A BIM ENABLED BLOCKCHAIN BASED CONSTRUCTION VENDOR SELECTION SYSTEM

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ABSTRACT

With growing complexity of construction projects, the industry is evolving on day-to-day basis. Each aspect of the industry has been influenced by this complexity. One of these aspects is supply of materials for construction projects. Unavailability of materials has been quite a reason for impediment in the construction process. To ensure availability of materials at construction site it is necessary to choose appropriate vendor for supply of materials. Growing diversity has led to have a chunk of vendors across the globe to supply construction materials. Moreover, fragmented nature of construction process has also been a cause for inappropriate selection of vendor. This study aims to develop a framework for selection of a construction vendor with a collaborative effort. Thus, the framework is devised using the integration of BIM and Blockchain technique. The integration of these both platforms ensure the provenance and collaboration of teams to opt a vendor. Moreover, this framework increases meritocracy and induce trust among the parties which ultimately would enhance the progress of a construction project at the execution phase.

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LIST OF ABBREVIATIONS

BIM	=	Building Information Modelling
BIM-BCVSS	=	Building Information Modelling – Blockchain Based Construction Vendor Selection System.
CVSS Schedule	=	Construction Vendor Selection Schedule
Sql	=	Structured Query Language

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CHAPTER 1

INTRODUCTION

1.1 Introduction

During the construction phase inappropriate supervision and management of construction materials at the site will directly affect the total cost, time and the quality of the construction project (Kasim, Anumba et al. 2005). In developing countries cost overruns in construction projects mostly occur due to delay within the delivery of materials and instrumentality to construction sites (Manavazhi and Adhikari 2002). Arranging the buying and issuing the delivery plans to vendors and following-up to create positive environment that vendors' material delivery is on time is the context of procurement (Payne, Chelsom et al. 1996). It is not possible to provide material at low value and with prime quality in the current competitive situation (Wadhwa and Ravindran 2007). The most vital call is the choice and preservation of a competent cluster of vendors to realize prime quality with adequate provide of materials (Garcia and Sant'Anna 2015).

1.2 Problem Statement

Choosing an appropriate vendor has always been considered a crucial job in procuring and supply chain management (Sarkar, Mohapatra et al. 2006). Certainly it is considered to be the most significant of all the tasks of the function as the choosing of vendor has a prominent influence on the performance optimization regarding the tangible and intangible aspects of goods and services (Dulmin, Mininno et al. 2003, Zhu, Sarkis et al. 2007). Furthermore, vendors have a direct and significant impact on the quality, cost and lead time of new products and technologies needed to meet new market demands (Humphreys, Huang et al. 2007).

Improper supervision and management of materials in execution phase at site will negatively influence the total project price, schedule and quality (Kasim, Anumba et al. 2005). According to Manavazhi and Adhikari (2002), the overrun in finances and schedule for construction projects typically occurred because of delay within the delivery of construction materials and equipment to construction sites; in scenario of developing countries. The context of procurement is to organize the purchasing and issuance delivery plans to suppliers and moving further to form positive culture of in time delivery by suppliers (Payne, Chelsom et al. 1996).

In the contemporary competitive environment, it is difficult to proffer material at economical rates and with superior quality (Wadhwa and Ravindran 2007). The choice and conservancy of a knowledgeable cluster of vendors to comprehend prime quality with adequate provide of materials is the most crucial call for proper vendor selection (Garcia and Sant'Anna 2015). Safa, stated that, the cost of materials in the construction sector is about fifty five percent of the total project cost associated and might influence eighty percent of the schedule of project execution, approximately (Safa, Shahi et al. 2014). Masi et al. (2013) found out that the normal capacity of procurement can reach an ultimate of 97% of the costs in engineering, procurement and construction companies.

A construction projects cost monitoring and control, during the execution phase could be affected positively by the selection of an appropriate vendor. (Aretoulis, Kalfakakou et al. 2010). The progress of a construction activity is highly dependent upon the constraint of either work or resources availability, wherein the latter is more prone to be found out by carrying out resource plans or managerial decisions that are independent of the construction procedures; this fact proposes that construction management is nothing but management of resources (Aissaoui, Haouari et al. 2007). Due to this motive, most of the text books pertaining to project management identify resources as key to meeting project plan and address their significant influence on the construction arrangement (Park, Lee et al. 2005). In contemporary highly competent and interconnected producing atmosphere, the success or failure of a company is highly dependent on performance of a vendor (Venkata Rao and Management 2007). Vendor selection problem consists of stochastic and recognitive uncertainties (Memon, Lee et al. 2015). Within supply chain management, a crucial aspect of decision-making lies in the selection of vendors and the amount of material to be procured from those vendors. There is a dire need to form the objectives in this regard and consider several selection criteria (Venkata Rao and Management 2007). Multi criteria when selecting an optimal vendors has been considered in a chunk of researches associated with vendor choosing process (Aissaoui, Haouari et al. 2007). The researches pertaining vendor selection can be differentiated into two main groups: (1) researches that focus on isolation of different supply source selection criteria and (2) those having concentration on assessment of the degree of their status from the acquiring organization’s perspective and those targeting to find dissimilar alternate vendors by devising and implementing specific approaches (Lin 2009). It is evident that a vendor selection should be done in an appropriate manner for successfulness of the project, in order to carry out such task there is a dire need to explore and devise a pattern of right vendor selection by adoption of latest distinct trends.

1.3 Research Objectives

- To identify inefficiencies in selection of vendors for a construction supply chain network.
- To develop a framework for BIM integrated blockchain based construction vendor selection system.
- To realize the BIM integrated blockchain based construction vendor selection system.
- To validate the realized system.

1.4 Scope of the Study

The scope of this study revolves around to enhance collaboration of different teams working on a project pertaining to procurement related activities. Moreover, the study also encompasses the view of authenticity in terms of cryptographic liability in selection of vendor process and smooth dissemination of information in a centralized BIM model.

1.5 The Overview

Chapter 2 of this research deals with systematic literature review pertaining to identification of inefficiencies in vendor selection process in order to achieve the first objective. Moreover, the literature pertaining to point out the attributes affecting vendor selection have also been carried out in this chapter.

Chapter 3 of this study is associated with the research design and methodology, the conceptual framework for BIM enabled blockchain based construction vendor selection system, the development framework of BIM-BCVSS.

Chapter 4 of this study deals with realization of the BIM-BCVSS.

Chapter 5 of this thesis deals with the case study for evaluation / validation of the devised BIM-BCVSS addon for Revit and

Chapter 6 deals with conclusion of this study and provides future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Inefficiencies in Vendor Selection

In literature choosing of a vendor framework mostly comprise of numerous stages. Aissaoui et al. (2007) indicated different steps of vendor selection: firstly, an initial step of formulating the problem and defining of a selection criteria is done. Afterwards the prequalification of probable vendors is completed, and concluding selections are consecutively explained. Chou and Chang (2008) recognized four stages in the procuring and supply literature, viz., defining the problem, devising a criteria, screening, and concluding assortment. As pointed out by Xia and Wu (2007), best quality or service performance may necessarily not be provided by vendors offering lowest unit prices. They indicated that supplier evaluation could be done on multi-objective decision of lowest cost, best quality and service performance (Wang and Che 2007).

Traditionally vendors are selected merely on basis of cost factors. Now-a-days many companies are considering multicriteria analysis and understood that sole reliance on cost factors leads to inefficient vendor selection (Parthiban, Zubar et al. 2013).

For attaining the first objective a total of 80 research articles were perused out of which 20 articles were taken into account that led to find a total of 16 inefficiencies pertaining to vendor selection as shown in Table 1. The inefficiencies were compiled after merging of overlapped inefficiencies as show in Table 2. The inefficiencies were then subject to content analysis in which these were firstly gone through a subjective analysis. This subjective analysis was performed to assign a literature score in order to form a hierarchy of the inefficiencies pertaining to vendor selection. These inefficiencies were then validated by pursuing a field survey. This survey was specifically carried out to find the relevancy of the identified inefficiencies of vendor selection pertaining to the construction industry. For attaining this goal, a preliminary survey questionnaire was formed and distributed among targeted experts of procurement in construction industry.

Table 1. Inefficiencies in vendor selection identified from literature.

Inefficiencies	**Author**
less focus on fast changing market conditions	(Luo, Wu et al. 2009)
have a smaller number of suppliers due to geographical aspects	
sole reliance on publicly available data	
less focus on quality techniques used by suppliers	
reliance on traditional criteria cost and quality	(Bevilacqua, Ciarapica et al. 2006)
less interest on multi-objective approach	
no intention for compliance checking of buyers' constraint	
reliance on traditional criteria cost and quality	
no connectivity in market to gain previous customer response about supplier	(Chan, Kumar et al. 2008)
less focus on supplier background	
no check on suppliers' capability	
less interest on multi-objective approach	
less focus of considering both qualitative and quantitative aspects	
less focus on quality techniques used by suppliers	
reliance on traditional criteria cost and quality	
lack of consideration on vendors' flexibility	(Parthiban, Zubar et al. 2013)
usage of inappropriate selection method	
less interest on multi-objective approach	
lack of interest on rejection of items in past	(Venkata Rao and Management 2007)
less focus of considering both qualitative and quantitative aspects	
no intention for compliance checking of buyers' constraint	
reliance on traditional criteria cost and quality	
less interest on multi-objective approach	
lack of consideration on vendors' flexibility	(Weber, Current et al. 1991)
reliance on traditional criteria cost and quality	
no connectivity in market to gain previous customer response about supplier	
lack of consideration on vendors' flexibility	(Kumar, Vrat et al. 2004)

Inefficiencies	**Author**
lack of interest on rejection of items in past	
sole reliance on publicly available data	
reliance on traditional criteria cost and quality	
usage of inappropriate selection method	(Bayazit 2006)
less interest on multi-objective approach	
lack of consideration on vendors' flexibility	
less focus of considering both qualitative and quantitative aspects	
less focus on fast changing market conditions	
reliance on traditional criteria cost and quality	
less interest on multi-objective approach	(Ghodsypour and O'brien 2001)
lack of consideration on vendors' flexibility	
less focus on quality techniques used by suppliers	
less interest on multi-objective approach	
no intention for compliance checking of buyers' constraint	(Aissaoui, Haouari et al. 2007)
have a smaller number of suppliers due to geographical aspects	
Lack of interest on environmental aspects	
reliance on traditional criteria cost and quality	(Weber 1998.)
Lack of interest on environmental aspects	
less interest on internet facilitated communications	(Humphreys, Wong et al. 2003)
less focus on quality techniques used by suppliers	
reliance on traditional criteria cost and quality	(Punniyamoorthy, Mathiyalagan et al. 2011)
less interest on multi-objective approach	
lack of consideration on vendors' flexibility	
less interest on internet facilitated communications for vendor performance data	(Ho, Xu et al. 2010)
less focus on quality techniques used by suppliers	
reliance on traditional criteria cost and quality	
less interest on internet facilitated communications for vendor performance data	
reliance on traditional criteria cost and quality	
lack of consideration on vendors' flexibility	(Olhager and Selldin 2004)
Lack of interest on environmental aspects	
less focus on supplier background	
no check on suppliers' capability	(Cao 2011)

Inefficiencies	Author
lack of consideration on vendors' flexibility	(Govindan, Rajendran et al. 2015)
usage of inappropriate selection method	
lack of interest on rejection of items in past	
less focus of considering both qualitative and quantitative aspects	(Erol and Ferrell Jr 2003)
no team involvement for assessment of supplier	
less interest on multi-objective approach	(Galankashi, Chegeni et al. 2015)
less focus of considering both qualitative and quantitative aspects	
no team involvement for assessment of supplier	(Memon, Lee et al. 2015)
lack of interest on rejection of items in past	
less focus of considering both qualitative and quantitative aspects	

The above table of inefficiencies was scrutinized and analyzed for their literature score and following results were obtained.

Table 2. Compilation and literature analysis of Inefficiencies in vendor selection

S. No	Inefficiencies	Literature Score	L.S/ Sum	Cumulative Score
1	less focus on fast changing market conditions	0.06	0.023715	0.023715415
2	have small number of vendors due to geographical aspects	0.1	0.039526	0.122529644
3	sole reliance on publicly available data	0.1	0.039526	0.162055336
4	less focus on quality techniques used by vendors	0.15	0.059289	0.221343874
5	reliance on traditional criteria cost and quality	0.55	0.217391	0.438735178
6	no connectivity in market to gain previous customer response about vendor	0.06	0.023715	0.462450593
7	less focus on vendor background	0.1	0.039526	0.501976285
8	no check on vendor' capability	0.06	0.023715	0.5256917
9	usage of inappropriate selection method	0.09	0.035573	0.561264822
10	less interest on multi-objective approach	0.45	0.177866	0.739130435
11	lack of consideration on vendor' flexibility	0.08	0.031621	0.770750988

S. No	Inefficiencies	Literature Score	L.S/ Sum	Cumulative Score
12	lack of interest on rejection of items in past	0.09	0.035573	0.806324111
13	less focus of considering both qualitative and quantitative aspects	0.15	0.059289	0.865612648
14	Lack of interest on environmental aspects	0.15	0.059289	0.924901186
15	no intention for compliance checking of buyers' constraint	0.09	0.035573	0.960474308
16	no team involvement for assessment of vendor	0.1	0.039526	1

A preliminary survey was conducted among the professionals working in the field related to construction industry. A chunk of procurement experts was targeted by using distinct platforms having expertise in procurement related activities pertaining to construction industry in Pakistan. As here, the case was related to highlight the relevancy of identified inefficiencies pertaining to vendor selection in construction industry, the specialization and experience of professionals who have been contacted for the survey will be able to satisfy the inefficiency validation survey at international scale. The survey was strictly conducted in compliance with the criteria of targeting professionals working in procurement process of construction industry with at least 5 years of experience, any response that did not meet the desired criteria was discarded. The said survey was designed such that it asked about relevancy of the inefficiencies identified to the construction sector. The responders were required to rate the relevancy of each inefficiency regarding vendor selection in construction industry on a 5-point Likert scale (1= Not Relevant, 2= Slightly Relevant, 3= Relevant, 4= Very Relevant and 5= Extremely Relevant). Due to unavailability of proper data a sample size of 30 was assumed and in total 33 responses were recorded. Out of these 33 responses 3 were discarded as manifested to be improperly filled. Table 3 shows the demographics of the respondents; Table 4 illustrates the analysis of all the inefficiencies based on field survey. These inefficiencies are ranked on the basis of relative importance index calculated from the field survey. The relative importance index (R.I.I) has been calculated by using the following formula as used by Rooshdi (2018) in his study:

$$R.I = \sum \frac{R}{Hx\,T}$$

where R is the weightage assigned by each respondent on a scale of one to five with one implying the least and five the highest. H is the highest weight and T is the total number of the sample. According to Akadiri (2011), five important levels are transformed from RI values: high (0.8 to 1), high to medium (0.6 to 0.8), medium (0.4 to 0.6), medium to low (0.2 to 0.4) and low (0 to 0.2). The inefficiencies are ranked in their respective order based on relative index. As all of the inefficiencies are in range of Medium to High, thus, all the inefficiencies have been taken into account in this study.

