities and advantages and benefit from the synergy of their combined use. With research in this field still in its infancy, this research regarding the cost estimation based IPD contributes in several ways. Firstly, the theoretical foundations and details of an innovative framework, along with analytical considerations for integrating these methodologies, are discussed in detail, extending the body of knowledge on the topic.

Secondly, the study moves one step ahead in revolutionising the cost structure, progressing from promoting the integration of various solutions as proposed in previous studies, to provide a workable, practical solution based on the integration of Monte Carlo simulation, TVD and ABC with BIM-enabled integrated project delivery (IPD). This provides researchers with a sound foundation for exploring the potential for such integrative approaches and for investigating potential improvement.

As well as its research-focused contributions, the achievement of this objective is also deemed invaluable for the world of practice. To be specific, the proposed framework provides a workable solution for BIM–IPD integration, producing reliable cost data from different sources that are applicable to various project delivery modes. Using BIM to develop a conceptual model that addresses client criteria enables the estimator who is building the statistical models to obtain a range of proposed costs against a degree of certainty. The achievement of this objective also open windows for further exploration for both researchers and practitioners alike.

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 (Pishdad-Bozorgi et al., 2013). Particularly, such integration will be a remedial solution to cost distortion problems that occur in applying existing methods (Miller, 1996, Kim and Ballard, 2001, Kim et al., 2011). Moreover, the model enhances the cost structure of BIM for IPD, as a recommended approach in the literature (AIA, 2007, Allison et al., 2018, Rowlinson, 2017).

- ***To develop a budgeting methodology that enables project participants making the right decisions, this methodology depends on the integration of 4D and 5D BIM and ABC.***

The research presented a cash flow methodology framework to maximise the value of integrating 4D/5D BIM in generating the project cash flow within the IPD approach. The developed framework includes three steps to integrate 4D/5D BIM as follows: (1) Integration of cost and schedule data to solve the endemic problem of integrating WBC and CBS. This research adopted ABC for cost estimation since the costs are assigned to activities and not resources; (2) Linking cost/schedule data to BIM elements for grouping and sorting the project packages and the IPD’s buyout stage, which requires a separate

cash flow plan for each package; and (3) Providing project parties with all required financial data for informed decision making, such as providing contractors with the estimated maximum/minimum cash inflow and giving indications to trade contractors for all possible overdrafts that might occur during the project execution stage.

The overhead resources are presented as activities, to enable determining the right proportional of overhead consumption for each trade package. This process leads to a reliable IPD cost profile structure to all project participants and enables contractor in taking timely/informed decisions at the buyout stage.

In practical terms, findings will be invaluable for IPD users, given the simplicity and user-friendliness of proposed models. All the tasks are aligned with the implementation stages and easily expressed to allow IPD users to predict all possible financial consequences during the project execution stage. Furthermore, the presented methodology framework prevents IPD cost distortion by distinguishing between all overhead costs and the agreed profit percentage.

- *To develop statistical models to control project cost/schedules with enabling determine risk/ reward monetary values for each party at each milestone payment.*

The study is an attempt to propose a model, to exploit EVM to calculate risk/reward sharing in the IPD approach, 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 are implemented automatically, with minimal human interfering.

With the above in mind, the study is novel in several ways. That is, this research 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.

The model presented here also addresses some chief deficiencies of EVM (c.f. Kim and Ballard, 2010, Kim and Ballard, 2002). 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 (Morgan et al., 1998).

To exploit the revolutionary blockchain technology to automate the main three transactions (reimbursed costs, cost saving and profit). There are two main reasons beyond the adoption of blockchain:

- *To enhance the transparency among project parties by keeping all endorsed transactions away from any amendments since this is the main feature of the blockchain Distributed Ledgers (DL).*
- *To assess the performance of project parties during the project execution, this could be done in buyout stage through inquiring the value of the three transactions (reimbursed costs, cost saving and profit).*

This study is one of the first in its kind that showcases the potential of blockchain and smart contracts technologies in addressing financial management deficiencies of IPD. In particular, the capabilities of hyperledger fabric are demonstrated, given that findings point to the alignment of its characteristics with IPD features. The IPD financial terms/processes are revolutionised to be consistent with the IPD financial characteristics. Since the number of transactions at each payment milestone is various based on the project performance, mathematical models are developed for each scenario, in which, gives the potential users a methodology to articulate the project performance as monetary values—specific transaction for each limb in the IPD such as profit, cost saving and reimbursed costs—subsequently, the party can invoke these values through the hyperledger fabric network as proposed.

The proposed financial system considers all distinguished characteristics of IPD, therefore, a wide range of flexibility is taken into consideration regarding the scalability

to enable any party to join the network (project) after the network is built up, however, the security and privacy merits have been taken into the consideration since the hyperledger fabric is permissioned blockchain, therefore the party needs to have specific details such as CA, MSP.

With the above in mind, the study is novel in several ways. That is, this research introduces an innovative way to deal with most of IPD shortcomings regarding financial management in a single/integrated platform, as well as it is a step ahead to integrate blockchain technology into the AEC industry with proving its real applications rather than exploring the possibilities and potentials.

In practical terms, the findings will be invaluable for IPD adopters, given the simplicity and user-friendliness of the proposed financial system with respecting all IPD goals and merits. The IPD, BIM and blockchain are aligned together in a dynamic process to allow IPD users to exploit all available capabilities with noting that BIM is highly recommended to work with the IPD approach. Therefore, all input data for the endorsement policies are designed to be derived from BIM models, particularly 4D and 5D.

Objective 4: To develop and verify a “proof of Concept” that demonstrate all proposed tools of the developed framework using BIM and Blockchain technologies.

A system has been developed, which is called CCMS that includes cost database structure based on ABC and EVM methods. This system includes a database that was created using MS Access in order to automate the estimation process, cost budget data and automating the calculations of risk/reward for owner and non-owner parties by programming the developed risk/reward models as calculation fields into the database. In order to enable linking the developed database with a system, therefore, the database has been synchronised with an online system is called “Caspio”. The data has been linked with an interactive website, which was named “CCMS4IPD”, this website is smart since any party

can log in using an agreed authentication information , then can search using their package names to get access to the cost estimation, budgeting and risk/reward values—financial report. The proposed EVM grid has been developed using MS Excel-enabled Macros and it is linked to the website to enable generating a graphical report.

Regarding the blockchain, a proof of concept is then developed to test the applicability of the framework, the following tools have been used.

- IBM blockchain cloud beta 2 platform due to it is a user-friendly manner, as well as, this tool does not require skilled operators with high levels of competency. This will be therefore easy-to-use tool and applicable for general practitioners across the AEC industry, even junior and novice users.
- IBM VSCode blockchain extension that enables writing the smart contract with providing templates to help novice users to write the function in the right way.

Objective 5: To evaluate the research outcome and measure the potential users' satisfaction for the developed tools, as well as, making recommendations for future research.

An illustrative case study was used to measure the applicability, scalability and validity of the developed tools. Through testing the outcome of these tools, the entire system showed its capability to perform all tasks under different scenarios. Subsequently, seven interviews were conducted with IPD and BIM experts, the interviewees showed great satisfaction regarding the developed framework and tools such as CCMS and blockchain network. The interviewees recommended the CCMS to the industry in order to enhance the cost management practices. They also recommended extending the blockchain network and smart contract to perform more functions. Moreover, the proposed framework can be presented to the industry in stages to enable adopting it. The practical

implications of the developed web-based management system (CCMS4IPD) were clear for all participants, that's why all their answers were positive towards the potential applicability of the system, as well as, the entire system is user-friendly. The future of research for each task is extended and presented in a separate section in this chapter.

9.3.RESEARCH PRACTICAL IMPLICATIONS

9.3.1. The Practical Implications of CCMS

The developed CCMS provides an integrated platform to IPD users, this system considers all relevant processes such as coupling IPD and BIM to deliver the project. The proposed system considers the three main tasks in the cost management (Estimation, budget and control). The estimation platform has been designed/developed according to the developed framework as an automated ABC sheet is developed to determine the overhead costs and other sheets to determine other costs based on retrieved information from 3D BIM model. The proposed model is designed to be user-friendly through providing clear and efficient user interfaces for only required inputs and automatically all calculated fields will be automatically determined.

Regarding the cost budget, a distinguished presentation way of the data is presented in this system by providing separate curves of direct and indirect costs, overhead costs and the accumulative BCWS, as well as, the minimum/maximum cash inflow. All these are calculated automatically and presented in the web-interface to enable parties searching for their package budget information. This will enable parties to make the proper decision during the buyout stage based on rich information whether as budget metrics or graphical data. The automation in calculating these fields enable users to apply such a sophisticated process which is integrating ABC into 4D BIM to calculate the cost budget of each trade package.

