Escuela Técnica Superior de
Ingenieros de Caminos, Canales
y Puertos.
UNIVERSIDAD DE CANTABRIA

Analysis of possible improvements by the combination of Lean Construction and BIM

Análisis de posibles mejoras mediante la combinación de Lean Construction and BIM

Author:
Adrián A. Cuberos Q.

Supervisor:
Dr.-Ing. Christian Karl Baier

Co-supervisor:
Prof. Dr.-Ing. Joaquín Diaz

Universitary Degree:
Master in Construction Research, Technology and Management in Europe – Máster en Investigación, Tecnología y Gestión de la Construcción en Europa

Santander, September 13, 2019

TRABAJO FIN DE MASTER

Abstract

The project is composed of different phases such as design, planning, execution, control, monitoring and management. Focusing on the execution phase, there are still some issues regarding to materials management that must be faced such as transportation, inadequate storage on site, delay in material that undoubtedly leads to higher cost and delayed time schedules.

Therefore, the aim of this Master Dissertation is to find the most adequate technologies, methods or principles in order to improve the material logistics on the construction site, following the Lean Construction principles, using technologies coming from the Industry 4.0 and using an open source platform which will be supported by using BIM to exchange information.

This Master Dissertation is divided in six (6) chapters, the first chapter is a brief introduction of the problem to be solved, the second chapter is a literature review, the third chapter are case studies, the fourth chapter is the new method proposed by the author, the fifth chapter is the respective conclusion and recommendations, and the sixth chapter contains the references used in this Master Dissertation.

After presenting all the literature review and the case studies, it was possible to find out that none of the cases studies were a part of a process, it is therefore, that a new method for supply chain management in construction called ‘’LOCATER’’ was defined.

The new method for the supply chain management in construction, helps anyone involved in a construction project by using emerging technological tools through an open source information platform in order to improve the different areas of the supply chain, helping the human labor improve the process.

In the future, the method can be improved by using a system that can track the material in real-time from the supplier to the construction site, as well as using the technology to track the material in real-time on the construction site.

Acknowledgements

I would like to thank my family, girlfriend, colleagues and friends for their wonderful collaboration. You supported me greatly and were always willing to help me in the good and in the bad times and for always cheering me up and giving me the strength to always keep going in the most difficult moments.

I would like to express my very great appreciation to Dr.-Ing. Christian Baier for the extraordinary support in this thesis process and for being my biggest mentor. His willingness to give his time so generously has been very much appreciated and not taken for granted.

I would also like to thank Prof. Dr.-Ing. Joaquín Diaz, for his advices and assistance in this thesis process and expertise.

I would like to thank the THM, UNICAN and all the professor involved in this Master to help me reaching my objectives and to help me being a better professional.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ADC: Automated Data Collection
AI: Artificial Intelligence
API: Application Programming Interface
ATO: Assembled to Order
BIM: Building Information Modelling
CAD: Computer-Aided Design
CML: Construction Material Library
CSC: Construction Supply Chain
CSCM: Construction Supply Chain Management
ERP: Enterprise Resource Planning
ETO: Engineered to Order
GPS: Global Positioning System
ID: Identity Card
IFC: International Foundation Classes
IFG: Geographic Information Systems
IoT: Internet of Things
IT: Information Technology
JIT: Just in Time
QC: Quality Control
MTO: Made to Order
MTS: Made to Stock
PD: Planning Databases
PDA: Personal Digital Assistance
PMI: Project Management Institute
PO: Purchase Orders
RFID: Radio-Frequency Identification
SCM: Supply Chain Management
UWB: Ultra-Wide Band
WLAN: Wireless Local Area Network

I. Introduction

1.1. Background and Problem Description

Throughout the twentieth century and beyond, the world has seen huge modifications in extensive types and variety of aspects in the construction sector. In our regard, there has been a massive transformation and advancement within the construction industry all over the world. Through constructing larger and better things, the construction industry has revolutionized approaches, methods, techniques and strategies. Similarly, in order to overcome the shortage of fit workforce, long-time duration and defective work, the construction industry has taken advantage of technologies to better recruit and preserve new workers and methods in the construction profession (Ahmed, 2019 cited in Escamilla & Ostadalimakhmalbaf, 2016).

At the same time, there are two approaches (Lean Construction and Building Information Modelling) that in recent years, claim to improve productivity, efficiency, quality in the construction industry and it is clear that synergies and mutual added value can be expected from applying them.