Table 3. Demography of the respondents

`Experience	**No of Questionnaires filled**	**Percentage**
< 5 years	2	6.060%
Between 6 to 10 years	7	21.21%
>10 years	24	72.72%

Table 4. Field analysis and Ranking of Inefficiencies in Construction Vendor Selection

ID	**Inefficiencies**	**Average Survey Score**	**Relative Importance Index**	**Rank**
I1	Reliance on traditional criteria cost and quality	4.48	0.897	1
I2	less interest on multi-objective approach	4.21	0.842	2
I3	Have a smaller number of Vendors due to geographical aspects	4.12	0.824	3
I4	Lack of interest on environmental aspects	4.09	0.818	4
I5	no team involvement for assessment of Vendor	4.09	0.818	4
I6	Less focus on fast changing market conditions.	3.97	0.794	5
I7	less focus of considering both qualitative and quantitative aspects	3.94	0.788	6
I8	Sole reliance on publicly available data	3.82	0.764	7
I9	usage of inappropriate selection method	3.79	0.758	8

ID	Inefficiencies	Average Survey Score	Relative Importance Index	Rank
I10	less focus on quality techniques used by Vendors	3.67	0.733	9
I11	no connectivity in market to gain previous customer response about Vendor	3.54	0.709	10
I12	lack of interest on rejection of items in past	3.45	0.691	11
I13	lack of consideration on vendors' flexibility	3.42	0.685	12
I14	no intention for compliance checking of buyers' constraint	3.39	0.679	13
I15	No check on Vendors' capability	3.33	0.667	14
I16	less focus on Vendor background	3.30	0.660	15

In order to find out a solution to mitigate the above inefficiencies, we first need to study Vendor Selection approaches.

2.2 Vendor Selection Approaches

Optimization and visualization techniques have been adopted in order to conduct just and transparent decision making; some of the techniques and tools for attaining this purpose have shown positive results. Techniques like datamining, pairwise ranking and alternative solutions have also shown their impact in consideration to vendor selection process and have subsequently improved the effectiveness in decision making. Multi-criteria decision assessment methods backs the decision-maker in scientifically assessing a chunk of replacements on numerous standards that may all be of a dissimilar nature (De Boer, Labro et al. 2001)

Various methodologies have been presented by scholars in order to resolve the multifaceted and ambiguous multi criteria decision making complications of vendor selection and assessment. Some of the models or approaches used for vendor selection are; Data envelopment analysis (DEA), mathematical models, AHP, linear programming and ANP etc. Some of the approaches adopted for vendor selection are discussed as under:

2.2.1 Data Envelopment Analysis (DEA)

The data envelopment analysis (DEA) technique is mostly focused on the efficiency of the system. In this approach, vendors and their processes are considered as a system. In which the outcomes (benefits) are known as the weighted sum of the outputs (e.g. performance of delivery, quality, etc.) of the vendors and the contributions are the weighted sum of inputs (e.g. costs). Using the outputs and inputs, the efficiency of the system is determined. Some scholars had prospected how to obtain the best weights to enhance the vendor' performance rankings (efficiency). Further to classify the efficiency of vendors this method is used (Agarwal, Sahai et al. 2011).

$$\text{Efficiency} = \frac{\text{Weighted sum of Inputs}}{\text{Weighted sum of Output}}$$

Weber (1996), initiated application of data envelopment analysis (DEA) for an individual product and also contemplated a prototype among the firms for vendor selection and selection of other products. In the model he evaluated six vendors who were to be selected for a baby food manufacturing company. His research reflected about how much cost saving and quality improvisation could be done by enhancing delivery performance. Braglia and Petroni (2000) applied DEA to check the associated behaviour of numerous vendors based upon the article of Baker and Talluri (1997) on a questionnaire study with 89 industrial companies in Brescia. 9 ruling factors for assessment of the suppliers were used by them. Liu et al. (2000) devised a basic DEA prototype for assessing the competence of a supplier. It had 3 inputs namely cost index, performance of delivery and distance factor. On the other hand, 2 outputs devised were supply variety and quality. To calculate the comparative efficiency of suppliers an application model based on DEA method was founded by Forker and Mendez (2001). A ratio of single input to multiple outputs was proposed to calculate the comparative efficiency. An evaluation of the relative competence of distinct suppliers based on the cross efficiencies was done by Braglia and Petroni (2000),. A proposal of evaluation criteria as an application of DEA for supplier assessment was initiated by Narasimhan et al. (2001); precisely for a international firm in the telecommunication business in which eleven factors have been considered and divided into inputs and outputs respectively. Out of them six were inputs, which represented vendor's competence and five outputs, which denoted vendor's ability. Vendors were distinguished by them into four sections, based on ability and competence.

Talluri and Baker (2002) evaluated possible stakeholders, which are vendors, manufacturers, distributor, retailers by using two input and four output attributes. For logistic distribution network design a three-phase approach was used by them. As per the requirements, a suitable vendor was chosen for diverse areas and products. Talluri and Narasimhan (2004) proposed the application of DEA for effective sourcing purpose. The prototype adopted cross-efficiencies and statistical approaches in grouping the supply base. Garfamy (2006) used DEA to reduce the total cost of ownership (TCO) and anticipated the implication of DEA in evaluation of the supplier competence upon TCO; and with the vital objective of becoming capable to minimize TCO with identification of standards they tried to simulate data of a theoretical organization. Ross et al. (2006) devised the DEA methodology on basis of an action research framework for an iterative analytical and broader aspect. The anticipated procedure merged both purchaser and seller performance characteristics and was found out to be capable of delivering quantifiable and usable outcomes. Two main objectives were set by them: firstly, to form a shared and equal accord of the differing necessities of the purchasers and sellers in the liaison circle and, secondly, to propose and evaluate a method, which could help to assess performance in the relationship. Seydel (2006) took DEA into account for solving supplier selection problem. The vital aspect of this research was that no input was considered in this model, unlike all other methods and researches. The ranking on basis of qualitative aspects was done on a seven point scale in the research. Further the article points that a lesser effort than simple multi-attribute rating technique was required by the proposed DEA model (Chen, Xu et al.). Saen (2006) devised a DEA based model to assess the technology sellers on three main factors. The thought was to form a DEA based model for selection of technology sellers, knowing in advance the nondiscretionary factors from seller's perspective and the qualitative factor, which ranked them on the scale of five. A chance-constrained DEA methodology to assess supplier competence by taking into account the stochastic performance measures was presented by Talluri et al. (2006). In order to forecast the supplier performance understanding the erraticism of vendor selection criteria is important, was predicted in the research. The input attribute adopted was cost, while the outputs were delivery and quality. The usefulness of model was presented by the comparison of the model with the deterministic DEA.

2.2.2 Linear Programming

The initial chunk of scholars who engrossed on the preference and consequences of performance erraticism in assessing several suppliers was Talluri and Narasimhan (2003). The researchers with the main goal to reduce the input attributes such as price and to increase the output attributes such as quality, performance in terms of delivery, etc envisioned the process as a system. Two linear programming models were proposed by Sahin, Cavlazoglu et al. (2015) such that clusters of suppliers with same attributes can be found without any difficulty, which offers distinguish options in final selection. A linear programming model was designed by Talluri and Narasimhan (2005), to assist decision makers or purchasers choose and assess distinct suppliers. The system is focused on quantifiable steps to choose possible suppliers, taking into account the strengths of existing suppliers and to eliminating low-performing suppliers, taking the case of a large, multinational, telecommunications company. Further comparison of the efficacy of the proposed model to conventional and advanced DEA was conducted by the researchers, to determine its benefits. Adopting the qualitative and numerical approach to increase the supplier score, a weighted linear programming (WLP) model for supplier selection was developed by Ng (2008),. An alteration phenomenon, which removes the necessity of optimization to resolve the weighted linear program was proposed by him.

2.2.3 Multi-Objective Programming

A multi-objective programming model to resolve supplier selection hurdles was designed by Narasimhan et al. (2006), which also came out with the optimal order quantity task. Five criteria, minimum order scope, maximum availability of supply, stipulate cost, quality, and assured levels of delivery-performance, were adopted for assessing the performance pf suppliers. Another multi-objective programming model to resolve the supplier assessment and choosing hurdle was presented by Wadhwa and Ravindran (2007), wherein three minimization functions were taken into account: cost, lead time, and rebuffs. Three resolution methods, weighted objective, goal programming and compromise programming method, were adopted for differentiation and comparison of the answers in order to resolve the mentioned cases.

2.2.4 Analytic Hierarchy Process (AHP)

Eighteen criteria were found out by Akarte et al. (2001), among them 6 were quantitative and 12 were qualitative for evaluation of a supplier, they categorized them into four groups: quality potentiality, product development potentiality, manufacturing potentiality, and price and deliverance. An internet-based system was developed by the researchers for evaluation of the suppliers. Furthermore, a five-step AHP-based model was initiated by Muralidharan et al. (2002), which consisted nine evaluating criteria for ranking and choosing suppliers. Staff of several sections, such as quality control, procurement, and warehousing, were indulged in the choosing process of optimal supplier. An AHP-based multi-criterion decision making model of evaluating and choosing a supplier proposed by Chan et al. (2007), was conducted on basis of 14 different criteria. They model was created to provide a framework for selection of appropriate suppliers and some detail on how to implement company's strategy for the suppliers was also provided by the model. A distributed system to find out suitable suppliers for components in a mass customization environment was designed and proposed by Hou and Su (2007). A progressive and vigorous method of assessing the product market position and development directions were basis of their system.

2.2.5 Analytic Network Process

A progressive tactical decision model based on ANP was initiated by Sarkis and Talluri (2002), to assist decision makers select best supplier for their company by taking contributions from all administrative levels, from tactical to operative, in the progressive ever-varying situation. Seven assessing criteria to evaluate the suppliers were found out and implied by the authors. An methodology based on principles of ANP, which includes responses and bilateral relationships in assessing and choosing optimal supplier for an organization was devised by Bayazit (2006). Ten assessing attributes in the model were found out by the scholars; and classified into supplier's performance and capability groups. To create interrelationships among all attributes, a pair wise contradiction matrix was created. An ANP based model to assess supplier and select him with respect to various assessing criteria was identified by Gencer and Gürpinar (2007).

2.2.6 Fuzzy Set Theory

A hierarchy based MCDM prototype was devised in order to counter the supplier selection problem. To assess the weightages and rankings of the assessment criteria, the researchers presented the lingual standards, denoted by trapezoidal or triangular fuzzy numbers. The validation was carried out for selection of a new product desired by high technological manufacturing firm. A systematic framework was formulated by Sarkar and Mohapatra (2006), to minimize the number of suppliers in order to aid the decision makers for selection of optimal supplier. They recommended that the main influencing paradigms in supplier selection were competence and performance. A capability-performance threshold to assist in arranging the suppliers in decreasing order of preference was presented in the study (Agarwal, Sahai et al. 2011).

2.2.7 Soccer Approach for Development of Vendor Selection Criteria

The decision for selection of criteria can vary upon the qualitative and quantitative aspects pertaining to a requisite vendor proposal (Mızrak Özfirat, Tuna Taşoglu et al. 2014). The procedure itself is defined as a multi attribute decision-making (MADM) problem (Thakur and Anbanandam 2015). Dickson (1966) was the first researcher to recognize 23 different criteria like price, quality, delivery, capacity, and performance for vendor selection.

Later on Carter (1995), presented the so known as seven Cs of vendor assessment (competency, capacity, commitment, control, cash, cost, and consistency) that has gained recognition to be among the main theories of vendor selection; later Carter modernized his own model with three additional new Cs: culture, clean, and communications. The SOCCER vendor assessment model (Rogers 2009) comprise of the fundamentals strategic direction, operational capability, customer approach, cost structure, economic performance, and research and development.

The detailed evaluation criteria SOCCER model (Rogers 2009) is easy to remember and it also encompasses the research and development factors that has been neglected by other models.

2.3. Attributes affecting Vendor Selection.

The attributes were identified by carrying out a thorough literature review. The attributes identified are enlisted in Table 5. These attributes are to be used in order to formulate criteria for vendor selection. The attributes will be made part of the system for evaluation and assessment of a construction vendor.