The developed financial report includes all needed information both the collected data and the results that show the values of risk/reward—Profit cost saving and reimbursed costs— for owner and non-owner parties. The profit, cost saving and reimbursed costs are calculated automatically in the CCMS and linked with the CCMS4IPD website, accordingly, any party can log in and search using the milestone number (i.e. 1, 2), subsequently, the financial report will be available after providing the security information. It includes the general status of the project as proposed in the framework. Additionally, the user can move from this report to the graphical report (EVM grid) in order to see the amount of deviation from the neutral point (on cost/on schedule). This enables the inexperienced owners and trade contractors to interact efficiently in the core team of the IPD project as this will maximise their understandings to such sophisticated financial process.

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.

9.3.2. The Practical Implications of DCMS—Blockchain based IPD.

The proof of concept provided here presents a workable solution to one of the major challenges of adopting IPD in the construction industry, namely, managing financial transactions among project parties under the distinguished characteristics of IPD. This is accomplished through proposing a methodology to determine all financial values as a set of transactions that should be submitted at each payment milestone. The number of submitted transactions should be evaluated based on the generic performance of the project. For example, in an optimal scenario when the project has achieved a cost saving, therefore, three transactions should be invoked by the trade contractor, the reimbursed

costs, profits, and the cost saving. These three transactions can be invoked in the presented blockchain (Hyperledger fabric) network as the developed smart contract includes these three transactions, as well as another transaction from inquiry to enable any party to check the project financial progress, regardless of the party geographical zone. Validating the proposed framework by applying it on a real network and developing a smart contract includes all needed functions, this research offers the details of a workable solution to the documented financial decencies of IPD, as discussed below.

- The profit pooling – paying profits after all project works are completed, regardless of the trade packages timeline (Roy et al., 2018) – has been solved as all profit transactions will be received by the profit pool after passing the automated endorsement and the validation processes. Subsequently, all recorded values will be immutable and any potential amendments could cause destruction to the entire network.
- Another revealed an endemic financial issue with IPD was the inconsistency of accounting between the owner and non-owner parties (Ashcraft, 2011, Kent and Becerik-Gerber, 2010, Lichtig, 2006) that can lead to misunderstanding among parties. This is in contradiction to the main purpose of IPD to create a sustainable relationship. Therefore, the hyperledger fabric has a single/consistent electronic format to record the data and all parties will receive the inquired data in the same sequence, amounts and tokens (i.e. currencies).
- The promise of IPD is management by decentralised teams – there is no dominant party. This necessitates intensive meetings to make all required decision (Ashcraft, 2012, Roy et al., 2018). The proposed utilisation of the IPD-based blockchain can reduce the need for such intensive meetings, due to all financial issues being managed through the hyperledger fabric network. As another

advantage in facilitating decision making among IPD core team members, the endorsement policies include rigorous algorithms to define the paths of decision, in terms of identity of decision-makers and the effectiveness of previous decisions (i.e. the consultant party should validate all financial data, therefore, this party as a vital decision-makers should be mentioned in all decision paths).

- According to Pishdad-Bozorgi and Beliveau (2016), IPD targets creating sustainable relationships among parties in the AEC industry. This requires performance evaluation by the end of the project, in terms of achieved reward against risks for each party. To conduct this, the hyperledger fabric network, through the inquiry function, can provide all recorded accumulative risk/reward values for each node (party) in the network. As such, the owner can determine the parties who achieved their targets for informed decision making on future collaboration.

In practical terms, this study provides a workable solution to overcome the documented challenges of adopting blockchain in the construction industry. The proposed proof of concept offers several benefits:

- A network blockchain that uses cryptocurrencies instead of fiat currencies and the contradiction between the private ledger in the bank and the distributed ledger in the blockchain has been managed through utilising the hyperledger fabric – depends on tokens in sending transactions – to build the network, as well as, deploying the smart contract. IPD requires only to record the three main transactions (profit, cost saving and the reimbursed costs) and the actual money can be sent through the normal bank accounts.
- There are contractual challenges like the necessity of coding of unstraightforward legal concepts and other practical challenges. With that in mind, this study

succeeds in developing a smart contract that includes all the needed functions; non-coded expressions and elements will not affect the efficiency of the entire financial process.

- This study opens new horizons towards promoting the adoption of blockchain in the AEC industry, as well as, moving from the conceptual stage to the empirical real of applications of blockchain use cases. This provides a steppingstone from which future research studies can be directed through presenting the merits of blockchain in the form of a workable solution to IPD challenges, which alternatively requires sophisticated financial management processes. The same concept can be applied to other procurement approaches – the financial aspects of each approach.

9.4.RESEARCH LIMITATION AND FUTURE RESEARCH

Given this research is to develop an integrated cost management system of IPD and this system comprises of different tasks, therefore, there are some limitations pertain to each process. Below shows these limitations and how will be considered in future research.

9.4.1. Cost Estimation

The cost estimation in this research is the expected cost; therefore, the market and allowable cost were not considered due to the need for application in a real-life case project. Moreover, the objective of the research was to prepare a detailed and continuous estimation technique for IPD, with the contingency and risk factors having been considered as part of the profit-at-risk percentage. All these limitations provide fertile grounds for research to improve the proposed framework and develop an integrated cost management system for IPD projects using Building Information Modelling (BIM).

Moreover, the calculation of the cost contingency was out of the scope since this research interest to enhance the process of cost management and the risk allocation will be considered in future research and subsequently added to the compensation structure. However, this does not affect the findings and the applicability of the cost estimation in the CCMS.

9.4.2. Cost Budget

The chief limitation of this research concerns the use of different platforms to implement the proposed framework, thus exposing the study to issues of interoperability. However, in the current study, all the proposed platforms are interoperable, such as Revit, Navisworks and Excel. Future studies can overcome this by defining the development of Navisworks plug-ins to develop a cost management system within IPD, using the application programming interface (API), coded by C#.NET. Particularly, to develop the budget metrics (i.e. minimum/maximum cash inflow) inside the 4D BIM platforms without needing to extract the data to an external spreadsheet.

9.4.3. Cost Control and Developed Sharing Risk/Reward Model

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 the main target of using IPD in construction projects. Nevertheless, further research is

in progress to maximise the advantage of the presented model, moreover maximising the benefit of implementing IPD within the AEC industry.

The findings in this part of research can be used to develop a plug-in to be designed to be embedded, using Application Programming Interface (API) that is coded by C#.NET instead of the developed CCMS , 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 is solved in a timely manner.

Regarding the developed DCCMS—IPD-Based blockchain, given that this research developed a platform to deal with the financial challenges of implementing IPD projects, therefore, this research can be extended horizontally since the proposed financial system is validated by developing a “Proof of Concept”, therefore, a fully integrated prototype that includes an automated way to retrieve the data from BIM model to the blockchain network—to develop the endorsement policy—will be developed in future research. There is much more to be done in improving the proposed prototype. The developed framework can be extended vertically by adding more functions such as contingency costs so that each party can invoke this function to record the incurred values and unneeded proportion and other legal terms can be coded to automate the entire process and reduce the impact of the third party to the smart contract, and subsequently these functions can be invoked and add new features to the network. Moreover, this study presented a generic methodology to develop a blockchain network and smart contract for the IPD, therefore,

the same methodology that was used with the IBM blockchain platform can be used with any other platforms such as Oracle.

Given that IPD has a sophisticated financial process and the developed framework system showed its applicability to provide reliable solutions, hence, this framework can be extended to work with different delivery approaches such as Design-Build (DB) approach. In this case, some changes should be considered as (1) the endorsement policy, ordering policy need to be amended since the risk/reward sharing mechanism is not utilised, (2) the functions in the smart contract needs to be adjusted as only a single payment should be invoked in DB approach, (3) the blockchain network members will be different as the subcontractors cannot be a participant due to there are no a contractual relationships between owner and them.

Even though, the applicability and practicability of the framework is validated using an illustrative case study, however, further validation is required through conducting case study research, in order to observe attitudes of project stakeholders regarding the applicability of the proposed financial system.

9.5.SUMMARY

This chapter summarised the research findings, provided an overview of the achievement of research objectives, Practical implications and limitations and future research. This research presented the development of a centralised/decentralised cost management system for the IPD approach, this system is developed to overcome the revealed challenges from reviewing the literature review and the questionnaire. Hence, this will foster the implementation of the IPD approach. The limitations and future research are summarised for each process in the entire cost management system—Cost estimation, budgeting and risk/reward sharing—as well as providing future directions to maximise

the benefits of the blockchain and smart contract technologies to revolutionise the financial management for the IPD approach.

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11. Appendixes

11.1. Appendix A (Ethical approval)



Technology Faculty Ethics Committee

ethics-tech@port.ac.uk

Date 15/05/18

Faris Elghaish

School of Civil Engineering and Surveying

Dear Faris,

Study Title:	Integrating Activity Based Costing into BIM: A Cost Management Optimisation Prototype under an IPD approach.
Ethics Committee reference:	Tech 2018 - F.A.K.E - 02

The Ethics Committee reviewed the above application by an email discussion between the dates of 27/04/18 and 15/05/18.

Ethical opinion

A favourable ethical opinion of the survey has been given to the resubmitted application following review by 3 members of the Committee.