By his side, Lean Construction methodology is rapidly gaining interest in the construction industry due to the lean production mind-set has been spreading from the automotive industry to many other industries such as healthcare, services, construction and IT (Tezel & Aziz, 2017 cited in Koskela, 1992, Bowen & Youngdahl, 1998, Poppendieck & Poppendieck, 2003, Poksinska, 2010) and its management methods and principles proved to be useful in the construction industry, since most of the feedbacks in construction projects are positive, although it is recognized that important implementation efforts are required (Guerriero, et al., 2017).

In the other hand, Building Information Modelling (BIM) is a key approach in making the projects' processes more fluent, transparent and integrated (Guerriero, et al., 2017). According to Tagliabue & Ciribini, (2018) as cited in Love *et al*. (2010), suggests that BIM requires a unique strategy which revolves around shared information content, from the beginning to the end of the collaboration.

The adoption of BIM model shared with all the actors of the work, on the one hand encourages the exchange of information, creating an uninterrupted flow between the world of design and that companies, construction and / or management, without excluding the customer, on the other hand creates the conditions for obtaining a lean process (Lean Construction) (Tagliabue & Ciribini, 2018 cited in Womack and Jones, 2003).

In the meantime, barriers should be taken into account. Especially it is known that novel management methods combined to Information Technologies are the source of change resistance from the professionals and require a period of time for technology adoption (Guerriero, et al., 2017).

A construction projects is composed by different phases (initiation, planning, construction, monitoring and controlling, and closure). However, the construction phase still has issues that must be faced.

For instance, in the article presented by Tunji-Olayeni *et al*. (2018) where was generated a cross sectional survey of 55 construction professionals comprising of Architects, Builders, Civil Engineers, Project Managers and Quality Surveyors about the logistics management on construction sites in Abuja, Nigeria.

They could find out that the main challenges associated with material logistics on construction sites are the transportation, inadequate storage and delay in material delivery, among others.

Challenge	N	Minimum	Maximum	Mean
Transportation	55	2	5	4.45
Inadequate storage on site	55	2	5	4.18
Delay in material and component delivery	55	1	5	4.13
Supply of low quality material	55	1	5	4.07
Poor coordination among material planning team	55	1	5	4.02
Inability to forecast activity period with accuracy	55	1	5	3.91
Inaccuracies in material delivery	55	1	5	3.67
Increase waiting time between activities	55	1	5	3.62

Table 1. Challenges associated with material logistics on construction sites.
[1] Tunji-Olayeni, *et al*., 2018

As well, that the principal method of forecasting material demand on construction sites is work progress.

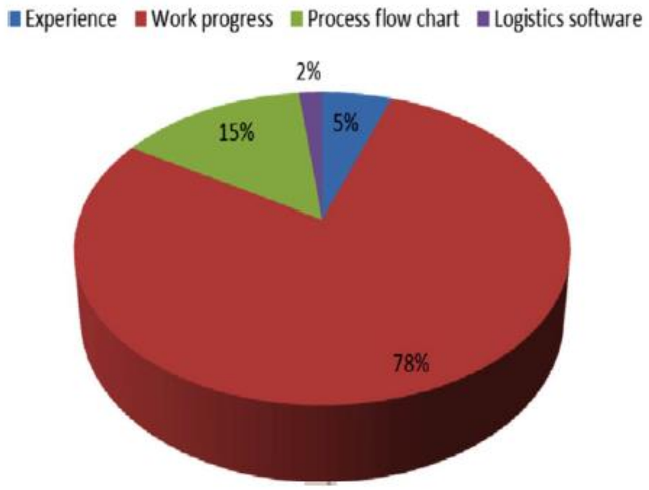

Figure 1. Method of forecasting material demand on construction sites.
[1] Tunji-Olayeni, *et al*., 2018

[1] Tunji-Olayeni, P., Afolabi, A., Eshofonie, E. & Ayim, B., 2018. Dataset for material logistics on construction sites. *Data in Brief,* Volume 20, pp. 1142-1147.

In that article, the authors point out the benefits of having a good performance of material logistics on construction sites such as: saves construction time, saves construction cost, improves customer satisfaction, timely delivery of materials, reduce storage space, reduce waiting time, reduce multi handling.

