World Academy of Science, Engineering and Technology
International Journal of Structural and Construction Engineering
Vol:12, No:3, 2018

Integrating Dependent Material Planning Cycle into Building Information Management: A Building Information Management-Based Material Management Automation Framework

Faris Elghaish, Sepehr Abrishami, Mark Gaterell, Richard Wise

***Abstract*—**The collaboration and integration between all building information management (BIM) processes and tasks are necessary to ensure that all project objectives can be delivered. The literature review has been used to explore the state of the art BIM technologies to manage construction materials as well as the challenges which have faced the construction process using traditional methods. Thus, this paper aims to articulate a framework to integrate traditional material planning methods such as ABC analysis theory (Pareto principle) to analyse and categorise the project materials, as well as using independent material planning methods such as Economic Order Quantity (EOQ) and Fixed Order Point (FOP) into the BIM 4D, and 5D capabilities in order to articulate a dependent material planning cycle into BIM, which relies on the constructability method. Moreover, we build a model to connect between the material planning outputs and the BIM 4D and 5D data to ensure that all project information will be accurately presented throughout integrated and complementary BIM reporting formats. Furthermore, this paper will present a method to integrate between the risk management output and the material management process to ensure that all critical materials are monitored and managed under the all project stages. The paper includes browsers which are proposed to be embedded in any 4D BIM platform in order to predict the EOQ as well as FOP and alarm the user during the construction stage. This enables the planner to check the status of the materials on the site as well as to get alarm when the new order will be requested. Therefore, this will lead to manage all the project information in a single context and avoid missing any information at early design stage. Subsequently, the planner will be capable of building a more reliable 4D schedule by allocating the categorised material with the required EOQ to check the optimum locations for inventory and the temporary construction facilitates.

***Keywords*—**Building information management, BIM, economic order quantity, fixed order point, BIM 4D, BIM 5D.

I. INTRODUCTION

THE material management process presents an important challenge in the construction industry due to the lack of required storage spaces as well as the supplying process which required an early data to prepare and manage it [15]. Moreover, dynamic changes in supply process can cause several problems during the execution stage [11].

According to Ren et al. [6], Radio Frequency Identification systems (RFID) can be used to manage the material through helping the team to collect the storage material information as well as tracking the material inside the site; however, there is another system which is called Congested Construction Logistics Planning (C2LP). This system is used to determine the optimum requirements from the material by prioritising materials as critical and non-critical and to move the non-critical material to offer storage spaces for critical materials [14]. Subsequently, this paper will introduce a complementary framework which includes some tools to deal with material management parameters, the spaces requirements and to prepare logistic planning by exploiting BIM big data at different stages in construction process.

This paper proposes a strategy to use BIM capabilities such as generating precise and quick Bills of Quantities (BoQ) at an early design stage. Because, material represents the highest significant part investment in construction resources, and therefore, it needs to be managed by using scrutinising methods and techniques, as well as it must be predicted at early design stage in order to avoid any future problems. BIM 5D provides a flexible and integrated BoQ which can be extracted from the intent or virtual BIM 3D model. Theses quantities represent the types usage of materials in the BIM 3D model, and these quantities are categorised in accordance with the adapted model in BIM platform. On this basis, all of the traditional barriers to implement material planning at early design stage have been solved technically.

The proposed framework will consider the dependent supply in order to optimise the Total Material Cost (TMC) which comprises Purchasing, Holding, Inventory, and Order costs. This will be implemented by determining the EOQ, and the Order Point (OP) to determine when and how many units of each material will be required.

II. LITERATURE REVIEW

A. The Importance of Material Management

Said and El-Rayes [17] concluded that the objective of creating a logistics model is to optimise the supplying process and to facilitate taking the decision of the site layout, decreasing the criticality of the project activities. Moreover, the relationships between the project design elements and the

Faris Elghaish is a PhD researcher at University of Portsmouth, UK (e-mail: faris.elghaish@port.ac.uk)

Sepehr Abrishami is a Lecturer and Course Leader at University of Portsmouth, UK.

Mark Gaterell is a Professor of Sustainability Development and Associate Dean of Research, Faculty of Technology, University of Portsmouth, UK.