Conditions of the favourable opinion

- That the minor edits to be supplied by email are addressed and approved by the supervisor before data collection begins.
- The form is also fully proof read to remove the typos or mistakes.

Recommendations: (You should give these due consideration but there is no obligation to comply or respond)

None

The favourable opinion of the EC does not grant permission or approval to undertake the research. Management permission or approval must be obtained from any host organisation, including University of Portsmouth, prior to the start of the study.

Summary of discussion at the meeting

The reviewers were satisfied that issues of students as participants had been addressed in the revised application.

Documents reviewed

The documents reviewed at the meeting were:

Document	Version	Date
Application Form	2	20/4/2018
Questionnaire	2	20/04/2018
Focus Group Documentation	2	20/04/2018
Participant Information Sheet	2	20/04/2018
Consent Form	2	20/04/2018

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements set out by the University of Portsmouth

After ethical review

Reporting requirements

The attached document acts as a reminder that research should be conducted with integrity and gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Notification of serious breaches of the protocol
- Progress reports
- Notifying the end of the study

Feedback

You are invited to give your view of the service that you have received from the Faculty Ethics Committee. If you wish to make your views known please contact the administrator ethics-tech@port.ac.uk

Please quote this number on all correspondence: Tech 2018 - F.A.K.E - 02



Yours sincerely and wishing you every success in your research

A handwritten signature in black ink, appearing to read 'J Williams'.

Professor John Williams
Chair Technology FEC

Email: ethics-tech@port.ac.uk

11.2. Appendix B (questionnaire form)

Developing an automated cost management system within Integrated Project Delivery (IPD) using BIM tools

This project aims to develop an automated cost management system within the IPD approach using BIM tools. The integration and automation of cost management processes within the project life-cycle is seen as a key determinant of success within architecture, engineering, and construction (AEC) projects. Moreover, given that BIM projects are mainly contended through IPD approach. Since IPD's cost structure works as a barrier to implement it, therefore this research focus on integrating Activity Based Costing (ABC) into main three cost management process (Estimation, budget, Control) in order to optimise the cost structure elements at the early design stage. subsequently, this will affect the begetting and controlling processes. on the other hand, the automation requires smart platforms to implement it, thus BIM tools will be utilised in this research and in some cases BIM would be developed to be compatible with proposed cost management system. Moreover, the integration of BIM and IPD can enhance the entire outcomes of design and construction process due to this integration is associated with several parameters such as cost/profit, schedule, ROI, safety, productivity and contractual relationships.

***Required**

1. What is your current role? *

Mark only one oval.

- ☐ Quantity Surveyor
- ☐ BIM manager
- ☐ BIM technician
- ☐ BIM 4D/5D/6D Consultant
- ☐ Project Manager
- ☐ Holding an academic position in BIM or construction management
- ☐ Other: _____

2. Please, choose one of the below categories to describe your BIM experience? *

Mark only one oval.

- ☐ Less than a year
- ☐ 1-5 years
- ☐ 6-10 years
- ☐ More than 11 years
- ☐ Other: _____

3. What is your discipline regarding BIM dimensions implementation ? *

Mark only one oval.

- ☐ 4D
- ☐ 5D
- ☐ 6D
- ☐ Other: _____

4. Which Level of BIM your organisation is currently using? *

Mark only one oval.

- ☐ Level 2
- ☐ Level 3
- ☐ Level 3+(Beyond)
- ☐ Other: _____

BIM-Based Cost Management Process

This section focus on the capabilities of current BIM-based cost management implementation.

5. Do you think that 5D BIM estimation process considers all different elements of cost structure (Direct, Indirect, and overhead costs)? *

5D BIM: Most of the definitions state that BIM 5D is the preferred method for extracting the quantities from the BIM 3D model in order to enable cost consultants to commence the costing process by inserting the productivity allowances and pricing values (Eastman et al., 2011).

Mark only one oval.

- ☐ Yes
- ☐ No
- ☐ Not Sure
- ☐ Other: _____

6. What is the proportion of overhead cost in your current project or previous projects? *

Mark only one oval.

- ☐ 2-5%
- ☐ 6-8%
- ☐ 8-10%
- ☐ 11-15%
- ☐ more than 15%
- ☐ Not Sure
- ☐ Other: _____

7. Which method do you use to determine the proportion of overhead costs in your project or organisation? *

ABC is a sustainable system, through which the costs can be tracked by measuring the level of consumption of the cost drivers. Moreover, it allows identification of all project costs in terms of direct, indirect and overhead costs which represent the consumption of resources by the activities in the organisation hierarchy levels (functional, batch, daily task level) (Kim and Kim, 2016)

Mark only one oval.

- ☐ Resource Based Costing (RBC)
- ☐ Activity Based Costing (ABC)
- ☐ Other: _____

8. Can the Activity Based Costing (ABC) allocate the overhead cost fairly (helps to determine the actual achievement in each trade package)? *

Mark only one oval.

- ☐ Yes
☐ NO
☐ Not Sure
☐ Other: _____

9. Which method do you use for cost controlling task? *

Mark only one oval.

- ☐ Men hours achievements against planned hours
☐ Earned Value Management (EVM)
☐ Other: _____

10. Do you agree that EVM can facilitate management of the project costs during the construction stage? *

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly Agree

11. Please rate current BIM-based cost management tools. *

Mark only one oval.

	1	2	3	4	5	
Not Useful	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very Helpful

4D/5D BIM optimisation and automation

The research focus on developing an innovative method to enable the 4D BIM automation/optimisation within the IPD approach. Similar to structural/architectural designs libraries, the research will provide a planning and scheduling library to facilitate automation through the formulation of schedule as well as embedding the multi-objective optimisation into the scheduling process.

12. How many 4D BIM models have you been involved so far? *

BIM 4D: 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 & Greenwood, 2016)

Mark only one oval.

- ☐ 1-3
☐ 4-6
☐ 7-10
☐ more than 10
☐ None
☐ Other: _____

13. From a scale 1-5, how do you think existing 4D BIM tools support the creation of List of Activities? *

Mark only one oval.

	1	2	3	4	5	
Not Useful	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very helpful

14. Do you think existing 4D BIM platforms enable you to select the optimum constructability method to execute the activity? *

Mark only one oval.

☐ Yes

☐ No

☐ Not Sure

☐ Other: _____

15. Adding the below features to the current BIM 4D/5D tools can improve AEC projects implementation *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Not Sure
Adding the overhead activities to the list of activities to be able to measure its efficiency	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Generating S curve automatically which includes all cost elements (Direct, Indirect and Overhead costs)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

16. Do you agree that cash flow curves are easily formulated using 4D/5D BIM? *

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly Agree

17. Do you agree that the integration of 4D and 5D BIM is applicable by existing methods to draw project budget (S curve) ? *

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly Agree

BIM-Based Integrated Project Delivery (IPD) approach

BIM projects are recommended to be delivered by (IPD) approach due to its ability to enhance the collaboration between the all participants. However, The IPD compensation approach is complicated due to its inability to determine fair Risk/Rewards ratios. Therefore, integrating The Earned Value Management (EVM) into IPD compensation structure is proposed to manage the compensation approach. Moreover, the framework includes a developed EVM-Grid which can be used to cite the Cost Performance Ratio (CPR), and Schedule Performance Ratio (SPR) in order to determine the actual progress for cost and schedule. Furthermore, set of equations have been developed in order to deal with all possible progress cases to enable fair sharing between owner, and non-owner parties. Additionally, the Activity Based Costing (ABC) has been adopted in this framework due to its ability to

optimise the cost structure. The framework introduces a comprehensive approach to allocate Risk/Rewards percentage under the three different cases (Within the agreed budget, within the profit at risk allowance, and exceeding Profit at risk limit.

18. Do you use Integrated Project Delivery (IPD) in your projects/organisation? *

Mark only one oval.

- ☐ Yes
☐ No
☐ We are planning

19. Please, choose one of the following points to describe what do you believe in terms of main barrier to use IPD? *

Mark only one oval.

- ☐ The Compensation approach (Risk/Rewards sharing) is not matured completed
☐ Tendering method due to it is open pricing
☐ The early involvement for all participants
☐ The allocation of responsibilities and risks are not clear
☐ Other: _____

20. Did you participate in any project in which the IPD has been used to deliver the project? *

Tick all that apply.

- ☐ Yes
☐ No

21. What is your degree of understanding of IPD approach? *

Mark only one oval.

	1	2	3	4	5	
No Idea	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Expert

22. A fair allocation system with clear implementation models can enhance implementing IPD. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

23. Integrating EVM into IPD can easily facilitate its implementation regarding sharing risk/rewards between owner/non-owner parties *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

24. By adding the following features to IPD cost management approach could be improved. *

Earned Value Management (EVM): According to PMI (2004), Earned Value Analysis (EVA) is a project management technique to measure the project progress by indicating cost and schedule simultaneously.