Table 5. Vendor selection attributes identified from literature

Attributes Identified	References
Management Philosophy	(Ayhan, Kilic et al. 2015),(Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016)

Attributes Identified	References
Rejection on Items in Past	(Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016), (Katsikeas, Paparoidamis et al. 2004),(Mafakheri, Breton et al. 2011)
Acceptance Rate	(Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016), (Katsikeas, Paparoidamis et al. 2004),(Mafakheri, Breton et al. 2011)
Delivery time flexibility	(Ayhan, Kilic et al. 2015),(Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Chowdhury and Quaddus 2015)
Reputation in Architecture Engineering & Construction	(Wang, Zhang et al. 2017), (Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Mensah, Merkuryev et al. 2015), (Jadidi, Cavalieri et al. 2015)
Supplier and Constructor Convenience	(Wang, Zhang et al. 2017), (Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015),

Attributes Identified	References
	(Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Mensah, Merkuryev et al. 2015), (Żak 2015)
Awareness of risks and its levels involved	(Wang, Zhang et al. 2017), (Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015)
Management methods	(Ayhan, Kilic et al. 2015),(Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016)
Return rates of products	(Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016), (Katsikeas, Paparoidamis et al. 2004),(Mafakheri, Breton et al. 2011)
Delivery date appropriateness and efficacy	(Ayhan, Kilic et al. 2015),(Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Chowdhury and Quaddus 2015)
Former Performance of Supply	(Chowdhury and Quaddus 2015),(Shen, Olfat et al. 2013), (Karsak, Dursun et al.

Attributes Identified	References
	2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016), (Katsikeas, Paparoidamis et al. 2004),(Mafakheri, Breton et al. 2011)
Ability of Local Law Compliance	(Gnanasekaran, Velappan et al. 2008) (Rajesh and Ravi 2015), (Mensah, Merkuryev et al. 2015)
Product Quotation	(Shen, Olfat et al. 2013), (Karsak, Dursun et al. 2015), (Ashtiani, Azgomi et al. 2015), (Ayhan, Kilic et al. 2015), (Ghodsypour and O'Brien 1998), (Parthiban, Zubar et al. 2012), (Scott, Ho et al. 2015), (Bruno, Esposito et al. 2016), (Katsikeas, Paparoidamis et al. 2004)
Intention to Cooperate	(Shou, Wang et al. 2015), (Mathiyazhagan, Diabat et al. 2015), (Ma, Shen et al. 2005), (Babazadeh, Razmi et al. 2017), (Jadidi, Cavalieri et al. 2015)
Market turbulences Adaption	(Shou, Wang et al. 2015), (Mathiyazhagan, Diabat et al. 2015), (Ma, Shen et al. 2005), (Babazadeh, Razmi et al. 2017)
Technology	(Shou, Wang et al. 2015), (Mathiyazhagan, Diabat et al. 2015), (Ma, Shen et al. 2005), (Babazadeh, Razmi et al. 2017)

Attributes Identified	References
Environmental certifications	(Galankashi, Chegeni et al. 2015), (Igarashi, de Boer et al. 2013), (Klibi and Martel 2012), (Wu and Barnes 2016)

2.3 Grouping of Criterion and Classification of Teams.

A targeted study was carried out from literature in order to identify the teams which would take part in the vendor selection process. The assessment was done in accordance with the vendor selection attributes identified. The literature helped to identify the roles of quality team, planning team and procurement team with respect to their functionalities and responsibilities pertaining to vendor selection in a supply chain. The classification and grouping are enlisted in Table 6 below.

Table 6. Classification and grouping of the attributes of construction vendor selection.

References	Classification	Main Criteria	Sub-criterion
(O'Brien 2013)	Quality Team	Product Quality	Return rates of products,
			rejection on items in past,
			acceptability rate
(Liu, Shahi et al. 2014); (Benton and McHenry 2010)	Planning Team	Delivery	Delivery date appropriateness and efficacy
			Delivery time flexibility
		Flexibility	Management methods
(Bakar, Tufail et al. 2011) (Johnson, Leenders et al. 2017) (Rowlinson 1999) (Watt 2014)	Procurement Team	Enterprise Capacity	management philosophy
			awareness of levels of risks,
		wellbeing of supplier	Intention to cooperate
			previous performance
			Reputation in Architecture Engineering

References	Classification	Main Criteria	Sub-criterion
			Construction (AEC) industry
		Technicality	Ability of local law compliance
			Vendor Constructor convenience
			Technology
			adaptability to market turbulences
		Sustainability	Environmental certifications
(Watt 2014)	Procurement Team	Cost	Product quotation or comprehensive product cost

2.5 Blockchain technology

A decentralized system for catching the authentic cryptographic signatures and storing a consistent, immutable, linear event log of transactions between connected nodes is known as Blockchain Technology (Risius, Spohrer et al. 2017). It is the technology that is most commonly known as technology working behind the cryptocurrency Bitcoin (Nakamoto 2008). Blockchain is a permissioned ledger technology that upholds the veracity of transactional data (Yli-Huumo, Ko et al. 2016). Allens (2016), classified this permissioned ledger system into two types i.e., a public or a private one. A ledger that has no centralization of ownership and is accessible to and maintained by any of the public member is known as a public ledger; each authorized node in the network is in possession of the identical copies of this ledger. In a private ledger, there are limited number of users authorized to carry out transactions and are under some outside form of control. The blockchain data exchange is distributed and all the participants in the network have access to the similar data as the other members. Maintainability of the data and information without any organizations or governmental administration in control is the essential feature of blockchain. According to Swan (2015), the blockchain technology can be classified into three categories as Blockchain 1.0, 2.0 and 3.0, where in decentralization of money and payments is the prominent aspect of blockchain 1.0. For example, cryptocurrency like Bitcoin falls under this category, having its core functionality as the assessment and maintenance of transactions between two individuals. The category of blockchain 2.0 is generically more associated with decentralization of markets that deals with transfer of units other than money, by the creation of a unit of value whenever transferred or divided. Blockchain 2.0 encompasses smart contracts, smart property, Decentralized Applications, public annals (i.e., public possessions, corporate licenses, and vehicle registrations), digital characteristics (i.e., identity cards, passports and driver licenses), and private annals (i.e. loans, signatures and escrows) can be shifted towards the blockchain and recorded. The third category i.e., Blockchain 3.0 is associated with judicial applications, economics and markets, specifically with the areas of government, health, science, literacy, culture, and art. The association freedom attribute with the blockchain becomes more distinct in Blockchain 3.0, being essentially an innovative standard for establishing an activity efficiently. The blockchain 3.0 can facilitate the harmonization and recognition of all means of anthropological communications, and an advanced directive of teamwork among humans and machines expressively. Blockchain administration is a crucial application of the blockchain 3.0 that uses the blockchain as a widespread, perpetual, continuous, consensus-driven, publicly auditable, redundant, record-keeping source to provide decentralized government services (Wang, Wu et al. 2017).

2.6 Blockchain-enabled supply chain management

Traditional supply chain is endangered by untrustworthy nature of environment among stakeholders. Verification and validity of price of products in purchasing has been quite a menace due to the lack of transparency and traceability; the use of the open permissioned ledger system i.e., blockchain technology has the potential to tackle these challenges. A study for creation of blockchain enabled supply chain as Figure 1 has been carried out for an off-site fabricated instrument from procurement to the end of the final installation; the initiation of system starts with the purchase order placed by the project owner enabling an intimation to the manufacturer who respond in sending the raw material to its vendors; alongside a notification to the inspection agency is sent for the inspection of the raw materials; upon inspection the materials are shipped and quarantined in the warehouse; and then scheduled for delivery this whole scenario is updated at regular intervals in blockchain based system. Since the data involvement to the blockchain system is validated, the trustworthiness of the data is significantly greater in number than the conventional; in addition, the prolonged supply chain provenance can be also attained, for example, each part of the device can be traced to the origin (Wang, Wu et al. 2017).

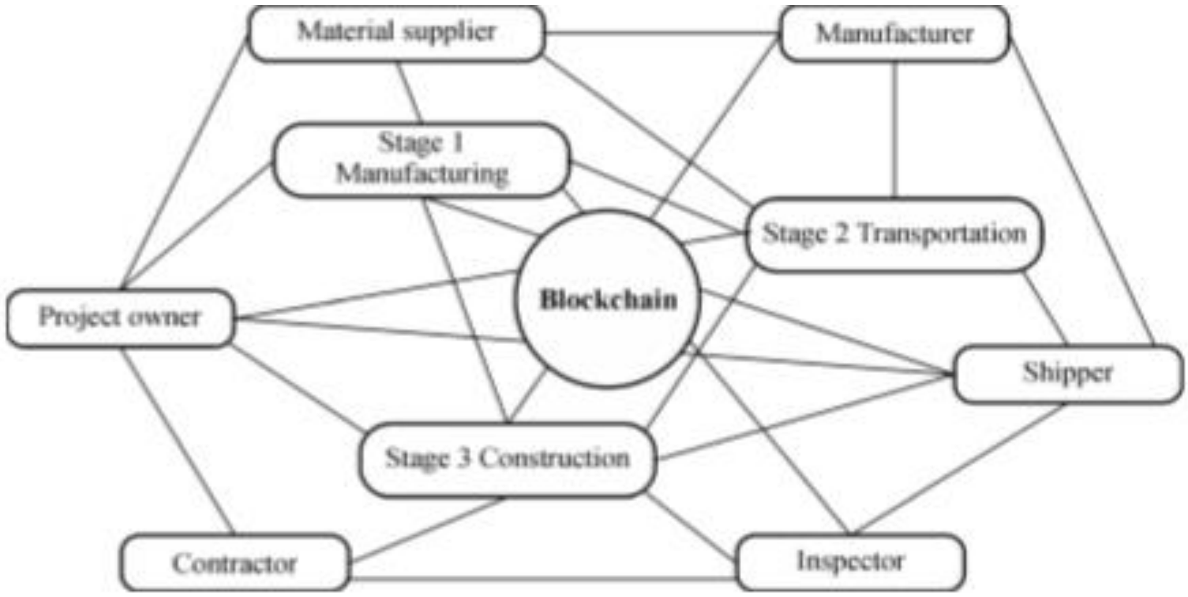


Figure 1 Blockchain enabled supply chain (Wang, Wu et al. 2017)

Industry and academia has observed vendor selection as a critical issue in the long-run for success of supply chains; careful selection and evaluation of vendors is a mandatory initial steps to guarantee the sustainability of supply chains (Song, Xu et al. 2017). The evaluation and selection of a vendor in a sustainable context is a multi-dimensional and multifaceted problem (Govindan, Rajendran et al. 2015). Usually, vendor selection and assessment is reliant on data that is not easily available, provable, and reviewed, especially in non-economic, social and environmental, sustainability extents (Foerstl, Meinlschmidt et al. 2018). This limitation barrier can be effectively alleviated by adoption of blockchain technology, wherein vendor' historical performance and sustainability data can be made available on the blockchain that will help companies to improve their vendor selection processes based on green performance values; blockchain not only facilitates the vendor selection processes, but provides information regarding the whole supply chain across multiple tiers and sub-vendors (Grimm, Hofstetter et al. 2016). The shared information on the blockchain provides companies the opportunity to enhances the vendor selection process in the supply chain and reduces costs in two tiers by removing intermediaries. Current supply chain sustainability database systems exist such as the Business Social Compliance Initiative (BSCI) database for voluntary vendor social and environmental auditing in the textile supply chain (Egels-Zandén and Wahlqvist 2007). A core issue of BSCI along with other voluntary databases is the soundness and reliability of their statistics and assessments; using blockchain technology and processes some of these credibility and validity concerns can be addressed as these databases may be used for vendor monitoring, development, and selection; their credibility and accessibility can only further support these initiatives (Kouhizadeh and Sarkis 2018).

2.7 Building Information Modelling

BIM is “a digital illustration of physical and practical features of a facility. As such it aids as a shared information mean for information about a facility forming a reliable basis for decisions during its life cycle from beginning onward” (NIBS 2007).

As product, BIM can be defined as Building Information Model, which is a dataset designed to define a building/facility (Watson 2010). As process, Building information modelling is the act of developing a Building Information Model (Watson 2010).

BIM offers several benefits from augmented efficacy, precision, swiftness, harmonization, steadiness, analysis of energy, reduction in cost of the project etc., to numerous participants from proprietors to designers, engineers, constructors and other built environment professionals.

BIM has been used in the industry as a tool for quite a long time but researchers are yet to find a way to use BIM to its full potential in the education industry. Several researchers have proposed to introduce BIM as a course in already packed construction curriculum but very few have identified its potential to serve as a learning tool. BIM has the ability to simulate the construction project in a virtual environment (Eastman 2008). BIM can provide a virtual 3D model of a construction facility in a digital form, commonly known as Building Information Model. A complete Building information Model contains precise geometry and relevant data required in support of procurement, construction and fabrication activities required to realize the building (Eastman 2008) which results in an intelligent and object oriented model with capabilities of parametric digital representation of the building, with the help of which helps in easy extraction of drawings and appropriate data and then analyzing for in time decision making improving the overall project delivery process (Guide 2006).

Another advantage which the BIM provides is the ease in inserting, extracting, updating, or modifying digital data to owners, clients, engineers, architects, contractors, vendors, and building officials (Goedert, Meadati et al. 2008).The consideration of BIM should not be limited to software purposes only but rather as a process along with software. BIM offers a large number of large number of applications to various fields of AEC which include visualization, design and constructability reviews, 4D scheduling and sequencing, quantity take-off (QTO), 5D costing and estimation, prefabrication, structural analysis, knowledge management, energy and lighting analysis, conflicts and clash detections, facility management etc. In humans, visualizing is one of three learning modalities, alongside listening (auditory) and doing (kinesthetic) (Barbe et al. 1979). This visualization aspect of BIM can be related to Neil Fleming's visual learning style of learner discussed earlier in literature. Also it allows for collaboration between different fields of AEC which can promote social learning (Bui, Merschbrock et al. 2018).