Richard Wise is a Senior Lecturer at University of Portsmouth, UK.

demand materials should be considered such as classifying the design model to interior and exterior places [18].

The optimisation of the TMC should consider two objectives; the first objective is to optimise the process of acquiring the material, this process includes different elements such as purchasing cost, ordering cost, carrying cost, and inventory cost. Therefore, all mentioned elements must be optimised by balancing between all of them to minimize the TMC. Another objective is to represent these costs with the schedule and entire cost management plan [17].

WRAP [19] defines that the material logistics planning is a practical method which has been designed to facilitate the achievement of triple project constraints; the time, cost, and quality. The logistic plan is designed to be management system for a variety of the materials which will be used in the project. However, according to Methanivesana [20], the efficient logistics management planning is crucial to optimise the entire project cost and schedule, and the efficient planning can enhance the collaboration between the participants whether in a vertical or horizontal supply chain. Moreover, this is considered as a main target of using BIM in the AEC industry to increase the compatibility and minimise the fragmentation throughout the entire construction process.

Saukkoriipi [21] asserts that the cost of flow the material to the construction site ranges from 20% to 47% of material cost. Therefore, any reduction in the flow cost will be reflected by considerable percentage in the TMC. However, Chenthoorun and Gnanasigamani [22] have attempted to integrate the logistic planning and the project scheduling by generating a short schedule. This schedule extracts from the entire project schedule and shows the daily tasks with the required material to execute these tasks.

B. ABC Analysis Theory (Pareto Principle)

ABC is the most widely use of analysing the inventory materials into three categories with respect to the annual financial unit usage to procure them [3]. The first category is A which represents the top 20% of the materials which requires expenditure 80% of the material costs to acquire these materials. Meanwhile, the second category is B which represents the next 30% of the material and they need to consume 15% of the material budget to own them. However, the left budget which represents 5% is sufficient to purchase the other 50% of the project material, and this category is called C [5].

Furthermore, according to Onwubolu and Dube [16], ABC is a vital technique to measure the efficiency of each inventory item and analyse how the TMC can be managed to reduce it. However, the implementation of an ABC can easily facilitate the control of total project cost because the failure in managing the material inside the AEC project will be reflected in cost overrun and will be the reason to fail the entire project [24]. Even though, ABC analyses and categorises the materials into critical and non-critical items; however, the critical items should be entered to another process to determine their Economic EOQ, and the Economic Order Point (EOP) to identify the optimum amount which should be ordered each interval or to determine the time when the project requires to request a new order from the suppliers [25].

C. BIM Quantification Process

According to Smith [9], the automated quantification process becomes applicable in using BIM, which leads to support the quantity surveyors (QS) by integrating between BIM 4D and 5D to offer a sophisticated cost management process. Moreover, this integration will increase the cost data sharing through BIM data to achieve BIM integrated and collaborative project delivery at each stage. Furthermore, Smith [9] states that the prime obstacle for using the automated BoQ is the QS, and the BIM users are still unfamiliar with this kind of advanced technology. Additionally, this leads to generate an untrusting environment regarding the derived quantities; as a result, the users cannot understand the concept and application of BIM processes and platforms. On the other hand, Smith [9] has applied his research to the top four companies which uses BIM to produce the quantification in Australia, the research collected data lead to declare that just two companies use the BIM 5D for cost planning, while the other two companies use it for narrow and ineffective issues such as getting BoQ. The first two companies state that the delivered data at an early design stage are inadequate, subsequently, this causes another problem during the construction stage. Moreover, the shortage in data causes an untrusting case to BIM model.

Wen [13] states that BIM 4D can be used to articulate the construction activities and to display them by using the animation tools. Moreover, visualisation option can minimise the uncertainty and fragmentation of construction process which are inherent in AEC projects. Furthermore, the project planner can optimise the constraints on the activities and the whole project schedule.

Currently, BIM is an integrated and complementary process which can integrate all project stages and stakeholders from inception to close out stage, generating Building Assets information model to optimise and manage the assets process during its economic life time span. The BIM 4D represents the scheduling process, and BIM 5D is a quantification method. Therefore, the integration of BIM 4D and 5D can articulate a new model for optimisation of cost across all project phases. Additionally, this integration enables to minimize the total cost by keeping the quality under the agreed specification.