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree	Not Sure
Utilising ABC in order to identify the different sources of overhead cost clearly	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adapting EVM with ABC to identify risk/rewards sharing fairly	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Providing an EVM grid to locate the Cost Performance Ratio (CPR) and Schedule Performance Ratio (SPR) to determine the holistic view of project progress	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developing an EVM-based Web report to enable tracking the project by all participants as well as easy access by different devices	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

25. Adopting ABC to develop list of activities enable getting a reliable cash out curve (S curve) by considering (Direct, Indirect, Overhead). *

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly Agree

26. Do you agree that adapting ABC in developing a cost management system could improve its function?

Mark only one oval.

- ☐ Yes
☐ No
☐ Not sure

27. How would you rate the following features to generate cash flows for all project parties before making the decision regarding accept the offer or reject it within the IPD buyout stage? *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Providing a separate cash flow for each participants including the proposed proportional cash in based on agree profit at risk percentage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
developing an automated model to show the duo payment for all parties based on their achievement against planned values	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>


) Developing an automated cost management system within Integrated Project Delivery (IPD) using BIM tools

28. Providing a comprehensive framework for cost management within the entire IPD stages could increase its implementation and minimising the waste in time and resources? *

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly Agree

29. If you want to get more information regarding the research's results, please write your email address below.

Powered by
 Google Forms

11.3. Appendix C (interview form)

Evaluation of "Developing an automated cost management system within Integrated Project Delivery (IPD) using BIM tools"

After watching the video and/or receiving the call, could you please answer the following questions.

Invitation Letter (the procedures of carrying out this interview has been endorsed by the faculty ethical committee.



Interview

Study Title: Developing an automated cost management system for the IPD approach using BIM and blockchain technology

Name of researcher and supervisor: Faris Ali Khairy Elghayth, under supervision of Dr Sepideh Abrishami

Contact details: (faris.elghayth@port.ac.uk)

Invitation

Thank you for reading this. I would like to invite you to take part in my research study by accepting to have interview with me. It is entirely up to you whether you participate but your responses would be valued. You have been identified as a potential respondent by checking your research papers and academic progress, we found that you are the best person who can validate our research. My study is: (Developing an automated cost management system for the IPD approach using BIM and blockchain technology). I neither need your name nor any identifying details; the interview can be completed anonymously and all reasonable steps will be taken to ensure confidentiality. Responses from completed interview will be collated for analysis; once this is complete the original questionnaires will be used in PhD research. Up to this stage, completed interview data will be stored in the university device and the data will be kept safe. If you wish to learn more about the results of the research please contact the researcher at the mentioned email.

Thanks, conclusion and further advice / support

Thank you for accepting to have this interview with me.

If you have any concerns regarding this research please contact me or my supervisor in the first instance. If you are not entirely happy with a response please contact, you can contact the supervisor through the following email (Sepideh.abrishami@port.ac.uk)

1. What is your current role?

Mark only one oval.

- ☐ Quantity Surveyor
- ☐ BIM manager
- ☐ Project Manager
- ☐ Holding an academic position in BIM or construction management
- ☐ Other: _____

2. Please, choose one of the below categories to describe your BIM experience?

Mark only one oval.

- ☐ 6-10 years
- ☐ 10 to 15 years
- ☐ More than 15 years
- ☐ Other: _____

3. What is your degree of understanding of IPD approach?

Mark only one oval.

	1	2	3	4	5	
No Idea	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Expert

4. Do you think the CCMS can solve the presented challenges of implementing IPD-based Cost management issues?

CCMS is the Centralised Cost Management System. This system represents the application of the proposed framework such as the Access database and the online database and the Web-based management system.

5. Do you think the DCMS using blockchain can enhance the trust and collaboration among IPD core team members?

DCMS is Decentralised Cost Management System. This represents the smart contract and the proposed blockchain network.

6. Do you believe that the proposed framework captures the cost management tasks of the IPD process adequately? Why?

7. Would you add or remove any of its tasks/processes, tools ? Which ones and why?

8. Do you find such a framework including its tools such as the Web-based management system useful? Why

9. Regarding the CCMS-based web, Does the web includes all cost data for the IPD users?, is the financial report understandable and readable?, Do you think the EVM-Grid facilitate for the IPD members to visualise their project status?.

10. Do you believe that the blockchain framework could foster the application of the blockchain for the sophisticated financial issues such as the IPD risk/reward sharing?

11. Please summarise your views about the proposed automated CCMS/DCMS of the IPD.

11.4. Appendix D (Sample of interview script)

Do you think the CCMS can solve the presented challenges of implementing IPD-based Cost management issues?

The CCMS proposed here can provide a real-life solution for integration several innovative methodologies. This will give practitioners the chance of using the full potential of these methodologies relying on the synergy provided among these by CCMS. Therefore, CCMS can be a step towards changing practices in the industry.

Yes as it provides a platform for real time shared cost information

Yes

Yes, sure it can as the web-based management systems allow financial information reports and sharing

Yes

Integrated project delivery (IPD) is seen by many practitioners and in the academia as the most effective delivery approach to implement BIM effectively. Despite that, IPD is rarely implemented in its pure form worldwide due to many technical, financial and legal challenges. One of the challenges upon these is the absence of tender stage. This framework has a significant contribution toward overcoming such challenge.

It has the potential to support IPD-based cost management. However, however some training has to be provided for the users.

Do you think the DCMS using blockchain can enhance the trust and collaboration among IPD core team members?

Yes

One major issue is the problem of unethical behaviour and trust among industry practitioners. DCMS can provide peace of mind for practitioners and as a result overcome the barriers of collaboration due to trust problems.

Yes as the blockchain encourages trust between stakeholders

Smart contracts is based on trust between stakeholders, so yes I think so

Yes it does through many features exist in this framework

It has the potential to support collaboration among the team, however as you known trust is a social element so attention must be given to cultural issues around the project environment.

Do you believe that the proposed framework captures the cost management tasks of the IPD process adequately? Why?

Yes. The framework captures all the details and all the requirements of an advanced cost management system. All details are considered and incorporated into the design of the framework.

Yes as it takes into consideration the direct, indirect and overhead costs in addition to the profit at risk percentage. Plus it gives clear picture about the cash in and out so no profits are hidden.

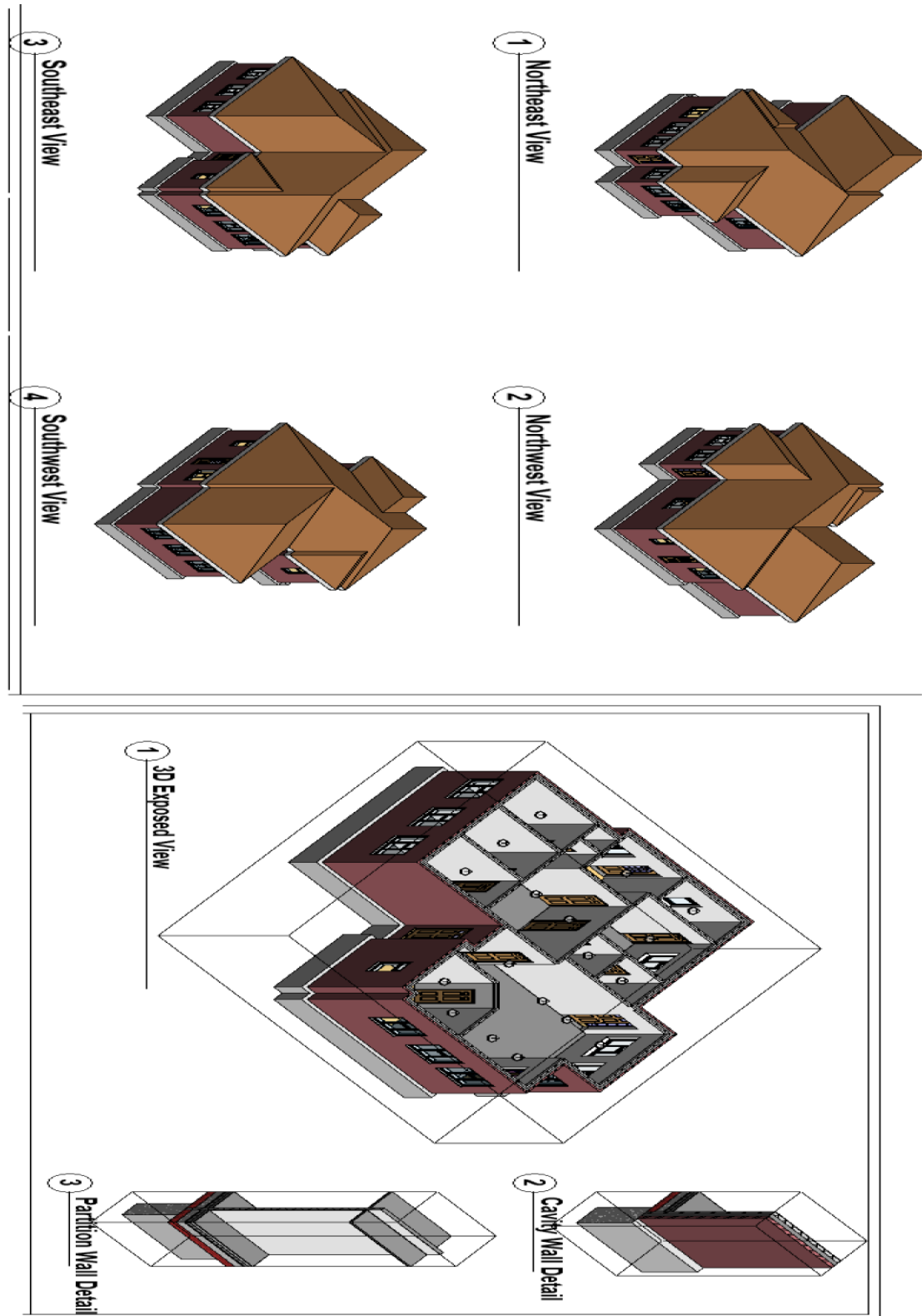
Yes, the framework captured all the necessary aspects and indicators required to properly manage the project.

yes it does, as the web-based system allows stakeholders to access financial data and be updated about the cash in and out and any possible risk

Yes. However, I am not sure if the framework will be the same in complex large size project.