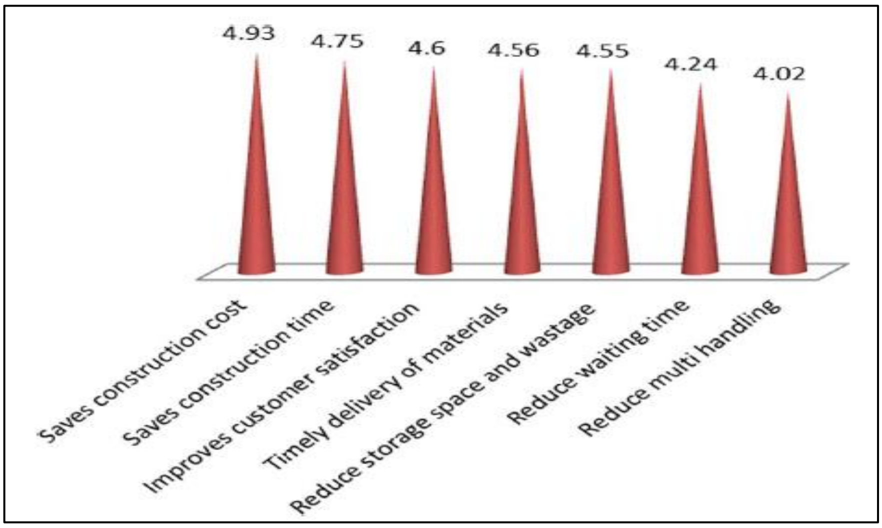

Figure 2. Benefits of material logistics on construction sites.
[1] Tunji-Olayeni, *et al*., 2018

As could be seen before, transportation, inadequate storage on site, delay in material and component delivery, supply of low quality material, poor coordination among material planning team, inability to forecast activity period with accuracy, inaccuracies in material delivery, increase waiting time between activities, are the main issues of material logistics in the process of construction sites that undoubtedly leads to the higher cost and delayed time schedules. Therefore, Ahmed (2019) said that all the management of construction project consists in reducing the time of completion and save the expenses of the construction. Time and cost management of construction exists in the construction process from the beginning of construction history but is not significantly effective at any time.

1.2. Aims and Objectives

A construction project is composed of different phases such as Design, Planning, Execution, Control and Monitoring, Management, however, as mentioned before, one of the main issues in the execution phase is the Material Logistic on Construction Sites, because it faces different challenges, such as inadequate storage, material delivery, transportation, as well as, that the main method of forecasting material demand on construction sites is work progress.

Therefore, this Master Dissertation will be focusing on the Execution phase. Precisely, it will focus on Material Logistics on Construction Sites due to such challenges can be faced with proper management in different areas such

[1] Tunji-Olayeni, P., Afolabi, A., Eshofonie, E. & Ayim, B., 2018. Dataset for material logistics on construction sites. *Data in Brief,* Volume 20, pp. 1142-1147.

as Construction Site Management, Construction Supply Chain, Construction Progress Monitoring, Tracking Materials.

There are already technologies, methods or principles that exist in the market which are coming from other industries and could be applied in the Construction Industry, as well, those technologies are not related to each other.

Therefore, this Master Dissertation will find the most appropriate methods regarding to the different areas mentioned before in order to face the challenges associated with the Material Logistic on Construction Site applying the technologies, principles, methods, researches that exist in the market and have shown benefits in the Construction Industry and in another industries.

It means that, this Master Dissertation will propose something called ''LOCATER: New Method for Supply Chain Management in Construction'' where the principles of Lean Construction will be followed, as well, the technologies from the Industry 4.0 will be applied and an open source platform which will be supported by using BIM to exchange information will be used.

Then, these are the objectives to follow:

1. Follow the Lean Construction Principles and implement those that can be applied on the construction site in order to reduce waste, improve productivity and safe management.

2. Trace the most likely strategic method to build an integrated system between supply chain and the construction site in order to be more effective and efficient.

3. Find the most appropriate technology from the Industry 4.0 to capture the current status of the construction project and track or have a real-time access to the locations of materials on construction sites in order to save time, costs and improve the productivity and efficiency of this process.

1.3. Research Methodology

In order to meet the objectives, a systematic approach to literature review will be carried out in a methodical, transparent and reproducible manner.

Know and learn about the effective use of opportunities in the different areas, such as Construction Site Management, Construction Supply Chain, Construction Progress Monitoring, Tracking Materials regarding to the Material logistics on Construction Site it is very difficult without doing a rigorous analysis that allows us to summarize structured information.

Therefore, this Master Dissertation will be carried out by following the steps:

1. Identify the research topic:

   - Material Logistics/Management/Procurement
   - BIM
   - Lean Construction
   - Industry 4.0
   - Site Management
   - Supply Chain
   - Progress Monitoring
   - Tracking Materials

2. In order to find the most relevant researches, the research topics mentioned above will be combined with the following keywords:

   - Kanban
   - 5S
   - Heijunka
   - JIT
   - CAD
   - GPS
   - Monitor Progress
   - Visual Detection
   - Laser Scanning
   - Photogrammetric Methods
   - Automatic Identification
   - RFID
   - Bar-coding
   - Wireless Technologies
   - Real-time Access
   - UWB
   - WLAN

3. Select the research direction and field:

   - Science and Technology
   - Civil Engineering
   - Automation in Construction
   - Building Technology
   - Organization Technology and Management in Construction
   - Building and Environment
   - Information Technology in Construction
   - Sustainability
   - Construction Economics and Building
   - Advanced Engineering Informatics

4. Search in different sources, such as journal papers, conference papers, books and doctoral thesis in well-recognized academic databases, such as:

- Web of Science
- ASCE library
- Science Direct
- Taylor and Francis
- IEEE Xplore
- Elsevier
- Scopus
- Google Scholar
- Research- Gate

The period of the time that will be chosen will be from 1900 and 2019, however, in order to select the most representative papers and reduce the sample to a manageable amount, only the most recent publications and those that are most cited will be selected for further analysis.