Management of temporary works on the site is critical to ensure that the construction activities will be proceeded. However, the existing planning method does not offer the option to display the temporary works as a part of the entire project schedule. BIM 4D offers an option to build the temporary facilities in a virtual environment by representing the temporary works in scale. Moreover, the animation option offers the participants to run a simulation for the execution process before proceeding it in actual site [1].

D. Risk Management

According to The Public Risk Management Association [12], risks can be defined as the effect of uncertainty on objectives, therefore the objectives are required to be clear and well defined. Risk Management is a complementary and dependent process, thus each task should be analysed and described clearly. For example, risk assessment stage roles are to evaluate the identified risks and risk analysis stage is to analyse the impact of the assessed risks. Subsequently, the risk analysis should take a place to determine the likely effects of the identified risks [12].

There are two types of risk assessment which depend on the collected data; quantitive risk assessment which relies on determining the effects of issue or event mathematically and statistically, whereas qualitative risk assessment which relies on determining the weight of the impact by quantifiable and estimable method [4].

RISTIĆ [23] and Shenoy [8] define that there are specific characteristics for Risk matrices, these characteristics can be concluded as a simple and understandable with using clear directions and indications inside the grids and the likelihood ranges must be consistent in order to ensure that the result will be reliable. Moreover, the grid must have clear and identifiable risk levels, and must show the different scenarios of mitigating the risks.

E. EOQ and the Optimal Order Point (FOP)

Building Intuition [2] suggests that EOQ represents the relationships between the ordering costs and the inventory cost, hence any alternation affects the TMC, and the optimisation of TMC requires a balance between the all costs which generate the TMC. The TMC comprises from ordering cost, purchasing cost, and inventory cost, as well as carrying cost. In order to determine the EOQ, the customers demand must be known as well as the dimensions of these units. Moreover, the lead time is critical in this process and it can be defined as "the time interval between placing the order and receiving the corresponding order quantity" [2]. Furthermore, the optimal order quantity can be measured by the degree of minimising the annual inventory cost with affecting the project progress. Equation (1) shows the different parts of the optimal quantity, the first part represents the ordering cost, and the second part represents the inventory cost, finally the purchasing cost is considered as well (see (1)).

$$\mathrm{AC(Q)} = \mathrm{K}\frac{\mathrm{D}}{\mathrm{Q}} + \mathrm{h}\frac{\mathrm{Q}}{2} + \mathrm{C} \times \mathrm{D} \quad (1)$$

where; K is the ordering cost per currency unit, D is the annual customer demand, Q is the required quantities per order, C is the price per unit. Furthermore, Fig. 1 shows how the optimal quantity can be determined through get the point of intersecting between the minimum average inventory cost with the minimum average ordering cost (purchasing, overhead, carrying costs).

After implementing the algebra differentiation, the EOQ will be calculated in accordance with this model as follows (2):

$$\mathrm{EOQ} = \sqrt{\frac{2\times\mathrm{K}\times\mathrm{D}}{\mathrm{h}}} \quad (2)$$

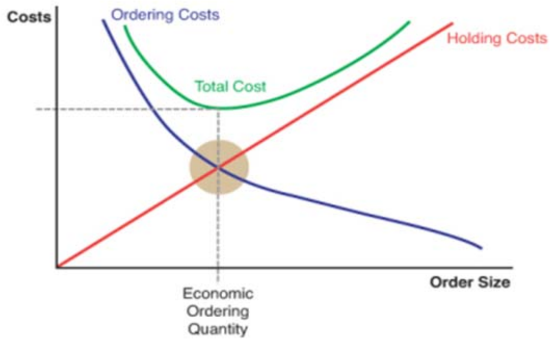

Fig. 1 A Graph of AC (Q) Versus Q

However, the supply rate and the consuming rate can be considered (model 2) and this will be explained later in the development process.

$$\mathrm{EOQ}= \sqrt{\frac{2\times \boldsymbol{K}\times \boldsymbol{D}}{\boldsymbol{h}} \times \frac{\boldsymbol{p}}{\boldsymbol{p}-\boldsymbol{d}}} \quad (3)$$

Moreover, the discount rate can be taken into consideration in case of adding the acquisition cost to (3) to priorities between different suppliers and select the one who achieves the minimum TMC [2].