11.5. Appendix E (3D BIM documents for the case study)

11.5.1. 3D BIM model



11.5.2. List of Schedules

Coping Strategy Tactic			
Age	Gender	Mean	SD
16	Male	2.76	0.76
16	Female	2.76	0.76
17	Male	2.76	0.76
17	Female	2.76	0.76
18	Male	2.76	0.76
18	Female	2.76	0.76
19	Male	2.76	0.76
19	Female	2.76	0.76
20	Male	2.76	0.76
20	Female	2.76	0.76
21	Male	2.76	0.76
21	Female	2.76	0.76
22	Male	2.76	0.76
22	Female	2.76	0.76
23	Male	2.76	0.76
23	Female	2.76	0.76
24	Male	2.76	0.76
24	Female	2.76	0.76
25	Male	2.76	0.76
25	Female	2.76	0.76
26	Male	2.76	0.76
26	Female	2.76	0.76
27	Male	2.76	0.76
27	Female	2.76	0.76
28	Male	2.76	0.76
28	Female	2.76	0.76
29	Male	2.76	0.76
29	Female	2.76	0.76
30	Male	2.76	0.76
30	Female	2.76	0.76
31	Male	2.76	0.76
31	Female	2.76	0.76
32	Male	2.76	0.76
32	Female	2.76	0.76
33	Male	2.76	0.76
33	Female	2.76	0.76
34	Male	2.76	0.76
34	Female	2.76	0.76
35	Male	2.76	0.76
35	Female	2.76	0.76
36	Male	2.76	0.76
36	Female	2.76	0.76
37	Male	2.76	0.76
37	Female	2.76	0.76
38	Male	2.76	0.76
38	Female	2.76	0.76
39	Male	2.76	0.76
39	Female	2.76	0.76
40	Male	2.76	0.76
40	Female	2.76	0.76
41	Male	2.76	0.76
41	Female	2.76	0.76
42	Male	2.76	0.76
42	Female	2.76	0.76
43	Male	2.76	0.76
43	Female	2.76	0.76
44	Male	2.76	0.76
44	Female	2.76	0.76
45	Male	2.76	0.76
45	Female	2.76	0.76
46	Male	2.76	0.76
46	Female	2.76	0.76
47	Male	2.76	0.76
47	Female	2.76	0.76
48	Male	2.76	0.76
48	Female	2.76	0.76
49	Male	2.76	0.76
49	Female	2.76	0.76
50	Male	2.76	0.76
50	Female	2.76	0.76
51	Male	2.76	0.76
51	Female	2.76	0.76
52	Male	2.76	0.76
52	Female	2.76	0.76
53	Male	2.76	0.76
53	Female	2.76	0.76
54	Male	2.76	0.76
54	Female	2.76	0.76
55	Male	2.76	0.76
55	Female	2.76	0.76
56	Male	2.76	0.76
56	Female	2.76	0.76
57	Male	2.76	0.76
57	Female	2.76	0.76
58	Male	2.76	0.76
58	Female	2.76	0.76
59	Male	2.76	0.76
59	Female	2.76	0.76
60	Male	2.76	0.76
60	Female	2.76	0.76
61	Male	2.76	0.76
61	Female	2.76	0.76
62	Male	2.76	0.76
62	Female	2.76	0.76
63	Male	2.76	0.76
63	Female	2.76	0.76

[illegible]

Election Results by Township				
Age	CR	SD/IN	Lean	Unaffiliated
18-29	61.5%	37.5%	1.0%	7.0%
30-39	54.5%	42.5%	1.0%	1.0%
40-49	51.5%	45.5%	1.0%	2.0%
50-59	48.5%	48.5%	1.0%	2.0%
60-69	45.5%	51.5%	1.0%	2.0%
70-79	42.5%	54.5%	1.0%	2.0%
80-89	39.5%	57.5%	1.0%	2.0%
90-99	36.5%	60.5%	1.0%	2.0%
100+	33.5%	63.5%	1.0%	2.0%
18-29	61.5%	37.5%	1.0%	7.0%
30-39	54.5%	42.5%	1.0%	1.0%
40-49	51.5%	45.5%	1.0%	2.0%
50-59	48.5%	48.5%	1.0%	2.0%
60-69	45.5%	51.5%	1.0%	2.0%
70-79	42.5%	54.5%	1.0%	2.0%
80-89	39.5%	57.5%	1.0%	2.0%
90-99	36.5%	60.5%	1.0%	2.0%
100+	33.5%	63.5%	1.0%	2.0%
18-29	61.5%	37.5%	1.0%	7.0%
30-39	54.5%	42.5%	1.0%	1.0%
40-49	51.5%	45.5%	1.0%	2.0%
50-59	48.5%	48.5%	1.0%	2.0%
60-69	45.5%	51.5%	1.0%	2.0%
70-79	42.5%	54.5%	1.0%	2.0%
80-89	39.5%	57.5%	1.0%	2.0%
90-99	36.5%	60.5%	1.0%	2.0%
100+	33.5%	63.5%	1.0%	2.0%
18-29	61.5%	37.5%	1.0%	7.0%
30-39	54.5%	42.5%	1.0%	1.0%
40-49	51.5%	45.5%	1.0%	2.0%
50-59	48.5%	48.5%	1.0%	2.0%
60-69	45.5%	51.5%	1.0%	2.0%
70-79	42.5%	54.5%	1.0%	2.0%
80-89	39.5%	57.5%	1.0%	2.0%
90-99	36.5%	60.5%	1.0%	2.0%
100+	33.5%	63.5%	1.0%	2.0%
18-29	61.5%	37.5%	1.0%	7.0%
30-39	54.5%	42.5%	1.0%	1.0%
40-49	51.5%	45.5%	1.0%	2.0%
50-59	48.5%	48.5%	1.0%	2.0%
60-69	45.5%	51.5%	1.0%	2.0%
70-79	42.5%	54.5%	1.0%	2.0%
80-89	39.5%	57.5%	1.0%	2.0%
90-99	36.5%	60.5%	1.0%	2.0%
100+	33.5%	63.5%	1.0%	2.0%

[illegible]