In BIM, real world components are described as three-dimensional objects like walls, windows and doors etc. in addition to geometric details, alternative information are often coupled to these objects which can include manufacturers' details, fire ratings, cost estimates and schedules (Goedert, Meadati et al. 2008).

According to Eastman (2008), BIM based simulation and communication can overcome language barriers Most construction projects involve workforces who speak multiple languages in the field.

The basic difference between BIM and CAD is the object-oriented parametric modeling which is the main feature of BIM With CAD based principles, it is quite simple to create a building drawing or a 3D model. However, making adjustments or changes to the model are fairly difficult (Krygiel and Nies 2008).

Advent of Building Information Modelling is one such example to adapt such new technologies as a change (Heiskanen and Innovation 2017, Mathews, Robles et al. 2017). It is mostly perceived that this technology is still at infancy stage and has risks in terms of standards and procedures resulting in lack of global adoption (Ghaffarianhoseini, Tookey et al. 2017). Lack of BIM education and misconception results in organizational and individual misunderstanding with regard to its potential (M. Winfield 2018.). On the Contrary, advanced research in exploration of BIM are quite progressive and are highly rating it for its integration and adaption capabilities. Keeping in mind the researches carried out in BIM domain, it is evident that this field has a very vast scope if utilized and understood appropriately (Eastman, Eastman et al. 2011). Failure in adaptation of technological advancements is one of the core issues hampering the advancement of the construction industry to succeed in comparison to logistics, automotive and mechanical engineering industries (Barima 2017).

2.8 BIM and Supply Chain

Various studies have been carried out in the domain of BIM. They are either engrossing the phenomenon of improving the information sharing among stakeholders of a construction supply chain or realization of the supply chain activities. One such research is the integration of BIM and GIS through which updated status of the materials within the supply chain can be vividly demonstrated in the model as another significant outcome of integrating GIS and BIM (Irizarry 2013). Another attempt is an effort to integrate barcode reading technology into BIM; this has been carried out in order to create an inventory management system that monitors the outflows and inflows of materials, this has been attempted by integrating 2D barcode technology in domain of BIM 7D and could be enhanced by using latest technologies like RFID (Lin, Su et al. 2014). The work carried out in domain of supply chain and BIM is quite tremendous but yet it needs exploration for integration of other aspects pertaining to essentials of a construction supply chain (Irizarry 2013).

CHAPTER 3

RESEARCH DESIGN AND FRAMEWORK

3.1 Introduction

The methodology for achieving the objectives described in chapter 1 is discussed in this chapter. Starting with the research design this chapter follows development of the framework. The research design comprises of a systematic methodology to achieve the objective of this study.

3.2 Research design

For attaining the first objective of our research, a systematic review of literature has been carried out from research articles for identification of the inefficiencies pertaining to construction vendor selection. A preliminary survey has then been carried out among the professionals in our construction industry to validate the existence of inefficiencies identified from literature.

In order to achieve the second objective, we studied the potential of BIM and BlockChain, discussed in the literature to eradicate the inefficiencies identified in the first phase. After this, literature analysis has been done to find out the various criterion of vendor selection process and grouped them into major criteria. The shortlisted criteria have been classified under the teams functioning for vendor selection process. Following this a framework for development of BIM-BCVSS has been devised. Furthermore, the realization of BIM-BCVSS has been done as described in chapter 4.

In the last phase Validation of the BIM-BCVSS has been done through a case study and qualitative interviews of the users that is described in chapter 5.

The workflow of this research has been designed and shown the Flow chart illustrated as Figure 2:

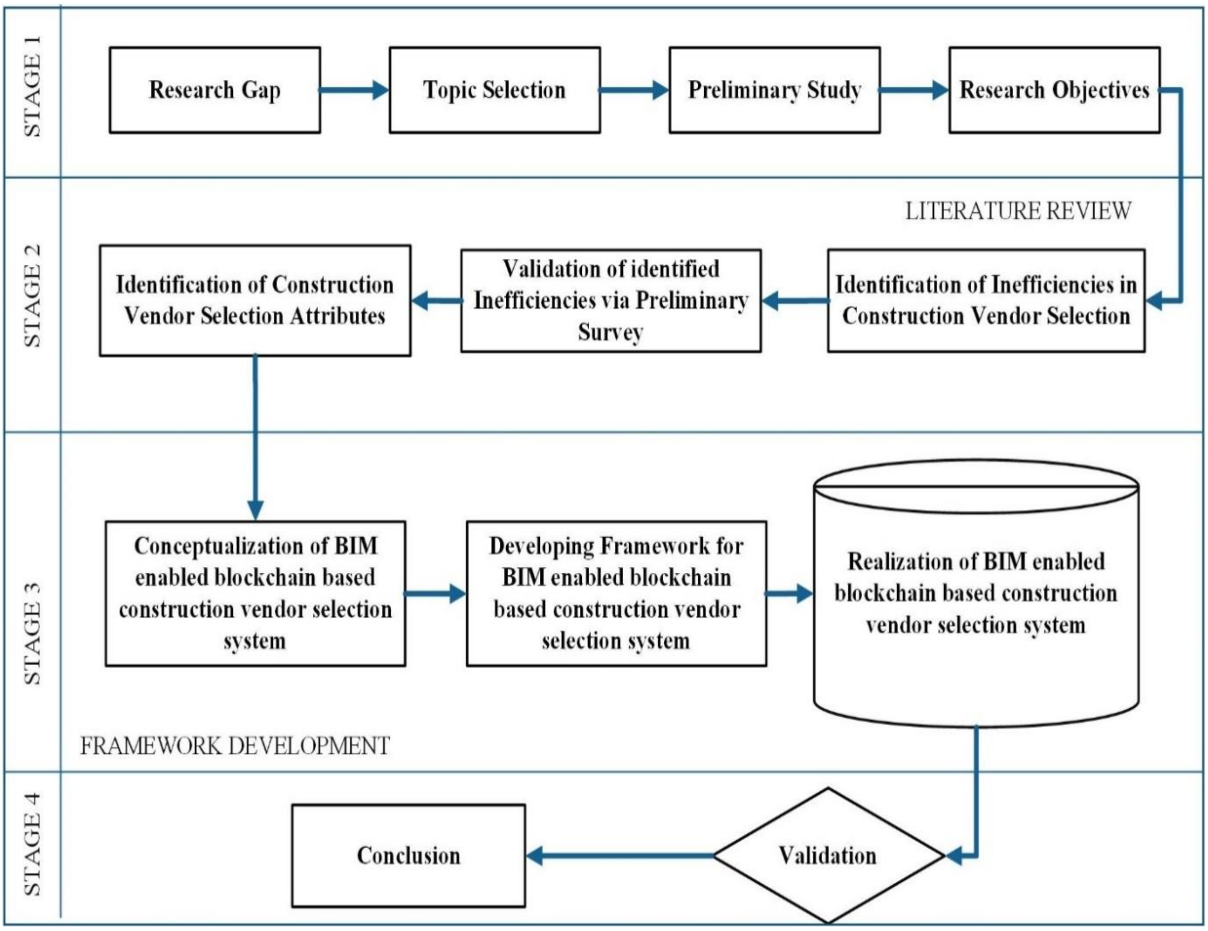


Figure 2. Research Methodology Flow Chart

3.3 Framework for BIM enabled Blockchain based Vendor selection system.

3.3.1 A Conceptual Framework for the Integrated System

The framework is formulated in a way to add blockchain based system as integral part of BIM. As per the formulation the system is to be designed in such a way that the vendor selection system could be initiated from a BIM tool. Figure 3 shows the whole conceptual model for BIM integrated blockchain based construction vendor selection system. After initiation from the BIM tool, the blockchain based vendor selection system launches. The system requires data from the proposal initiation team, which are differentiated according to their roles prescribed into a smart contract and workflow part of the system. The team needs to add all the attributes pertaining to the performance of the vendor; these attributes are based on multi criteria decision making. As a team initiates a new proposal for vendor selection the other teams in the blockchain network are required to present their consent regarding the acceptance or rejection of the initiated proposal. According to the consent of all the parties involved in decision making for vendor selection, the system act in accordance with all the directions coded in the smart contract. The system reacts to decide the status of the initiated case based upon the provisions coded in smart contract to either accepted or rejected. The system is designed in such a way that an approval from all the concerned nodes in the chain is necessary. If a node disapproves the initiated proposal should be considered as rejected. All the transactional data of this network system is to be recorded into the blockchain based system which ensures the protection of data. This system should be based on provenance and meritocracy of construction vendor selection. The data pertaining to transactions carried out could be imported into the BIM tool database. This data imported into the database is to be made part of the model and BIM file of the project. Moreover, the system update data feature into BIM could prove to be a reminder system for a team to take the action on any new transaction recorded regarding any vendor proposal. For example, if Team A initiates a transaction (if Team A is responsible to initiate the transaction according to provisions in smart contract and the workflow of system), another person from Team B can be notified about it when He updates the transactional data record into BIM by integrated plugin system. This will bring the proposal into concern of Team B and an action in response could be taken swiftly on basis of team's analysis. As the system is based on blockchain technology so no any modification of data could be done unless a new consensual based transaction is carried out and recorded on the ledger. Thus, the involvement of several teams will ensure that the vendor selection is based on group decision with multiple criteria. The application could be created by opting any of the blockchain platforms available. The system could either be created using Etherium platform services or Hyperledger services or Azure Blockchain services. Depending upon the usability and ease of creating application the author will opt any one of the aforementioned choices. Moreover, these all will be described in the detailed framework.

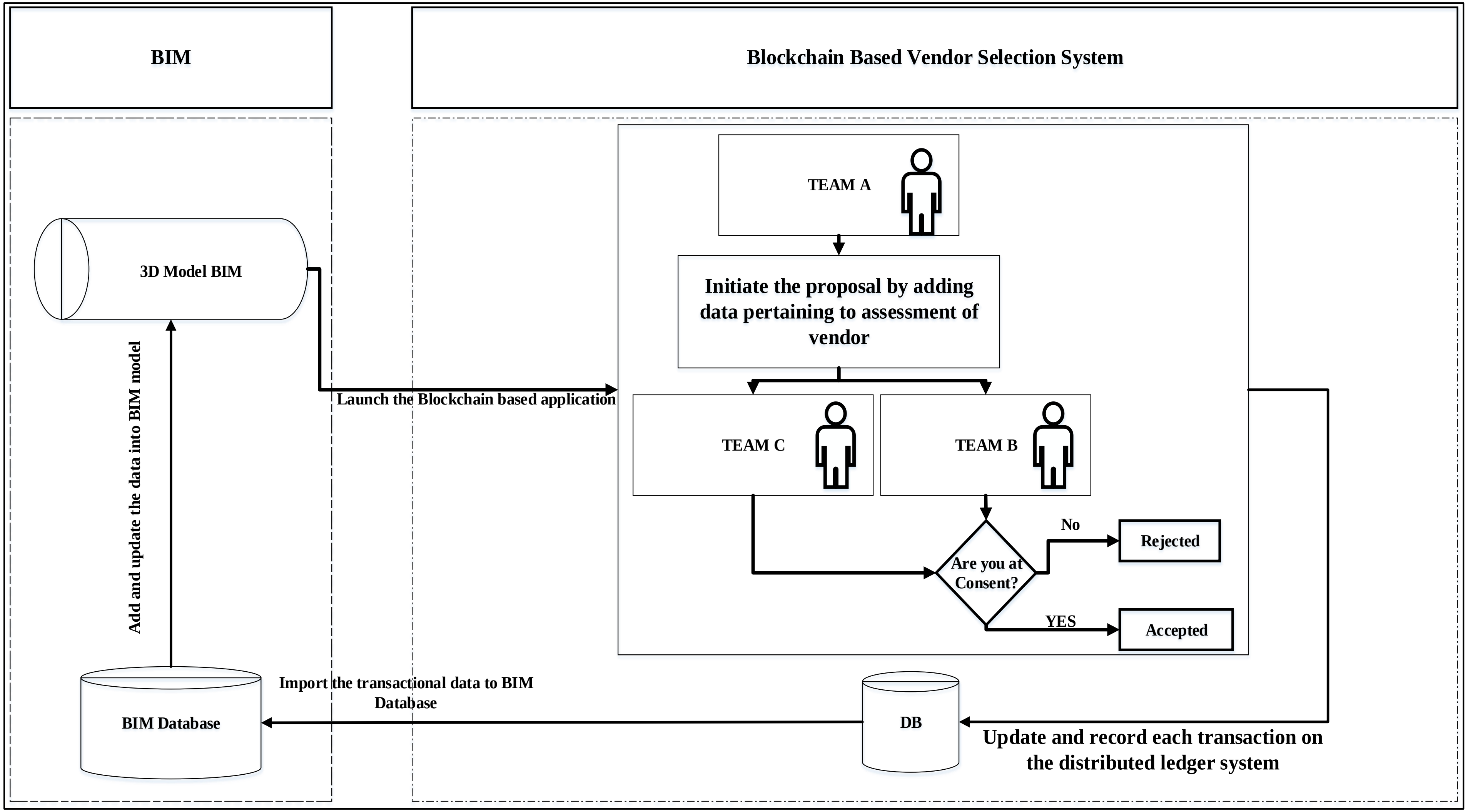


Figure 3. Conceptual Framework for BIM integrated blockchain based vendor selection system.