FOP is considered as continuous monitoring system to follow the level of stock through specific process or project [10]. The determination of EOP relies on two factors, the first factor is the lead time, and the second factor is the daily usage units (see (4)) [7].

- FOP = demand during lead time

$$\mathrm{FOP} = \mathrm{D} \times \mathrm{L} \quad (4)$$

where; D is the daily usage (time unit usage); L is the lead time; Moreover, the safety stock can be considered, and the equation will be as follows:

$$\mathrm{FOP} = \mathrm{D} \times \mathrm{L} + \mathrm{SS} \quad (5)$$

where SS is the safety stock.

III. The Framework Development Process

Material management based BIM automation (MaBIM) framework comprises of three sections (see Fig. 4). The first section is quantification process; the project material can be identified by using the extracted quantities from the BIM 5D process. The second section is the material categorising task; therefore, the ABC material categorising method will be used to categorise the material into three categories A, B, and C. the framework will integrate the risk management output with ABC categorising method. The Risk log includes the risk event and issues which may affect the project progression, therefore the user can predict the effect of the material events and issues from the Risk log, and the third section is the BIM-based material automation process. The below steps show the developed tool to determine this:

1) Determine the impact of material risks (see Fig. 2):

$$\text{The impact of material risks} = \frac{\sum \textit{Exposure of risk events and negative issues}}{\textit{The average of rik exposure of all risks and negative issues}}$$

Fig. 2 states the classification of risk exposure and how it can be reflected with the ABC material categorising theory. In order to determine the risk exposure average for the material events and negative issues, the risk exposure can be determined as the event impact multiplying the probability. Moreover, Fig. 2 shows the relationship between the risk impact and likelihood. The highlighted numbers inside Fig. 2 represent the risk exposure which can be determined as the probability × the impact, and Table I shows the reflection of these values.

Probability	Matrix of probabnility and impact based on ABC classification								
0.9	0.09	0.018	0.27	0.036	0.45	0.054	0.63	0.072	0.81
0.8	0.08	0.016	0.24	0.032	0.4	0.048	0.56	0.064	0.72
0.7	0.07	0.014	0.21	0.028	0.35	0.042	0.49	0.056	0.63
0.6	0.06	0.012	0.18	0.024	0.3	0.036	0.42	0.048	0.54
0.5	0.05	0.01	0.15	0.02	0.25	0.03	0.35	0.04	0.45
0.4	0.04	0.008	0.12	0.016	0.2	0.024	0.28	0.032	0.36
0.3	0.03	0.006	0.09	0.012	0.03	0.018	0.21	0.024	0.27
0.2	0.02	0.004	0.06	0.008	0.1	0.012	0.14	0.016	0.18
0.1	0.01	0.002	0.03	0.004	0.05	0.006	0.07	0.008	0.09
Impact	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	A		A+B		A+B+C				

Fig. 2 Risk impact and likelihood relationship

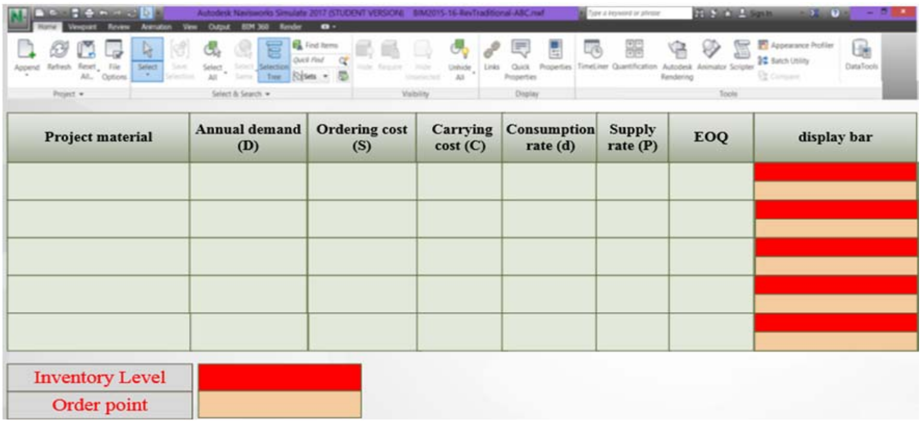

Fig. 3 The proposed option to be embedded in any BIM 4D platform

In order to achieve the automation purpose, this requires identification of the impact and probability by using definitive numbers as follows:

TABLE I
RISK IMPACTS AND PROBABILITY RANGES

rages of risk exposure	0-20%	20-50%	≥50%
ABC reflection	A	A+B	A+B+C

Table I shows that the ranges of the risk exposure and the ABC material classification, for example, if the average of risk exposure factor is from 0 to 20%, mean that the project is low risk regarding the material, and only category A requires to be monitored; however, in the case where the risk exposure average is located between 20 to 40%, this means that the project is a medium risk and this requires analyzing of both A and B materials which represent more than 50% of the total material as well as 95% of material costs. In case of the average of risk exposure more than 50%, this means that this project is critical and high risky material, and all material needs to be analysed and considered as a critical material which can affect the total project cost. A and B categories can affect the total project costs by increasing the short material cost, because if the material delayed to reach the site on the required time, this means that the short cost will increase as the B and C categories represent about 80% of the project material.

2) Determining the EOQ for the critical materials, the EOQ can be determined in accordance with three models, this framework will use the second model, because it is considered the consumption rate and the usage rate (see (3)), this enables BIM 4D to display this through the proposed option which this framework recommends to embed it in any BIM 4D platform and the MaBIM will show a virtual application of the proposed option. Moreover, the third advanced model in terms of the discount rate can be a part of the decision making to determine which supplier will be cheap to achieve the minimum Total Annual Material Cost (TAMC).
3) Fig. 3 shows the proposed option to be embedded in any

BIM 4D platform to manage the material cost and to be as indicator to the user to monitor the material demand and supply tasks. It intended that the proposed browser will be opened directly with loading the project raw materials and the annual demand through connecting the quantities and the duration of executing the material. Other parameters will be inserted manually by the user, afterwards, the EOQ elements will be completely available and it will be determined automatically.

4) The material spaces management (warehouses) requires analyzing and simulating in BIM 4D, therefore after determining the EOQ for the critical material in accordance with steps (1, 2 and 3). The EOQ and FOP enable the planner to determine when the material will be required, as well as identifying the exact quantities. For instance, the critical 20% (A) which represents 80% of the material costs needs to be stored close to the site or by another way if there is any chance to store it inside their working area, this would be more safe and workable.

IV. Discussion and Findings

The proposed framework will be used to manage the material within the different project stages. The MaBIM facilitates for BIM 4D users to get the maximum benefit of using the automated quantification process. This process has several benefits as follows:

1- Exploiting the evolutionary quantification process in BIM 5D in order to integrate the material management into BIM 4D to fill this gap and add another option to BIM 4D which enables the planner to deliver a comprehensive logistic plan.

2- The integration between risk management process and material categorising will enable the core team members (project participants) using an Integrated Project Delivery (IPD) approach to determine the uncertainty percentage from the detailed design stage and before commencing the execution stage. Moreover, it integrates the ABC classification theory with the risk management output data (Risk Log) to get a double check of the material risks.

3- The proposed new option leads to generate an automated material management process for the first time in BIM process, as well as, using indicators bars to display the existing inventory level and the ordering point. Thus, this will facilitate the project managers in order to prepare the project logistic plan. Moreover, this option combines between the pre-identified materials during the early design stage as well as the reminder option during the execution stage.

4- The core team members (project participants) will acquire all the needed materials through the project execution stage before executing the project, therefore this facilitates to give them an opportunity to obtain discounts from the suppliers.

5- Furthermore, the BIM 4D planner will be informed in regards to the critical material, and the required spaces to inventory these material, therefore the BIM 4D space management will be attainable, and this will make BIM 4D more functional for the BIM user, because the lack of incapability to manage project material has caused a concern for BIM 4D implementation.