BANK OF AMERICA									
DATE	DESCRIPTION	AMOUNT	CHECK	DEBIT	CREDIT	BALANCE	INTEREST	FEE	REMARKS
10/1/2018	DEPOSIT	100.00			100.00	100.00			
10/2/2018	DEPOSIT	250.00			250.00	350.00			
10/3/2018	DEPOSIT	150.00			150.00	500.00			
10/4/2018	DEPOSIT	75.00			75.00	575.00			
10/5/2018	DEPOSIT	50.00			50.00	625.00			
10/6/2018	DEPOSIT	25.00			25.00	650.00			
10/7/2018	DEPOSIT	12.50			12.50	662.50			
10/8/2018	DEPOSIT	6.25			6.25	668.75			
10/9/2018	DEPOSIT	3.12			3.12	671.87			
10/10/2018	DEPOSIT	1.56			1.56	673.43			
10/11/2018	DEPOSIT	0.78			0.78	674.21			
10/12/2018	DEPOSIT	0.39			0.39	674.60			
10/13/2018	DEPOSIT	0.19			0.19	674.79			
10/14/2018	DEPOSIT	0.09			0.09	674.88			
10/15/2018	DEPOSIT	0.05			0.05	674.93			
10/16/2018	DEPOSIT	0.02			0.02	674.95			
10/17/2018	DEPOSIT	0.01			0.01	674.96			
10/18/2018	DEPOSIT	0.00			0.00	674.96			
10/19/2018	DEPOSIT	0.00			0.00	674.96			
10/20/2018	DEPOSIT	0.00			0.00	674.96			
10/21/2018	DEPOSIT	0.00			0.00	674.96			
10/22/2018	DEPOSIT	0.00			0.00	674.96			
10/23/2018	DEPOSIT	0.00			0.00	674.96			
10/24/2018	DEPOSIT	0.00			0.00	674.96			
10/25/2018	DEPOSIT	0.00			0.00	674.96			
10/26/2018	DEPOSIT	0.00			0.00	674.96			
10/27/2018	DEPOSIT	0.00			0.00	674.96			
10/28/2018	DEPOSIT	0.00			0.00	674.96			
10/29/2018	DEPOSIT	0.00			0.00	674.96			
10/30/2018	DEPOSIT	0.00			0.00	674.96			
10/31/2018	DEPOSIT	0.00			0.00	674.96			
11/1/2018	DEPOSIT	0.00			0.00	674.96			
11/2/2018	DEPOSIT	0.00			0.00	674.96			
11/3/2018	DEPOSIT	0.00			0.00	674.96			
11/4/2018	DEPOSIT	0.00			0.00	674.96			
11/5/2018	DEPOSIT	0.00			0.00	674.96			
11/6/2018	DEPOSIT	0.00			0.00	674.96			
11/7/2018	DEPOSIT	0.00			0.00	674.96			
11/8/2018	DEPOSIT	0.00			0.00	674.96			
11/9/2018	DEPOSIT	0.00			0.00	674.96			
11/10/2018	DEPOSIT	0.00			0.00	674.96			
11/11/2018	DEPOSIT	0.00			0.00	674.96			
11/12/2018	DEPOSIT	0.00			0.00	674.96			
11/13/2018	DEPOSIT	0.00			0.00	674.96			
11/14/2018	DEPOSIT	0.00			0.00	674.96			
11/15/2018	DEPOSIT	0.00			0.00	674.96			
11/16/2018	DEPOSIT	0.00			0.00	674.96			
11/17/2018	DEPOSIT	0.00			0.00	674.96			
11/18/2018	DEPOSIT	0.00			0.00	674.96			
11/19/2018	DEPOSIT	0.00			0.00	674.96			
11/20/2018	DEPOSIT	0.00			0.00	674.96			
11/21/2018	DEPOSIT	0.00			0.00	674.96			
11/22/2018	DEPOSIT	0.00			0.00	674.96			
11/23/2018	DEPOSIT	0.00			0.00	674.96			
11/24/2018	DEPOSIT	0.00			0.00	674.96			
11/25/2018	DEPOSIT	0.00			0.00	674.96			
11/26/2018	DEPOSIT	0.00			0.00	674.96			
11/27/2018	DEPOSIT	0.00			0.00	674.96			
11/28/2018	DEPOSIT	0.00			0.00	674.96			
11/29/2018	DEPOSIT	0.00			0.00	674.96			
11/30/2018	DEPOSIT	0.00			0.00	674.96			
11/31/2018	DEPOSIT	0.00			0.00	674.96			

[illegible]

Bridges Incorporated				
Bridge	Year	Rating	Height	Cost
1901	1901	1	100	
1902	1902	2	120	
1903	1903	3	140	
1904	1904	4	160	
1905	1905	5	180	
1906	1906	6	200	
1907	1907	7	220	
1908	1908	8	240	
1909	1909	9	260	
1910	1910	10	280	
1911	1911	11	300	
1912	1912	12	320	
1913	1913	13	340	
1914	1914	14	360	
1915	1915	15	380	
1916	1916	16	400	
1917	1917	17	420	
1918	1918	18	440	
1919	1919	19	460	
1920	1920	20	480	
1921	1921	21	500	
1922	1922	22	520	
1923	1923	23	540	
1924	1924	24	560	
1925	1925	25	580	
1926	1926	26	600	
1927	1927	27	620	
1928	1928	28	640	
1929	1929	29	660	
1930	1930	30	680	
1931	1931	31	700	
1932	1932	32	720	
1933	1933	33	740	
1934	1934	34	760	
1935	1935	35	780	
1936	1936	36	800	
1937	1937	37	820	
1938	1938	38	840	
1939	1939	39	860	
1940	1940	40	880	
1941	1941	41	900	
1942	1942	42	920	
1943	1943	43	940	
1944	1944	44	960	
1945	1945	45	980	
1946	1946	46	1000	
1947	1947	47	1020	
1948	1948	48	1040	
1949	1949	49	1060	
1950	1950	50	1080	
1951	1951	51	1100	
1952	1952	52	1120	
1953	1953	53	1140	
1954	1954	54	1160	
1955	1955	55	1180	
1956	1956	56	1200	
1957	1957	57	1220	
1958	1958	58	1240	
1959	1959	59	1260	
1960	1960	60	1280	
1961	1961	61	1300	
1962	1962	62	1320	
1963	1963	63	1340	
1964	1964	64	1360	
1965	1965	65	1380	
1966	1966	66	1400	
1967	1967	67	1420	
1968	1968	68	1440	
1969	1969	69	1460	
1970	1970	70	1480	
1971	1971	71	1500	
1972	1972	72	1520	
1973	1973	73	1540	
1974	1974	74	1560	
1975	1975	75	1580	
1976	1976	76	1600	
1977	1977	77	1620	
1978	1978	78	1640	
1979	1979	79	1660	
1980	1980	80	1680	
1981	1981	81	1700	
1982	1982	82	1720	
1983	1983	83	1740	
1984	1984	84	1760	
1985	1985	85	1780	
1986	1986	86	1800	
1987	1987	87	1820	
1988	1988	88	1840	
1989	1989	89	1860	
1990	1990	90	1880	
1991	1991	91	1900	
1992	1992	92	1920	
1993	1993	93	1940	
1994	1994	94	1960	
1995	1995	95	1980	
1996	1996	96	2000	
1997	1997	97	2020	
1998	1998	98	2040	
1999	1999	99	2060	
2000	2000	100	2080	

Division Schedule A					
League	Week	Month	Division	Team	Manager
24-25	21-22	12-13	18-19	10-11-12-13	none
24-25	21-22	12-13	20-21	10-11-12-13	none
24-25	21-22	12-13	22-23	10-11-12-13	none
24-25	21-22	12-13	24-25	10-11-12-13	none
24-25	21-22	12-13	26-27	10-11-12-13	none
24-25	21-22	12-13	28-29	10-11-12-13	none
24-25	21-22	12-13	30-31	10-11-12-13	none
24-25	21-22	12-13	1-2	10-11-12-13	none
24-25	21-22	12-13	3-4	10-11-12-13	none
24-25	21-22	12-13	5-6	10-11-12-13	none
24-25	21-22	12-13	7-8	10-11-12-13	none
24-25	21-22	12-13	9-10	10-11-12-13	none
24-25	21-22	12-13	11-12	10-11-12-13	none
24-25	21-22	12-13	13-14	10-11-12-13	none
24-25	21-22	12-13	15-16	10-11-12-13	none
24-25	21-22	12-13	17-18	10-11-12-13	none
24-25	21-22	12-13	19-20	10-11-12-13	none
24-25	21-22	12-13	21-22	10-11-12-13	none
24-25	21-22	12-13	23-24	10-11-12-13	none
24-25	21-22	12-13	25-26	10-11-12-13	none
24-25	21-22	12-13	27-28	10-11-12-13	none
24-25	21-22	12-13	29-30	10-11-12-13	none
24-25	21-22	12-13	31-1	10-11-12-13	none
24-25	21-22	12-13	2-3	10-11-12-13	none
24-25	21-22	12-13	4-5	10-11-12-13	none
24-25	21-22	12-13	6-7	10-11-12-13	none
24-25	21-22	12-13	8-9	10-11-12-13	none
24-25	21-22	12-13	10-11	10-11-12-13	none
24-25	21-22	12-13	12-13	10-11-12-13	none
24-25	21-22	12-13	14-15	10-11-12-13	none
24-25	21-22	12-13	16-17	10-11-12-13	none
24-25	21-22	12-13	18-19	10-11-12-13	none
24-25	21-22	12-13	20-21	10-11-12-13	none
24-25	21-22	12-13	22-23	10-11-12-13	none
24-25	21-22	12-13	24-25	10-11-12-13	none
24-25	21-22	12-13	26-27	10-11-12-13	none
24-25	21-22	12-13	28-29	10-11-12-13	none
24-25	21-22	12-13	30-31	10-11-12-13	none
24-25	21-22	12-13	1-2	10-11-12-13	none
24-25	21-22	12-13	3-4	10-11-12-13	none
24-25	21-22	12-13	5-6	10-11-12-13	none
24-25	21-22	12-13	7-8	10-11-12-13	none
24-25	21-22	12-13	9-10	10-11-12-13	none
24-25	21-22	12-13	11-12	10-11-12-13	none
24-25	21-22	12-13	13-14	10-11-12-13	none
24-25	21-22	12-13	15-16	10-11-12-13	none
24-25	21-22	12-13	17-18	10-11-12-13	none
24-25	21-22	12-13	19-20	10-11-12-13	none
24-25	21-22	12-13	21-22	10-11-12-13	none
24-25	21-22	12-13	23-24	10-11-12-13	none
24-25	21-22	12-13	25-26	10-11-12-13	none
24-25	21-22	12-13	27-28	10-11-12-13	none
24-25	21-22	12-13	29-30	10-11-12-13	none
24-25	21-22	12-13	31-1	10-11-12-13	none