3.3.2 Azure Blockchain Platform

Azure Blockchain service is a platform that enables us to deploy and create distributed applications backed by blockchain essentials. The Azure blockchain workbench is a fully equipped platform that also provides a templated web-based user interface system and endorse your ideal applications to run on them. To pursue this, one needs to understand the deployment process of azure blockchain workbench which could be processed by going through the documentation available by Microsoft Azure publicly. Following the document, a whole process of virtual machine could be deployed. Alongside, the azure blockchain workbench being a fully essential service for creation of blockchain based business applications, provides its own web-based user interface. As illustrated in Figure 4, after the deployment of azure blockchain workbench services, it requires your application idea to deploy and create a blockchain based transactional application. This application idea is endorsed via a workflow and a smart contract. The application accepts JavaScript Object Notation file for workflow, and a Solidity file for smart contract endorsement in native format. A software Visual Studio Code could be rendered for the services of writing (.JSON) and (.Sol) files. After framing a workflow and writing a suitable smart contract for that workflow, the deployment of blockchain based application could be pursued via uploading those files to the web-based user interface provided by azure blockchain workbench service at the time of deployment via a URL. After the uploading an analysis of code pertinence is check by the service automatically which points out the bugs. If the files are without any error, they are uploaded, and the user is asked for the deployment of application. Once the deployment process completes the application is ready to use. Here the user is asked to assign the roles in the application as per the workflow. Once the roles are assigned the application is in a mode to be fully furnished for use. Keeping in mind the view of blockchain, only authorized nodes will be able to use this application and carry out transactions among them. For example, for a simple business application, according to the workflow roles the initiator will be asked to initiate a contract. After the initiation process, other nodes in the network are notified by a message to take their concerned necessary actions. Here the consent part takes place for the proof-of-concept point of view. All the nodes are part of the network to reach a successful transaction. Subject to the initiation and actions of other nodes in the network a transition in state could be observed automatically. As these states were assigned in the workflow and regulated by the smart contract, so their change per transaction could be observed in accordance. Furthermore, all the transactional data is recorded in the database and also placed on the dashboard, as blockchain ensures data security, so, no data can be amended or modified but a new transaction could be carried out to make a modified data the existing one a part of the chain.

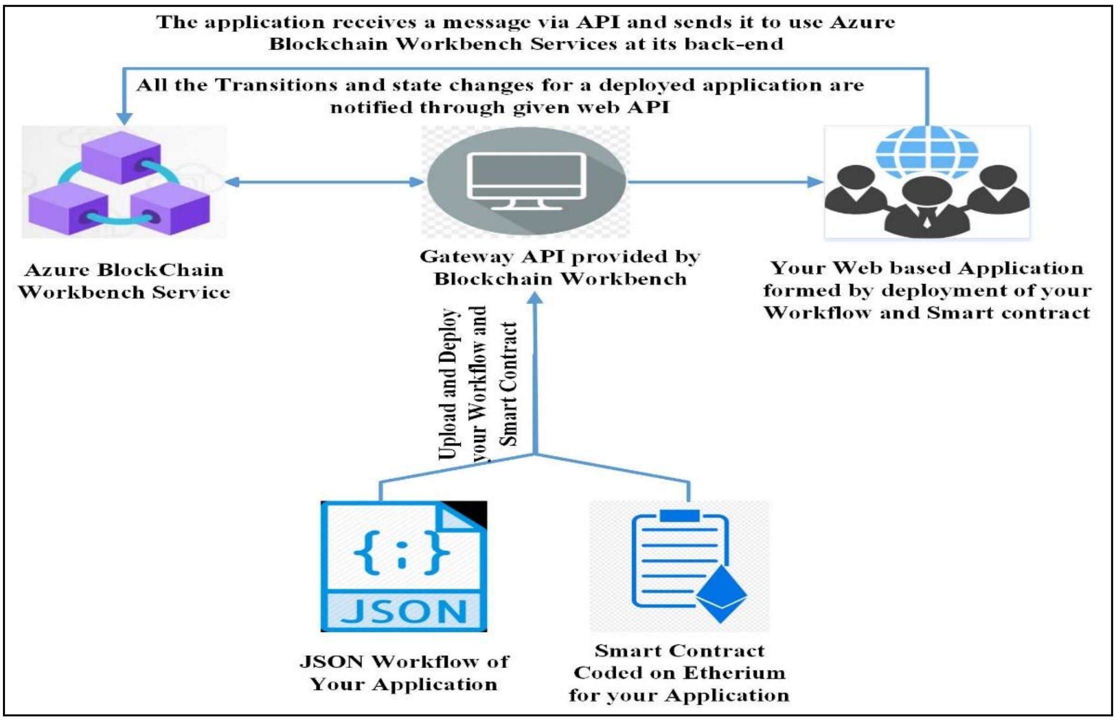


Figure 4. Azure Blockchain Workbench working and deployment.

3.3.3 Development of the BIM-BCVSS

The system was designed to be built in a way to endorse the integration of a BIM tool, namely, Autodesk Revit with a blockchain based web application that could work as an addon. The system could be initiated as and run to carry out the transactions as shown in Figure 5. First and most important step was to create a blockchain based application. This was done by using the Azure Blockchain Workbench services. Firstly, following the documentation available the deployment of azure blockchain workbench was done. After the completion of deployment, the design of workflow in a JSON format and writing of a smart contract were undertaken. The workflow of the application is also shown in Figure 5. According to the workflow, three teams in a construction company are made responsible to carry out the task for vendor selection. All the teams have distinct roles which are to be carried out in a systematic way to reach a consensus. Further a smart contract encompassing the whole workflow was coded using the platform of solidity. After devising the workflow and coding the smart contract, these were deployed and the application pertaining to construction vendor selection was created. The application was then made an integral part of the BIM tool called as Revit. This was done by using .NET Framework 4.7 and programming language C-sharp on Visual Studio. Alongside, a connection string setup was also used using SQL to connect Revit Database with Azure SQL DB and Server, in order to fetch data from the source. Moreover, the .NET Framework method was used to create such an application which could store data to a BIM model directly. This storage was done to be in a form of a schedule. A system was created using the abovementioned tools to directly create a schedule in the BIM Model. This schedule creation was designed in a way that it includes the data pertaining to the transactions carried out on the system via connection strings. Moreover, the Ribbon panel named as BIM-BCVSS and its buttons were created using the same tools as creation of the application. The buttons are named as Open system and Load data according to their functionality.

The functional process of the application could be manifested by the framework in Figure 5. The software opens the BIM model. After running Revit, the application for construction vendor selection can be accessed via ribbon panel BIM-BCVSS. It includes the push button to directly run the web application. Hitting on the push button redirects the user towards the login page, where user is required to put on the credentials and wait for the validation and authentication to complete. Only the authentic user can access the system. Upon successful login, the user is required to fulfill its task as per the workflow and smart contract. Here if the user belongs to procurement team, he is required to initiate a new vendor proposal. According to the roles, a procurement team member is required to put forward a proposal of any potential vendor for selection in front of the other teams for evaluation and their consent. This proposal is based on some attributes of vendor. These attributes were identified from literature and made part of the system; they play a part of being the criteria for vendor selection. Each team could analyze the attributes before opting their consent for selection. The attributes are listed in Table 5. The data input can be either in qualitative form or in a quantitative form depending upon the user. The system offers to both input types. The system is based on adoption of multi criteria decision making approach. Here the user can see different attributes affecting vendor. On basis of these multi attributes a user can evaluate or self-assess the performance of vendor depending on their own respective important criteria. After the initiation of a new construction vendor proposal by the procurement team, a notification or message is sent to the other connected nodes in the network for their respective actions. Other teams could take their actions by similarly going through the process of launching the system via REVIT. Hovering through the BIM-BCVSS ribbon panel and Open system. Then by doing a login with their authentic credentials. Now as the other team, for example the planning team enters the application, it can simply open the initiated proposal. Upon clicking on the initiated proposal, the planning team is diverted to act on the initiated proposal. the action is in the form of two choices, namely, accepted and rejected. Now if the planning team chooses to accept the proposal, it is then put into subject for the last approval in order to change the status of vendor from new to accepted. Similarly, the quality team could perform the same steps for login process and enter into the system. Here also after the initiation process, the team is notified with the message to take the action. The quality team also have two choices either to accept or to reject the proposal. Upon choosing the accept choice. The vendor could be selected upon consensus. If the system observes that all the respective nodes are upon consensus to accept the proposal, the system changes the state from new to accepted. On the contrary, if any one of the nodes in the network disagrees with the proposal by opting the reject choice, the contact would be terminated by the system simply displaying the rejected state. For example, if the planning team upon the entering the system observes a new proposal and evaluate it, then opts for reject option. The system will directly change the state of the proposal from new to rejected and terminate the contract, without any consent from the other team. On the other hand, the addon has another feature of loading the transactional data into the BIM Model. The data could be imported and made part of the BIM model as a schedule. Upon opting for the load data part of the addon, the system tries to contact the Azure SQL database and fetch the respective data pertaining to the transaction. Further the system creates a schedule and adds the respective data through fetch command. This loading data could also be called as a reminder system to act. If procurement teams initiate a new proposal for construction vendor selection and planning team or quality team loads the data into their BIM model, they can see the additional information in form of data that includes the state and timestamp along with user information. The respective team will have the knowledge now that a new proposal has been initiated and it can take an immediate action by thorough evaluation of the attributes put forward. Moreover, opting the load data into BIM can update the schedule by importing new transactions carried out. This will create an environment of collaboration and a sense of meritocracy in selecting a construction vendor. Thus, the data pertaining to all the transaction on blockchain database could be imported into Revit 3D BIM model and saved into a (.rvt) file as a part of BIM.

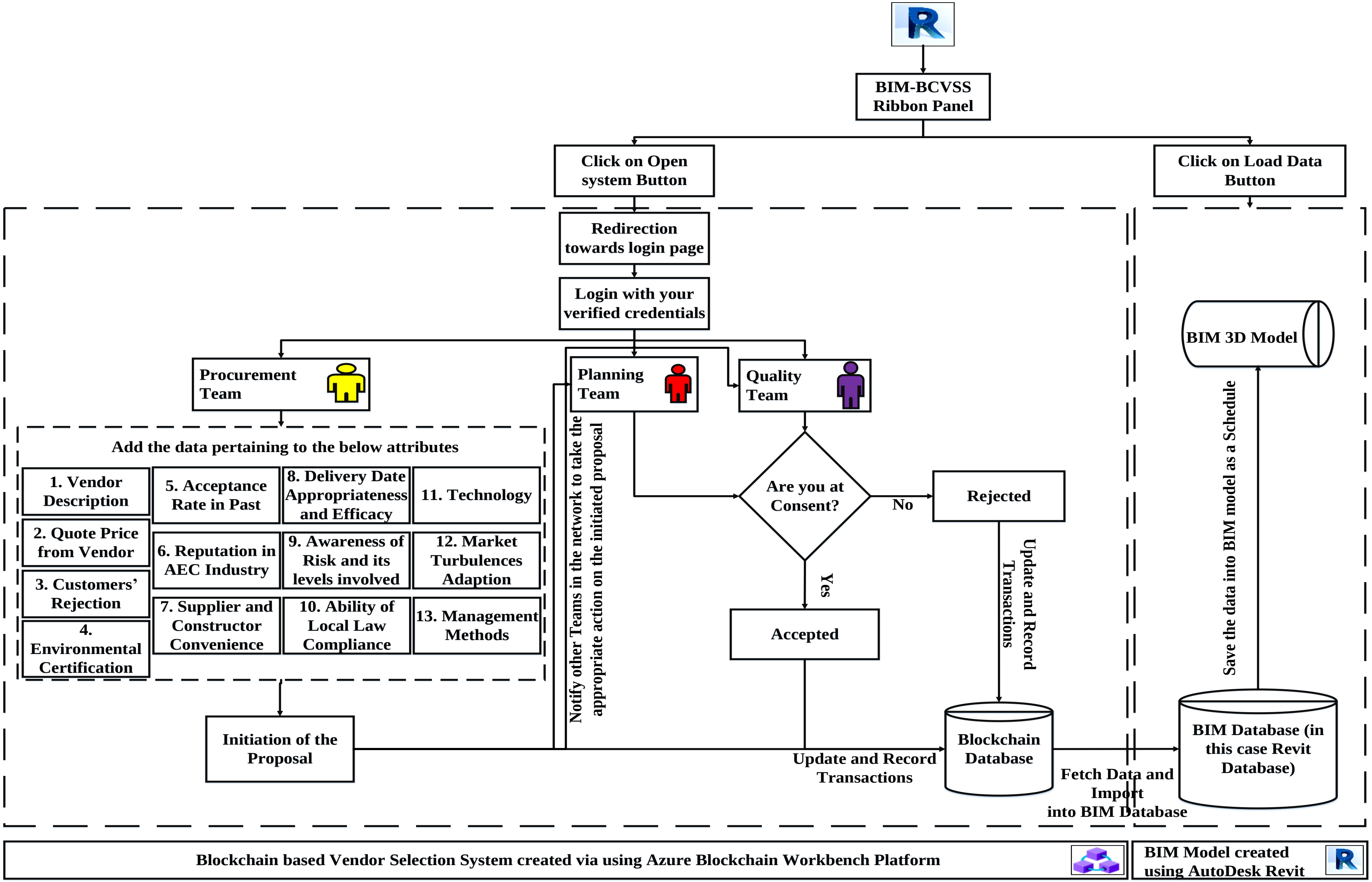


Figure 5. Framework for BIM integrated blockchain based construction vendor selection system

CHAPTER 4

THE BIM-BCVSS PLUGIN

4.1 The BIM-BCVSS Plugin

The plugin if created by using .Net Framework 4.7 and C-sharp programming language using visual studio community. It is comprised of the following panel and buttons as shown in Figure 6:

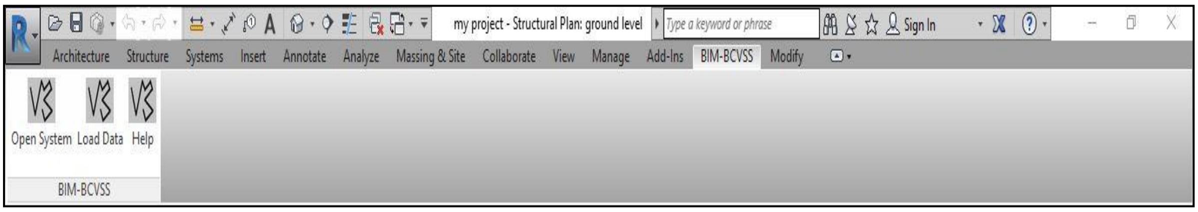


Figure 6.BIM-BCVSS Ribbon Panel and Push Buttons

4.2 The BIM-BCVSS Ribbon Panel

The ribbon panel includes 3 push buttons respective to their functions. These buttons are Open system button, Load data button and Help button.