V. BIM Based Material Management Automation (MaBIM) Framework

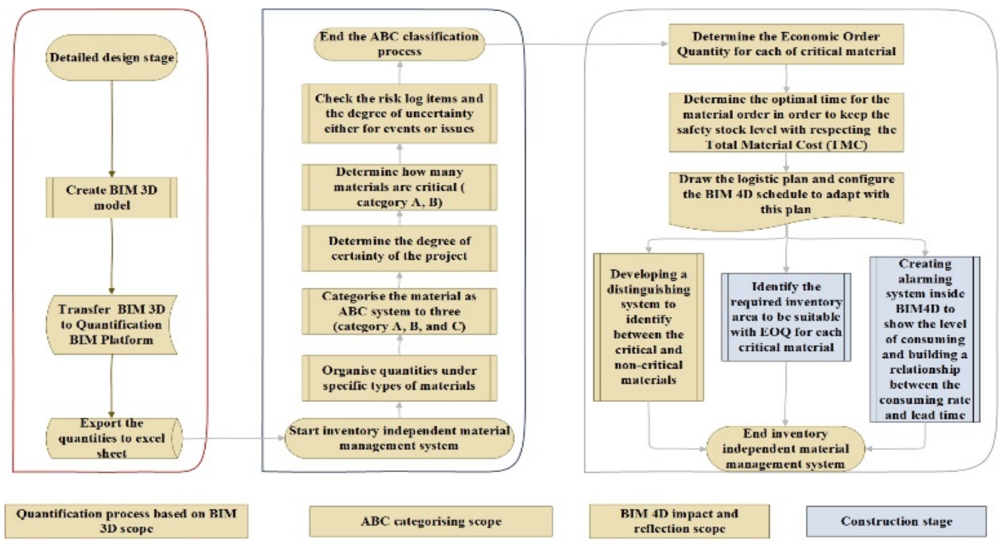

Fig. 4 BIM based material management automation (MaBIM) framework

VI. Comparison between the Proposed Model and the Existing BIM Based Material Management Capabilities

Table II shows the differences between the current material implementation management scheme and the proposed framework by using some specific parameters.

TABLE II
COMPARISON BETWEEN THE PROPOSED MODEL AND THE EXISTING BIM BASED MATERIAL MANAGEMENT CAPABILITIES

Parameters	The current model	The proposed framework
Using the BIM 3D model	✓	✓
Check the criticality of project material	×	✓
Considering the EOQ or order point	×	✓
Displaying the consumption rate	×	✓
Automated process	×	✓
Dealing with the item or quantities	Items	Items and Quantities

VII. CONCLUSION

This paper has presented a holistic framework to manage the project material costs from the early design stage to close out stage. Due to most of the challenges to implement BIM pertaining to the inability of BIM user to follow the integrated process from the project inception to the demolition, the proposed framework considers these challenges and has presented some tools to comply with the entire project stages. So that it has started by using the developed BIM 3D model and developing tools to manage the material through the different stages, for example during the detailed design stage the framework includes a method to integrate between the risk management and ABC material categorising theory to determine the critical and non-critical materials. Moreover, during the execution stage, the framework includes an embedded browser within BIM 4D to monitor the project by considering the EOQ and the FOP which will help the core team members to obtain the logistic plan from the early design stage and controlling the material movement process (supplying and consuming) during the execution stage. Furthermore, BIM 4D relies on the visualisation and animation options before executing the project. Therefore, the availability of EOQ and FOP enables the planner to prepare the required storage space for inventory during the early planning stage as well as preparing a precise logistic plan.