11.6. Appendix F (CCMS Outcome for the Case Study)

11.6.1. CCMS (ABC sheet)

ID	Codes	Activities	Task type	Cost driver	Units	Cost unit	LMB2	Total Cost	Project parties	Overhead Cons	Actual One	CS000A	CS00PA	TCS00C
+	1 010G	Setting out	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0.8	£1,200.00	£0.00	£300.00	£300.00
+	2 010G	Inspection of formworks	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	1	£2,884.62	£0.00	£0.00	£0.00
+	3 010G	Inspection of rebar works	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	1	£2,884.62	£0.00	£0.00	£0.00
+	4 020G	Inspection of foundation batch	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	1	£2,884.62	£0.00	£0.00	£0.00
+	5 010G	Setting out walls	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0.8	£1,200.00	£0.00	£300.00	£300.00
+	6 020G	Inspection of masonry works	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	1	£2,884.62	£0.00	£0.00	£0.00
+	7 010F	Setting out separation of rooms	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	Finishing Package Contractor	1	£1,500.00	£0.00	£0.00	£0.00
+	8 020F	Mobilese material	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Finishing Package Contractor	1	£1,000.00	£0.00	£0.00	£0.00
+	9 010F	Inspection of separation of rooms	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Finishing Package Contractor	1	£2,884.62	£0.00	£0.00	£0.00
+	10 020G	Mobilese roof material	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	General Package Contractor	0.737	£737.00	£0.00	£263.00	£263.00
+	11 010G	Setting out	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0.9	£1,350.00	£0.00	£150.00	£150.00
+	12 020G	Inspection roof package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	13 010G	Setting out of floors	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	14 010G	Inspection of floors	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	15 030G	Cost control report for general works	Package Level	Proportion of the Packe	1	£3,250.00	£3,250.00	£3,250.00	General Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	16 020WD	Mobilese windows and doors	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Windows & Doors Package Cont	0	£0.00	£0.00	£0.00	£0.00
+	17 020WD	Inspection of D&W package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Windows & Doors Package Cont	0	£0.00	£0.00	£0.00	£0.00
+	18 030WD	Cost control report for D&W works	Core Team Level	Proportion of the Packe	1	£3,250.00	£3,250.00	£3,250.00	Windows & Doors Package Cont	0	£0.00	£0.00	£0.00	£0.00
+	19 020C	Mobilese ceiling material	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	20 010C	Setting out of ceiling	Daily task Level	Number of days	1	£1,500.00	£1,500.00	£1,500.00	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	21 010C	Inspection of the ceiling grids	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	22 020LF	Mobilese lighting fixtures	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Lighting Fixture Package Contract	0	£0.00	£0.00	£0.00	£0.00
+	23 020LF	Inspection of the ceiling package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Lighting Fixture Package Contract	0	£0.00	£0.00	£0.00	£0.00
+	24 030C	Cost control report for ceiling works	Core Team Level	Proportion of the Packe	1	£3,250.00	£3,250.00	£3,250.00	Ceiling Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	25 020LF	Inspection of the lighting fixture package	Package Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Lighting Fixture Package Contract	0	£0.00	£0.00	£0.00	£0.00
+	26 030LF	Cost control report for lighting and fixture w	Core Team Level	Proportion of the Packe	1	£3,250.00	£3,250.00	£3,250.00	Lighting Fixture Package Contract	0	£0.00	£0.00	£0.00	£0.00
+	27 020F	Mobilese finishing works	Package Level	Number of receipts	1	£1,000.00	£1,000.00	£1,000.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	28 010F	Inspection of the floor carpet	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	29 010F	Inspection of the paint work	Daily task Level	Number of inspections	1	£2,884.62	£2,884.62	£2,884.62	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	30 030F	Cost control report for finishing package	Core Team Level	Proportion of the Packe	1	£3,250.00	£3,250.00	£3,250.00	Finishing Package Contractor	0	£0.00	£0.00	£0.00	£0.00
+	31 40	Final cost control report for the entire work	Core Team Level	Number of Reports	1	£3,250.00	£3,250.00	£3,250.00	Architect/Consultant, Ceiling Pack	0	£0.00	£0.00	£0.00	£0.00
+	(New)				0	£0.00				0				
	Total					£72,000.00	£72,000.00	£72,000.00			£21,410.08	£0.00	£1,013.00	£1,013.00

11.6.2. CCMS (LIMB-1 sheets)

ABC Sheet Financial Report LIMB-1 (Direct and Indirect costs)						
Codes	Construction Package	MC-Based BIM	LC-Based BIM	EquipCost-Based BIM	LIMB1	
CWLIMB-1	Ceiling Package	£2,140.20	£1,715.00	£0.00	£3,855.20	
FWLIMB-1	Finishing Package	£3,553.80	£1,334.40	£0.00	£4,888.20	
GWLIMB-1	General Package	£38,038.90	£21,318.90	£366.80	£59,724.60	
LFWLIMB-1	Lighting Fixture Package	£17,037.90	£296.50	£0.00	£17,334.40	
WDWLIMB-1	Windows and Doors Packag	£31,919.10	£763.00	£0.00	£32,682.10	
*		£0.00	£0.00	£0.00		
Total		£92,689.90	£25,427.80	£0.00	£118,484.50	

11.6.3. CCMS (Compensation structure)

ABC Sheet Financial Report LIMB-1 (Direct and Indirect costs) Packages costs								
Project parties	Limb-1	Overhead α	Limb-2 (CTV	Limb-2	Limb-3	Total Cost/Package	Project Compensation Str	
Ceiling Works Contractor	£3,855.20	3.25%	£105.74	£11,519.20	3096.0276	£15,480.14	£18,576.17	
Finishing Works Contractor	£4,888.30	4.13%	£134.07	£15,403.80	4085.23464	£20,426.17	£24,511.41	
General Works Contractor	£59,724.70	50.40%	£1,638.09	£27,557.60	17784.07822	£88,920.39	£106,704.47	
Lighting Fixture Contractor	£17,344.40	14.64%	£475.71	£7,134.60	4990.94224	£24,954.71	£29,945.65	
Windows and Doors Works Contractor	£32,682.20	27.58%	£896.39	£7,134.60	8142.63732	£40,713.19	£48,855.82	
*	£0.00			£0.00				
Total		100.00%	£3,250.00	£68,749.80	38098	£190,494.60	£228,593.52	

11.6.4. CCMS (Developing calculation fields for sharing/reward model)

ABC Sheet

Financial Report

Field Name	Data Type
MV for RD for each party (LIMB-1)	Calculated
PoO	Number
PoNO	Number
Reward For Owner (LIMB-1)	Calculated
Reward For non-Owner parties	Calculated
CSOOA	Number
CSOPA	Number
CSOC for NO	Calculated
CSOC for O	Calculated
TR4O	Calculated
TR4NO	Calculated
Reimbursed C	Calculated
Profit	Calculated

Expression Builder

Enter an Expression to calculate the value of the **calculated column**:

(Examples of expressions include [field1] + [field2] and [field1] < 5)

IIf([EVO4Profit]>0,([TCS]-([Profit]+[MV for RD for each party (LIMB-1)]+[CSOC for NO]+[CSOC for O])),([TCS]-[Profit])+[DC above TCS])

OK

Cancel

Help

<< Less

Expression Elements

Financial Report

Functions

Constants

Operators

Expression Categories

Payment Milestones

Project Case

NOARP

OARP

P@R per

CPI

SPI

EVO

Adjusted EVO

EVO4Profit

PLIMB-1

Expression Values

<Value>

Expression Builder

Enter an Expression to calculate the value of the **calculated column**:

(Examples of expressions include [field1] + [field2] and [field1] < 5)

IIf([EVO4Profit]>=[P@R per],[LIMB-3],[EVO4Profit]*10*[LIMB-3])