4.2.1 The Open System Button

When clicked on the button, it launches the web system in any web browser. This system is made by using Azure Blockchain Workbench services, these services provide a template web page system and URL alongside. The system opened thus redirects to the desired URL of the system. Here as the system launches, a sign in page appears to verify the credentials of user as shown in Figure 7. The user thus needs to login with the authentic id and password provided and included in the system. After successful login process the user can perform activities and use the system within the roles prescribed in the workflow. The workflow interacts with smart contract and executes the functions accordingly.

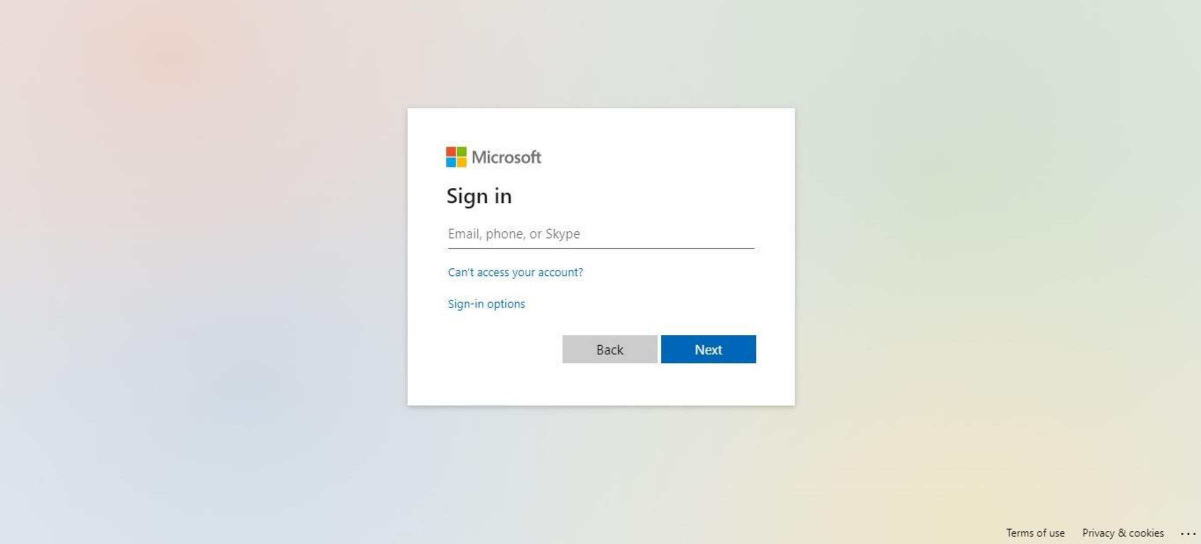


Figure 7 Redirection to Login Screen after Clicking on Open System Button

If the person is a team member of procurement team, He is directed to initiate the proposal by entering the all the respective attributes and deploying the scenario as shown in Figure 8.

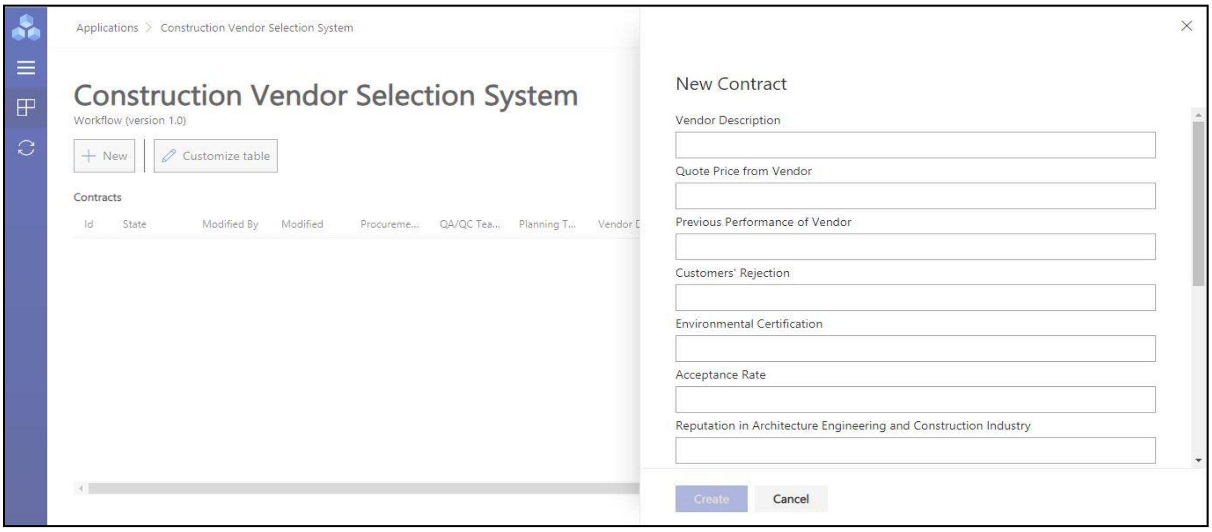


Figure 8. Vendor Initiating Screen appeared by clicking on new button used by Procurement team

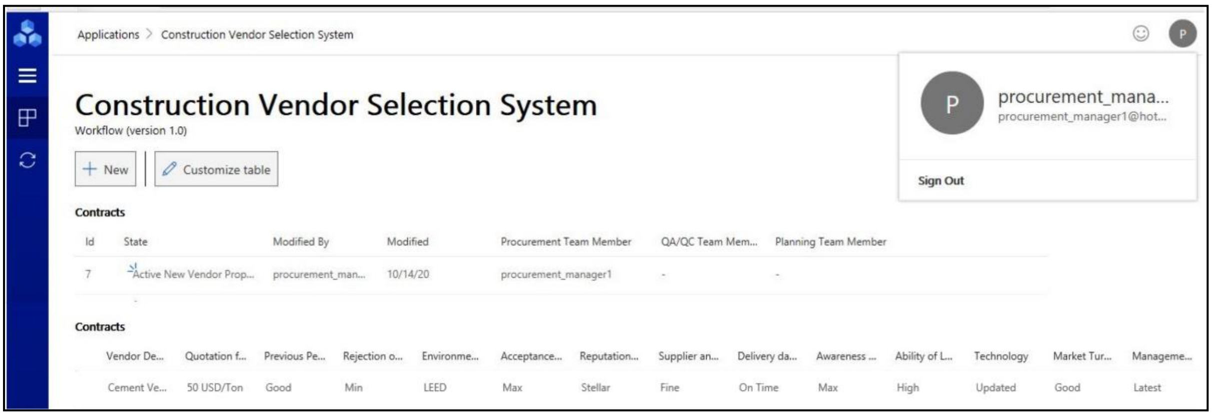


Figure 9. Initiated active Proposal on dashboard of the system.

The attributes listed in Table 5 are the desired attributes used as criteria for a proposal evaluation. Hence, the process is initiated by the procurement team. After the initiation, the status on dashboard displays that this proposal is active now and is subject to some action as shown in Figure 9. Now when a personnel of Planning team logins with its respective credentials, He / She can take a respective action on the proposal initiated within the prescribed roles and provisions in workflow and smart contract. Here the member gets a message upon selecting the active proposal as shown if Figure 9.

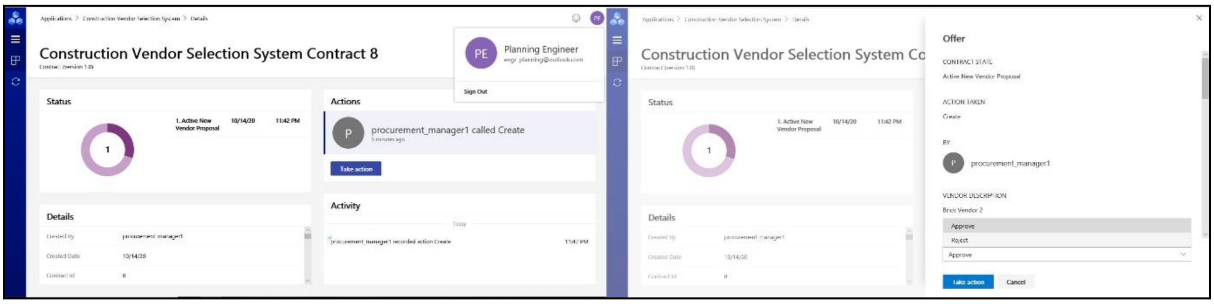


Figure 10. Action Required by any team other than procurement team.

Here the member is given two choices as per contract to either accept or reject the proposal, as shown in Figure 10 If the member opts for the option to reject based on his perception / analysis of vendor attributes, the display status changes directly to terminated state that is rejected as shown in Figure 12

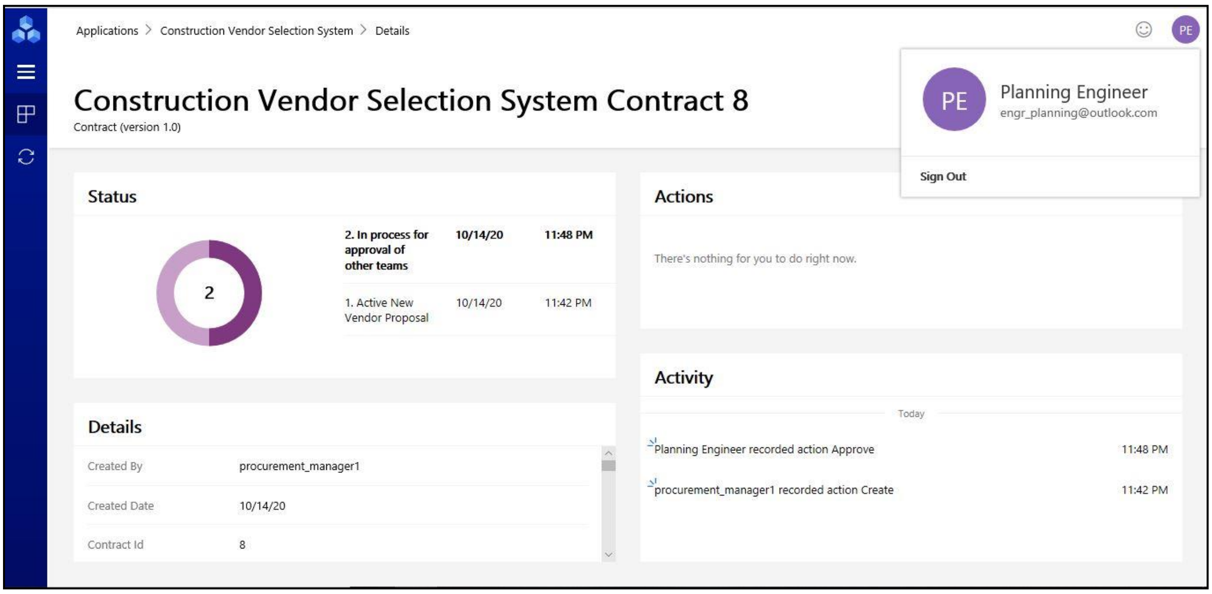


Figure 11. The change of state to in process for other teams' approval

On the contrary, if the member opts to accept the proposal then the acceptability of the vendor will be subjected to the agreement of another team in the network Figure 11. Here now similarly, the quality team, after its successful login can see the activeness of the proposal initiated. Like planning team, if the quality team selects to reject the proposal it will be rejected as shown in Figure 12. But if the team after consensus of planning team to accept the proposal agrees on accept state. Then according to the smart contract, the status will change from active proposal to the accepted proposal as shown in Figure 12.