REFERENCES

[1] "4D Simulation and Construction Planning | Autodesk University Workshop. (2017). Auworkshop.autodesk.com", http://auworkshop.autodesk.com/library/bim-curriculum-construction/4d-simulation-and-construction-planning, 2018. (Online). Available: http://auworkshop.autodesk.com/library/bim-curriculum-construction/4d-simulation-and-construction-planning. (Accessed: 21- Mar- 2017).
[2] Building Intuition, International Series in Operations Research & Management Science. 2008.
[3] H. Altay Guvenir and E. Erel, "Multicriteria inventory classification using a genetic algorithm", European Journal of Operational Research, vol. 105, no. 1, pp. 29-37, 1998.
[4] M. Schieg, "Risk management in construction project management, Journal of Business Economics and Management", pp. 7:2, 77-83, 2006.
[5] J. Miller, Implementing activity-based management in daily operations. New York: Wiley, 1996.
[6] Z. Ren, C. Anumba and J. Tah, "RFID-facilitated construction materials management (RFID-CMM) – A case study of water-supply project", Advanced Engineering Informatics, vol. 25, no. 2, pp. 198-207, 2011.
[7] N. Sanders, "Inventory Policy in a Fixed-Order Quantity System | Operations Management Defined | InformIT", Informit.com, 2018. (Online). Available: http://www.informit.com/articles/article.aspx?p=2167438&seqNum=8. (Accessed: 11- Feb- 2018).
[8] S. Shenoy, "Planning For Managing Risks On a Project -", Pmexamsmartnotes.com, 2018. (Online). Available: https://www.pmexamsmartnotes.com/plan-risk-management/. (Accessed: 11- Feb- 2018).
[9] P. Smith, "Project Cost Management with 5D BIM", Procedia - Social and Behavioral Sciences, vol. 226, pp. 193-200, 2016.
[10] "What Is A Fixed Order Point?: supplychain-mechanic.com", Supplychain-mechanic.com, 2018. (Online). Available: http://supplychain-mechanic.com/?p=116. (Accessed: 11- Feb- 2018).
[11] C. Tam and T. Tong, "GA-ANN model for optimizing the locations of tower crane and supply points for high-rise public housing construction", Construction Management and Economics, vol. 21, no. 3, pp. 257-266, 2003.
[12] The Public Risk Management Association, "A structured approach to Enterprise Risk Management (ERM) and the requirements of ISO 31000", AIRMIC, Alarm, IRM, 2010.
[13] Y. Wen, "Research on Cost Control of Construction Project Based on the Theory of Lean Construction and BIM: Case Study", The Open Construction and Building Technology Journal, vol. 8, no. 1, pp. 382-388, 2015.
[14] D. Young, C. Haas, P. Goodrum and C. Caldas, "Improving Construction Supply Network Visibility by Using Automated Materials Locating and Tracking Technology", Journal of Construction Engineering and Management, vol. 137, no. 11, pp. 976-984, 2011.
[15] Q. Yu, K. Li and H. Luo, "A BIM-based Dynamic Model for Site Material Supply", Procedia Engineering, vol. 164, pp. 526-533, 2016.
[16] G. Onwubolu and B. Dube, "Implementing an improved inventory control system in a small company: a case study", Production Planning & Control, vol. 17, no. 1, pp. 67-76, 2006.
[17] H. Said and K. El-Rayes, "Automated multi-objective construction logistics optimization system", Automation in Construction, vol. 43, pp. 110-122, 2014.
[18] A. Schlueter and F. Thesseling, "Building information model based energy/exergy performance assessment in early design stages", Automation in Construction, vol. 18, no. 2, pp. 153-163, 2009.
[19] WRAP, "Material Logistics Plan Good Practice Guidance", 2007.
[20] V. Methanivesana, "Improving Construction Logistics A case study of Residential Building Project", Stockholm, 2012.
[21] P. Saukkoriipi, "Waste in construction projects call for a new approach", 2007.
[22] S. Chenthoorun and M. Gnanasigamani, "A Study of Analysis And Performance Measurement Of Construction Logistics", International Journal of Science and Engineering Research (IJ0SER), 2017.
[23] D. Ristić, "A Tool For Risk Assessment", safety Engineering, 2018.
[24] N. Kasim, S. Liwan, R. Shamsuddin, R. Zainal and N. Kamaruddin, "Improving On-Site Materials Tracking for Inventory Management In Construction Projects", International Conference of Technology Management, Business and Entrepreneurship, 2012.
[25] J. Ali, R. Khan, N. Ahmad and I. Masqood, "Random Forests and Decision Trees", IJCSI International Journal of Computer Science Issues, 2012.