OK

Cancel

Help

<< Less

Expression Elements

Financial Report

Functions

Constants

Operators

Expression Categories

Payment Milestones

Project Case

NOARP

OARP

P@R per

CPI

SPI

EVO

Adjusted EVO

EVO4Profit

PLIMB-1

Expression Values

<Value>

347

11.7. Case study cost estimation sheets

11.7.1. Direct and indirect cost estimation based BIM data

A	B	C	D	E	F	G	H	I
NO	the item	The Quantit	unit	the cost/unit (£)	The total MC (£)			
1	Wall Foundation 750 wide x 1000 deep	1,792.381	ft3	2.69	4821.504148			
2	Wall Foundation 539 wide x 1000 deep	1072.385456	ft3	2.69	2884.716875			
3	Wall-Ext_103Bwk-120Ins-100LBlk-12	2,219.162	ft2	4.5	9986.229191			
4	Wall-Int_12P-100Blk-12P_	2106.811468	ft2	4.5	9480.651607			
5	Room Separation	26.08103675	ft	10.66	278.0238517			
6	Room finishing	2019.11387	ft2	0.81	1635.482234			
7	Compound Ceiling 600x600mm_Grid	2019.116527	ft2	1.06	2140.263518			
8	Doors_IntSgl_6 910x2110mm	330.4690924	ft2	17	5617.974571			
9	Doors_ExtSgl_w-Side Panel 1360x2110mm	123.3065328	ft2	36.6	4513.019101			
10	Doors_ExtSgl_w-Glazing_Bars_Arched 1010	35.27072842	ft2	18.4	648.9813661			
11	Floor-Grnd-Bearing-19Qiles-56Scr-100Ins	434.838	ft2	2.69	1169.714155			
12	Floor-Grnd-Bearing-15Carpet-60Scr-100Ins	1,608.220	ft2	1.02	1640.384672			
13	Lighting_Fixtures_Pendant_1 100_Watt_Inc	355.031	ft2	47.99	17037.93396			
14	Windows_Tpl_Casement_Top-Hung_Centre	492.830	ft2	38	18727.5233			
15	Windows_Sgl_Casement_Top-Hung 910x12	44.825	ft2	53.8	2411.601279			
16	Roof-Pitched_38Tile-25Bat-0Felt-25bat-10	3,729.279	ft3	2.6	9696.125628			
16	the total Material Cost				92690.12946			
21	NO	the item	he Quantit	unit	labour			
22					productivity	required crews (£)	the cost/ crew (£)	the total cost (£)
23	1	Wall Foundation 750 wide x 1000 deep	101.500	m3	19	5.342105263	1480	7906.315789
24	2	Wall Foundation 539 wide x 1000 deep						
25	3	Wall-Ext_103Bwk-120Ins-100LBlk-12	62.840	m3	16.5	3.80845865	640	2437.413536
26	4	Wall-Int_12P-100Blk-12P_	59.65815899	m3	16.5	3.615645999	640	2314.013439
27	5	Room Separation	7.9495	m	47	0.169138298	320	54.12425532
28	6	Room finishing	187.5817358	m2	88	2.131610634	120	255.7932761
29	7	Compound Ceiling 600x600mm_Grid	187.5819827	m2	35	5.35948522	320	1715.03527
30	8	Doors_IntSgl_6 910x2110mm	30.70157009	m2	35	0.877187717	280	245.6125608
31	9	Doors_ExtSgl_w-Side Panel 1360x2110mm	11.45554682	m2	35	0.327301338	280	91.64437454
32	10	Doors_ExtSgl_w-Glazing_Bars_Arched 1010	3.276756297	m2	35	0.093621608	280	26.21405037
33	11	Floor-Grnd-Bearing-19Qiles-56Scr-100Ins	40.398	m2	34	1.188169191	800	950.5353526
34	12	Floor-Grnd-Bearing-15Carpet-60Scr-100Ins	149.408	m2	35	4.268813926	240	1024.515342
35	13	Lighting_Fixtures_Pendant_1 100_Watt_Inc	32.983	m2	17.8	1.853002122	160	296.4803396
36	14	Windows_Tpl_Casement_Top-Hung_Centre	45.785	m2	35	1.308152705	280	366.2827574
37	15	Windows_Sgl_Casement_Top-Hung 910x12	4.164	m2	35	0.118983002	280	33.31524068
38	1	Roof-Pitched_38Tile-25Bat-0Felt-25bat-10	301.200	m2	25	12.048	640	7710.72
39	16	the total labour costs						25428.01558
42	NO	the item	he Quantit	unit	Equipment (£)			
43					productivity	required crews	the cost/ crew	the total cost
44	1	Excavation	300	m3	229	1.310043668	280	366.8122271
45	2	the total labour costs						366.8122271
47	NO	the item	he Quantit	unit	labour (£)			
48					productivity	required crews	the cost/ crew	the total cost
49	1	Roof-Pitched_38Tile-25Bat-0Felt-25bat-10	301.200	m2	25	12.048	640	7710.72
50	2	the total package cost						7710.72
52	NO	the item	he Quantit	unit	labour			
53					no of working da	required crews	the cost/ crew	the total cost (£)
54	1	general labours	1.000	no	116	116	80	9280
55	2	the total indirect labor cost						9280

11.7.2. Monte Carlo Simulation based BIM Data Sample


Items	Quantities	Unit	cost/unit	Best values	Possible values	Worst values
Wall Foundation 750 wide x 1000 deep	1792.4	ft3	2.3	3792.7	4122.5	4328.6
Wall Foundation 539 wide x 1000 deep	1072.4	ft3	2.3	2269.2	2466.5	2589.8
Wall-Ext	2219.2	ft2	4.2	8574.8	9320.5	9786.5
Wall-Int	2106.8	ft2	4.2	8140.7	8848.6	9291.0
Room Separation	26.1	ft	9.5	227.9	247.8	260.2
Room finishing	2019.1	ft2	0.75	1393.2	1514.3	1590.1
Compound Ceiling 600x600mm_Grid	2019.1	ft2	0.95	1764.7	1918.2	2014.1
Doors 910x2110mm	330.5	ft2	15	4560.5	4957.0	5204.9
Doors 1360x2110mm	123.3	ft2	35	3970.5	4315.7	4531.5
Doors_ExtSgl w-Glazing_Bars_Arche	35.3	ft2	17	551.6	599.6	629.6
Floor-Grnd-Bearing	434.8	ft2	2.4	960.1	1043.6	1095.8
Floor-Grnd-Bearing carpet	1608.2	ft2	1	1479.6	1608.2	1688.6
Lighting_Fixtures1 100_Watt	355.0	ft2	45	14698.3	15976.4	16775.2
Windows1810x1210mm	492.8	ft2	36	16322.5	17741.9	18629.0
Windows 910x1210mm	44.8	ft2	51	2103.2	2286.1	2400.4
Roof-Pitched	3729.3	ft3	2.4	8234.2	8950.3	9397.8
The total Material Cost				79043.8	85917.1	90213.0

FORM UPR16

Research Ethics Review Checklist

Please include this completed form as an appendix to your thesis (see the Research Degree Operational Handbook for more information)



Postgraduate Research Student (PGRS) Information		Student ID:	786199
PGRS Name:	Faris Elghalsh		
Department:	School of Civil Engineering and Surveying	First Supervisor:	Sepehr Abrishami
Start Date: (or progression date for Prof Doc students)	01/02/2018		
Study Mode and Route:	Part-time <input type="checkbox"/> Full-time <input checked="" type="checkbox"/>	MPhil <input type="checkbox"/> PhD <input type="checkbox"/>	MD <input type="checkbox"/> Professional Doctorate <input type="checkbox"/>
Title of Thesis:	AN AUTOMATED IPD COST MANAGEMENT SYSTEM: BIM AND BLOCKCHAIN BASED SOLUTION		
Thesis Word Count: (excluding ancillary data)	82643		
If you are unsure about any of the following, please contact the local representative on your Faculty Ethics Committee for advice. Please note that it is your responsibility to follow the University's Ethics Policy and any relevant University, academic or professional guidelines in the conduct of your study. Although the Ethics Committee may have given your study a favourable opinion, the final responsibility for the ethical conduct of this work lies with the researcher(s).			
UKRIO Finished Research Checklist: (If you would like to know more about the checklist, please see your Faculty or Departmental Ethics Committee rep or see the online version of the full checklist at: http://www.ukrio.com/what-we-do/code-of-practice-for-research/)			
a) Have all of your research and findings been reported accurately, honestly and within a reasonable time frame?	YES	<input checked="" type="checkbox"/>	
	NO	<input type="checkbox"/>	
b) Have all contributions to knowledge been acknowledged?	YES	<input checked="" type="checkbox"/>	
	NO	<input type="checkbox"/>	
c) Have you complied with all agreements relating to intellectual property, publication and authorship?	YES	<input checked="" type="checkbox"/>	
	NO	<input type="checkbox"/>	
d) Has your research data been retained in a secure and accessible form and will it remain so for the required duration?	YES	<input checked="" type="checkbox"/>	
	NO	<input type="checkbox"/>	
e) Does your research comply with all legal, ethical, and contractual requirements?	YES	<input checked="" type="checkbox"/>	
	NO	<input type="checkbox"/>	
Candidate Statement: I have considered the ethical dimensions of the above named research project, and have successfully obtained the necessary ethical approval(s)			
Ethical review number(s) from Faculty Ethics Committee (or from NRES/SCREC):	Tech 2018 - F.A.K.E - 02		
If you have not submitted your work for ethical review, and/or you have answered 'No' to one or more of questions a) to e), please explain below why this is so:			
<div style="border: 1px solid black; height: 20px; width: 100%;"></div>			
Signed (PGRS):			Date: 02/07/2020

UPR16 – April 2018