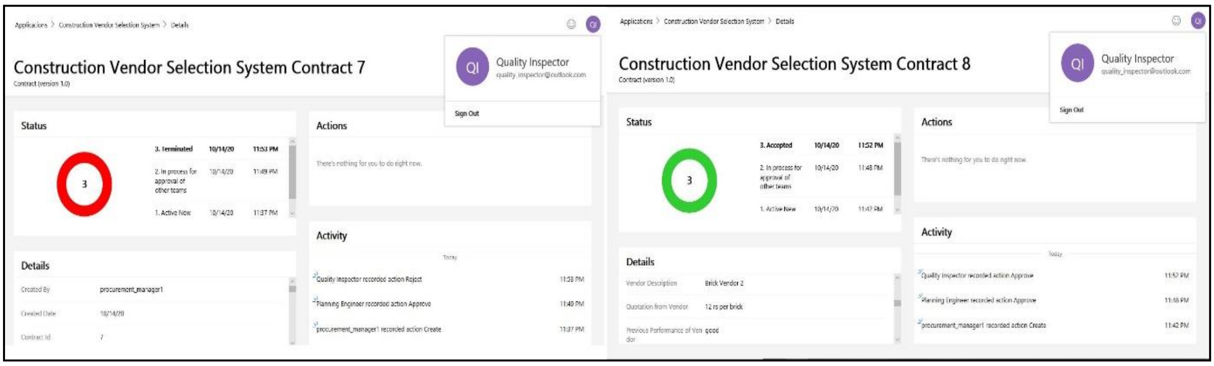


Figure 12.Rejected or Accepted State of the proposal

The subject to take respective action is not based on any hierarchy, any of the two teams (i.e. planning or quality) could be the one to be the first to either reject or accept the vendor proposal and put the acceptability state subject to consensus of other member. One of the benefits of this blockchain based system is maintenance of data that cannot be modified or amended. If someone wants to modify this data a new proposal is to be initiated with the updated information of attributes and subjected to selection process, further then added as a new entity. The data record is always available on the blockchain and is manifested to every node on the network on a dashboard system as shown in Figure 13

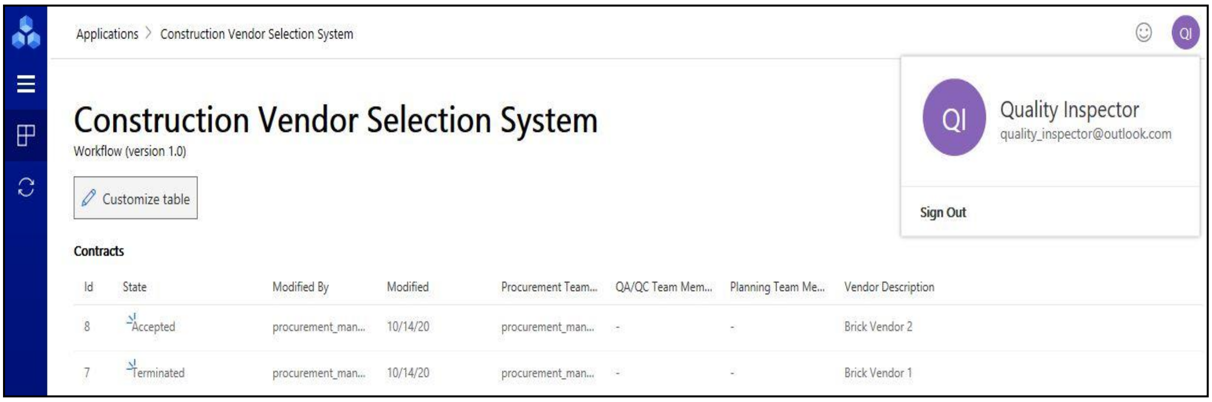


Figure 13. Dashboard manifesting non-modifiable data.

4.2.2 The Load Data Button

This button when initiated contacts the Azure Sql Database which stores a replica of all the transactional related data carried out in our blockchain network. This data base is connected to the blockchain database and stores all the data in form of tables and views. Using connections strings the data stored into the Azure Sql database is fetched and stored in Revit database. This button is coded in such a way that it creates a schedule in the BIM model named CVS Schedule, as shown in Figure 14, and imports the data related to blockchain transactions carried out. The data imported is saved in the form of table as a schedule in the BIM Model as shown in Figure 14. The data extracted and added into BIM model comprises of Transaction From, Transaction To, Transaction Hash, Block Hash, Block Number, Time Stamp, User Details and State of contract as shown in Figure 14.

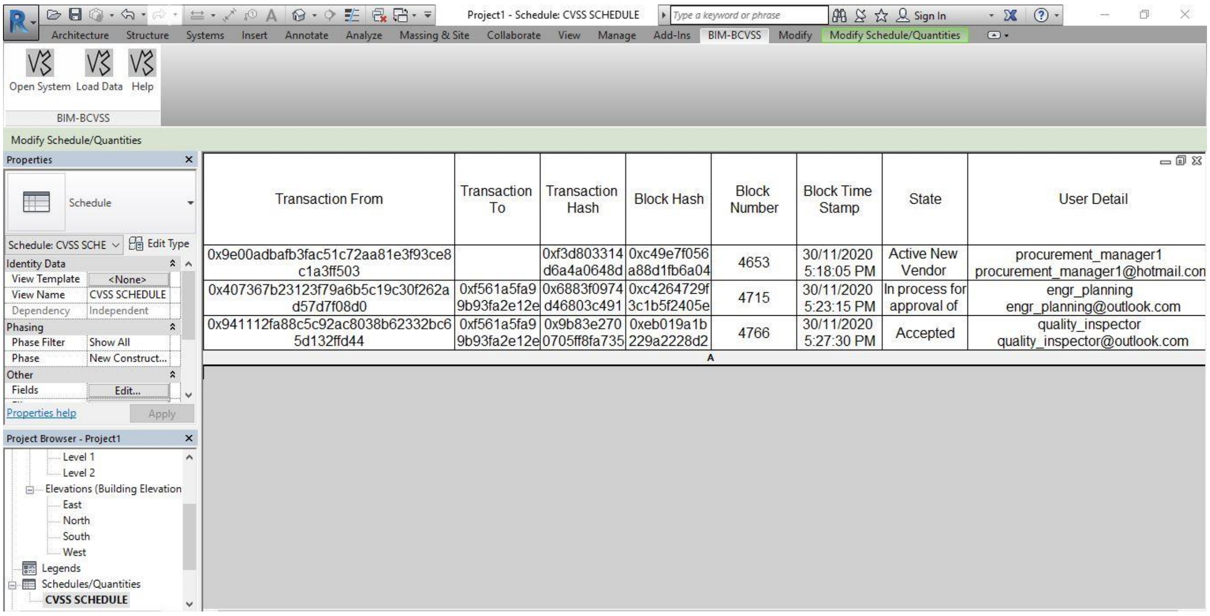


Figure 14. Creation of CVSS Schedule by clicking on Load Data Button

4.2.3 The Help Button

This button is provided for the guidance of user. Its main function is training of the users related to selection system. This button displays an image with steps to carry out a transaction and import its related transactional data, as shown in Figure 15. The image file is so created that it illustrates a flow of transition of distinct roles as per the workflow of the application. The instructional image displays that a procurement member is required to initiate the proposal, while the other two teams are required to act as per their prescribed roles in the workflow. Moreover, it also guides regarding the schedule that is to be created by clicking on the load data button.

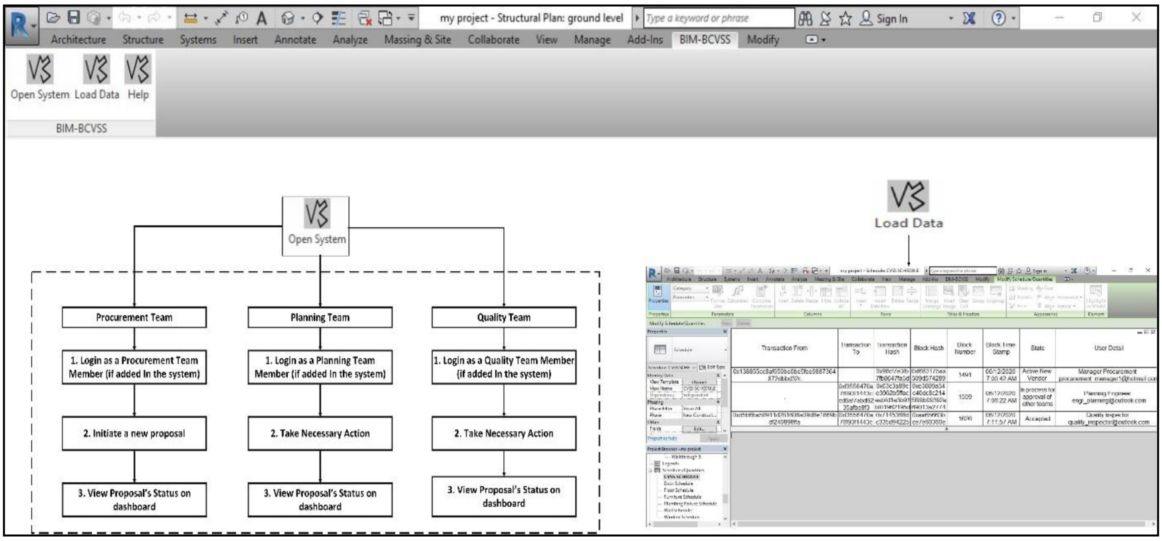


Figure 15. Instructional Picture Displayed when clicked on Help Button.

CHAPTER 5

EVALUATION OF THE SYSTEM

5.1 Case Study

For the evaluation / validation of this system a case study of two identical houses under construction was considered. These houses are in Defence Housing Phase-2 Hyderabad, Sindh Pakistan. Firstly, the system was made and implemented for first house, as shown in Figure 16. Each house has a dimension of 65 X 45 feet. The system was initiated by 3 personnel regarding transactional activity of vendor selection. First member was from procurement department, second from the planning department and third from quality department. All these personnel are highly experienced and qualified. As shown in Figure 17, all the related transactions were carried out at distinct instances and then a record database was maintained which proved to be helpful in selection of vendors for the second house to be constructed. The proposals which were initiated for the first house were also taken in account for the seconds house also. The system mostly dealt with vendor supplying the material for grey structure. Furthermore, in order to record the response of persons regarding this system interviews of the users were conducted to find out the efficacy of the system to tackle all the inefficiencies listed in Table 4. The designated persons recorded the transactional activity in their BIM software and kept a record of their transactions in a hard copy as well. From Figure 17, a person designated with the procurement team initiated the process for the first construction material vendor, that is with respect to procurement cement and further carried out their transaction with changing nature of material. These transactions will never be modified and comprise of a timestamp. This gives an immunity towards any discrepancy in construction material vendor selection. Furthermore, it builds up the trust among working parties / departments in the process and ensure smooth flowing of meritocracy in the process. The system helped to increase the collaboration between the parties of different nature. Taking the attributes from Table 5 the construction company finalized their proposal based on both type of entries, namely the objective and the subjective measuring technique. The members included in this process were added to carry out all the transactions and the members inclusion is shown in Figure 18 and Figure 19 shows all the data which was loaded in BIM Model as a schedule and kept as a record and integral part of the BIM Model.

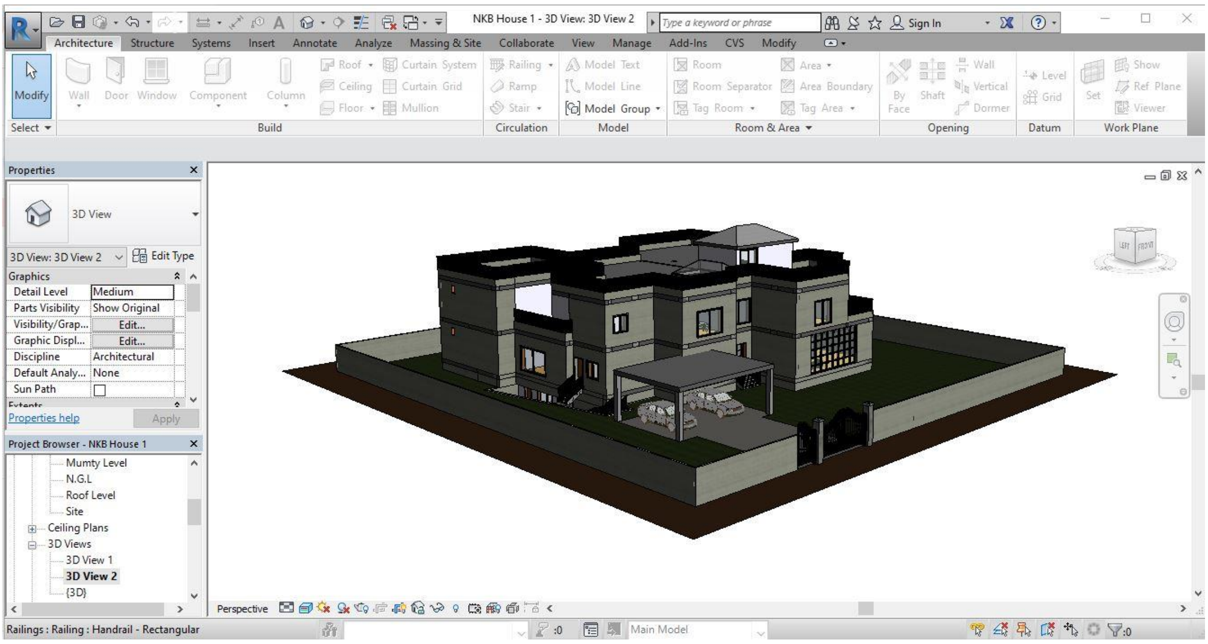
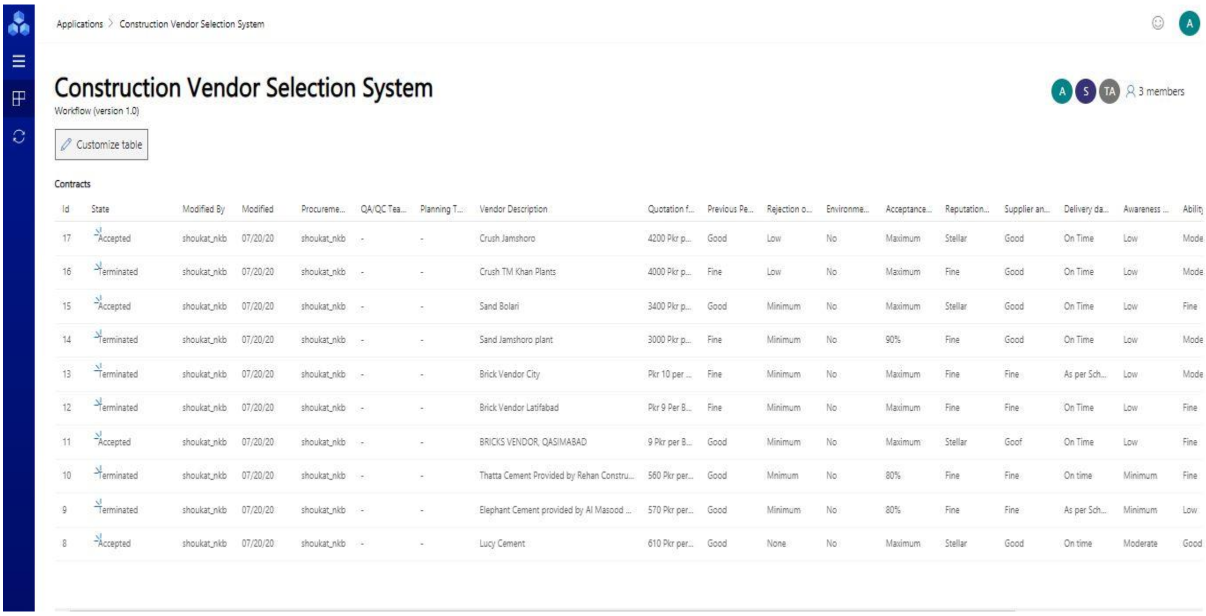


Figure 16. BIM model for the desire House to be constructed and adopted in this Case Study.



Id	State	Modified By	Modified	Procureme...	QA/QC Tea...	Planning T...	Vendor Description	Quotation f...	Previous Pe...	Rejection o...	Environme...	Acceptance...	Reputation...	Supplier an...	Delivery da...	Awareness ...	Ability
17	Accepted	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Crush Jamshoro	4200 Pkr p...	Good	Low	No	Maximum	Stellar	Good	On Time	Low	Mode
16	Terminated	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Crush TM Khan Plants	4000 Pkr p...	Fine	Low	No	Maximum	Fine	Good	On Time	Low	Mode
15	Accepted	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Sand Bolari	3400 Pkr p...	Good	Minimum	No	Maximum	Stellar	Good	On Time	Low	Fine
14	Terminated	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Sand Jamshoro plant	3000 Pkr p...	Fine	Minimum	No	90%	Fine	Good	On Time	Low	Mode
13	Terminated	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Brick Vendor City	Pkr 10 per ...	Fine	Minimum	No	Maximum	Fine	Fine	As per Sch...	Low	Mode
12	Terminated	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Brick Vendor Latifabad	Pkr 9 Per B...	Fine	Minimum	No	Maximum	Fine	Fine	On Time	Low	Fine
11	Accepted	shoukat_nkb	07/20/20	shoukat_nkb	-	-	BRICKS VENDOR, QASIMABAD	9 Pkr per B...	Good	Minimum	No	Maximum	Stellar	Goof	On Time	Low	Fine
10	Terminated	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Thatta Cement Provided by Rehan Constru...	560 Pkr per...	Good	Mnimum	No	80%	Fine	Fine	On time	Minimum	Fine
9	Terminated	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Elephant Cement provided by Al Masood ...	570 Pkr per...	Good	Minimum	No	80%	Fine	Fine	As per Sch...	Minimum	Low
8	Accepted	shoukat_nkb	07/20/20	shoukat_nkb	-	-	Lucy Cement	610 Pkr per...	Good	None	No	Maximum	Stellar	Good	On time	Moderate	Good

Figure 17. Dashboard of all the transaction carried out for selection of vendors in the project. Mostly vendor selection is pertaining to grey Structure Material Vendors.

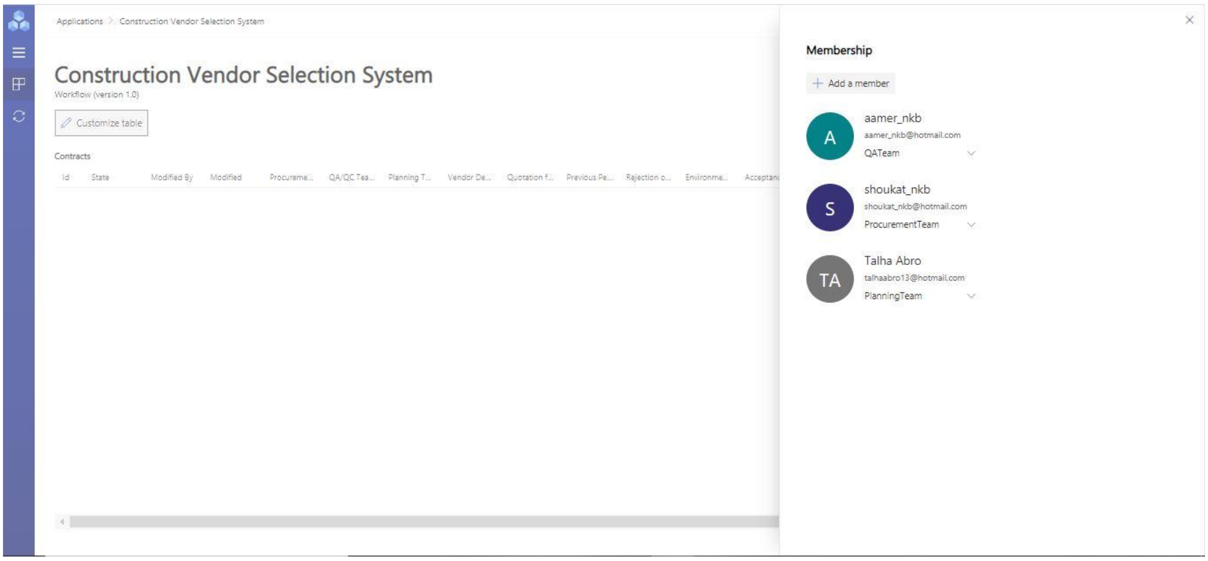


Figure 18. members of Different Teams at Site who were included for this case study.

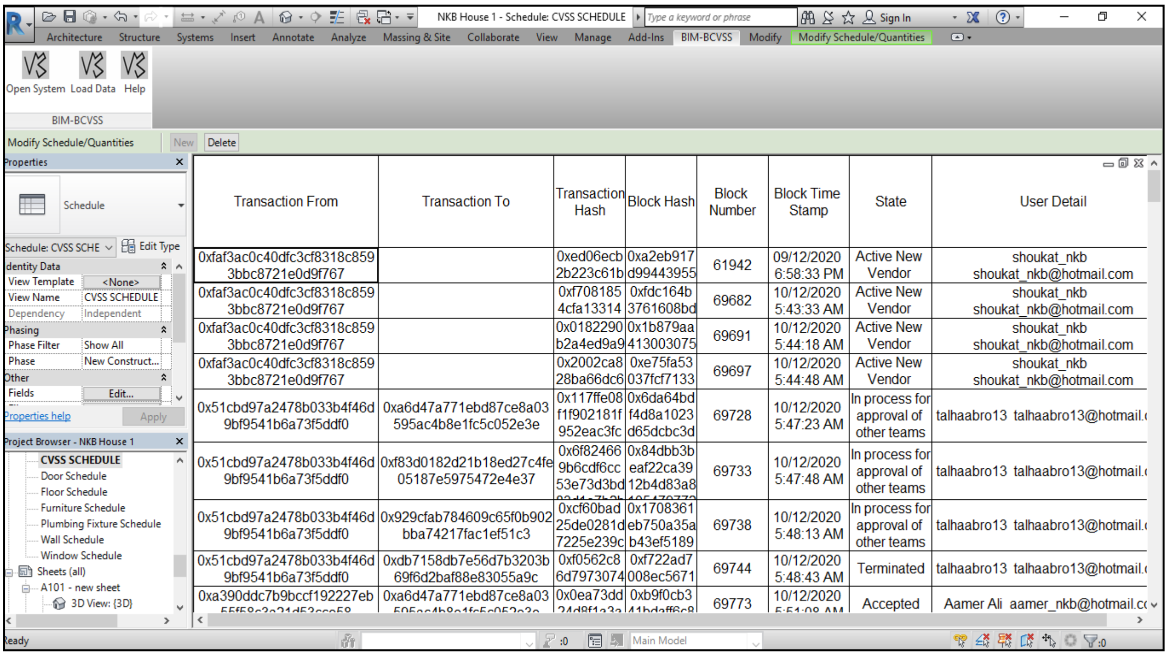


Figure 19. creation of Schedule for BIM Model of Residential House by selecting Load data Button.

5.2 Qualitative Analysis of the efficacy of the BIM-BCVSS

The response of users was recorded in two rounds. After installing and setting up of the BIM-BCVSS addon on the systems, the users were instructed about usage of the BIM-BCVSS and then they were interviewed in two rounds. In the first round the users were asked to enlist or identify the main features or Performance characteristics of the BIM-BCVSS system as shown in Table 7. The performance characteristics of BIM-BCVSS as identified by the users are compiled, the overlapping characteristics having similar meaning are merged and enlisted in Table 8. Furthermore, in the second round the users were required to rate the performance characteristics of BIM-BCVSS as identified by them in the first round of interview on a 5-point Likert scale regarding the satisfaction level of BIM-BCVSS (ranging as 1= highly unsatisfactory, 2= unsatisfactory, 3= slightly satisfactory, 4= satisfactory and 5= highly satisfactory). The results are incorporated in Table 9. The results manifest that the performance features identified by the users lies among the range of being satisfactory to highly satisfactory. Also, in the second round of interview, each user is required to mark the performance characteristics of BIM-BCVSS identified in the first round of the interview against the inefficiencies enlisted in Table 4. The compiled result of this second round is shown in Table 10. The results of this second-round manifests that the system is effective in order to counter all the inefficiencies existing in vendor selection. The feature of Multi-Criteria Decision Making of BIM-BCVSS has been marked the most effective as it counters most of the inefficiencies by the users as shown in Table 10. Through these interviews the efficacy of the BIM-BCVSS has been assessed and found out to be highly satisfactory as the system devised is able to tackle all the inefficiencies listed in Table 4. Moreover, the users identified that visualization of location of a vendor through map or any other platform should be added in order to enhance the geographical location aspect.

Table 7. Performance Characteristics identified by users.

S. No.	User	Performance Characteristics of BIM-BCVSS Identified
1	1	Merit Consensus of Teams Tracking of Record and Authenticity
2	2	Multi-Criteria Approach Consensus of Teams and Collaboration Disclosure of Information among Parties
3	3	Multi-Criteria based Selection. Teams Involvement to Select Vendor

Table 8. Compilation and Mergence of Overlapping Performance Characteristics identified by the Users.

S.no	Compiled Performance Characteristics of BIM-BCVSS
1	Merit

S.no	Compiled Performance Characteristics of BIM-BCVSS
2	Provenance
3	Multi-Criteria based selection
4	Information Sharing
5	Consensus and Enhanced Collaboration

Table 9. Rating of Performance characteristics by the users and its average score

S.no	Performance Characteristics	User 1	User 2	User 3	Average score
1	Multi-criteria based selection	5	5	5	5
2	Consensus and Enhanced Collaboration	5	4	5	4.666666667
3	Provenance	5	5	5	5
4	Information Sharing	5	5	4	4.666666667
5	Merit	5	5	5	5

Table 10. Performance characteristics of BIM-BCVSS vs Inefficiencies in Construction Vendor Selection

	Performance Characteristics of BIM-BCVS	Inefficiencies in Vendor Selection Process															
		I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16
User 1	Provenance	*		*			*		*	*	*	*	*	*	*	*	*
	Consensus and Enhance Collaboration	*				*		*		*		*	*	*	*	*	*
	Merit	*	*				*	*	*	*		*	*	*	*	*	*
	Multi-criteria based selection	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Information Sharing		*	*		*		*	*		*		*		*		*
User 2	Provenance	*		*			*		*	*	*	*	*	*	*	*	*

	Performance Characteristics of BIM-BCVS	**Inefficiencies in Vendor Selection Process**															
	Consensus and Enhance Collaboration	*				*		*		*		*	*	*	*	*	*
	Merit	*	*				*	*	*	*		*	*	*	*	*	*
	Multi-criteria based selection	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*
	Information Sharing		*	*		*			*		*		*		*		*
User 3	Provenance	*		*			*		*	*	*	*	*	*	*	*	*
	Consensus and Enhance Collaboration	*				*		*		*		*	*	*	*	*	*
	Merit	*	*				*	*	*	*		*	*	*	*	*	*
	Multi-criteria based selection	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
	Information Sharing		*	*		*		*	*		*		*		*		*

The users rated the system to be at the verge of being satisfactory and highly satisfactory as shown in Table 9. It ensures that the system is useful to carry out the construction vendor selection process. Moreover, its adoption in BIM provides a record of transaction pertaining to project in a model and a single file. This will also help in further sharing of data and keeping up the record apart from the Blockchain based system. The blockchain aspect of this system provides immunity to the data from any sort of malpractice. Thus, the system is a great addition to the construction industry in terms to testify the veracity of a construction vendor proposal.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

BIM is a platform with tendency to adapt distinct technologies for betterment of various aspects pertaining to construction. A new technology namely Blockchain is at the verge of exploration for creation of management and governance applications. Thus, an effort has been made in this study to integrate a blockchain based construction vendor selection system with BIM. This integration has been achieved by identification of inefficiencies in construction vendor selection and carrying forward towards the identification of the attributes affecting the construction vendor selection. The development of framework was pursued that inducts the vendor selection attributes identified and was then visualized in form of BIM-BCVSS. The visualized system was then subject to validation via its implementation on the ongoing construction project and qualitative assessment by interviews of the users. The key contribution of this study is enhancement of collaboration of different teams working on a construction project. Moreover, the feature of authenticity and cryptographic ownership has been regarded as the essential aspect of merit assurance by the users in the validation phase. The study not only provides a method to integrate the blockchain based application but also looks forward to the industry professionals for recognition and adoption in the field and researchers for further exploration and invention of other integration processes.

6.2 Future Recommendation

Creation of this system is an effort to integrate blockchain based business applications with BIM. The system thus created has been good in terms of aspects involved. But it could have been made more effective and enhanced by provision of additional features. The authors recommend adding some features like the location of a construction vendor in terms of co-ordinates or a map in points, as highlighted by the users in the evaluation process. Furthermore, the system has the capability to adapt any sort of changes with respect to time. The approach manifests that further many of the aspects pertaining to construction could be adopted for a decentralization.

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