This Research Methodology will help to select the most appropriate technologies, methods or principles, which will then be applied in the different areas of investigation, in order to explain how they work and how they can be applied.

1.4. Limitations and Scope

As mentioned above, the scope of this Master Dissertation is to find the most appropriate technologies, principles, methods regarding to Construction Site Management, Construction Supply Chain, Construction Progress Monitoring, Tracking Materials, following the Lean Construction Principles, using the technologies of the Industry 4.0 and having an open source platform supported by BIM to exchange information, all this in order to face the challenges associated with the Material Logistics on Construction Site, in order to select them, explain how they work and how can be applied.

Therefore, although the approach of this Master Dissertation is a literature review, which unfortunately will not be validated, which is a critical element of scientific research, the idea is to select those technologies, principles or method for each area that previously have been validated with case studies and have demonstrated several benefits.

Knowing also that these technologies, principles, methods could be improved in the future, and that as a consequence, these ‘’Best Practices of Material Logistics on Construction Site’’ should be improved / adapted or there may also be a case where another technologies, principles or methods that replace or refute what is sated here.

The credibility of the results and findings of this Master Dissertation depends on the accuracy and reliability of data collected from the academic databases and how much has been investigated in the areas in question.

On the another hand, the application of the proposal to be treated in this Master Dissertation will require that the companies have a good knowledge, understanding and are open to implement concepts such as BIM, Lean Construction. As well, another limitation is that the technologies coming from Industry 4.0 could have a high cost.

These findings will come from other authors, and in the event that in the future this Master Dissertation wants to be proven, the corresponding permits from those authors will be required.

Another limitation is the author's experience, the selected findings will be at his discretion, and may not represent the entire Material Logistics cycle on Construction Site or not include other technologies, principles or methods that may provide better benefits than those proposed by the author.

1.5. Structure of the document

This Master Dissertation aims to find the most appropriate technologies, principles, methods regarding to Construction Site Management, Construction Supply Chain, Construction Progress Monitoring, Tracking Materials, following the Lean Construction Principles, using the technologies of the Industry 4.0 and having an open source platform supported by BIM to exchange information, all this in order to face the challenges associated with the Material Logistics on Construction Site, in order to select them, explain how they work and how can be applied.

This Master Dissertation is divided into six (6) chapters and is structured as follows: in the first Chapter, a brief introduction is first provided, then the theoretical background and problem description of the main research topics such as BIM, Lean Construction and Industry 4.0, after the aims and objectives of the Master Dissertation are described to get clear an idea of the problem to be solved, then the research methodology to be used is presented and, in the end, the limitations and scope are explained.

The second Chapter is a literature review that presents the latest research and technical findings regarding to Construction Site Management, Construction Supply Chain, Construction Progress Monitoring, Tracking Materials.

The third Chapter is case studies of the latest research and technical finding, which explains why they have been chosen and divided into four (4) subchapters that are related to the areas of Construction Site Management, Construction Supply Chain, Construction Progress Monitoring and Tracking Materials, so once selected technologies, principles or methods are explained in detail how they work and how they can be applied.

The fourth Chapter, the new method proposed by the author is expressed regarding to the improvements, benefits or advantages that would be found with the implementation of Lean Construction and BIM, together with the Industry 4.0 regarding to the entire supply chain process.

Finally, the fifth chapter is the corresponding conclusion, recommendation and future research works, followed by the sixth chapter that contains the references used in this Master Dissertation.

II. Literature Review

2.1. Construction Site Management

Lean Construction is a production management philosophy derived mainly from the Toyota Production System. It aims at increasing quality and decreasing costs and lead time of a manufacturing system by systematically identifying and eliminating wastes (Guerriero, et al., 2017).

The main wastes on construction sites found by the Lean literature are moving, waiting, or searching materials, multiple handling of materials, accidents or losses. According to Guerriero *et al*., (2017) cited in Diekmann, J. E. *et al*. (2005), wastes represent 55% to 65% of the production effort. On the other hand, the unnecessary operations add up to 25% of the building material costs and result in about 10% of the total building costs excluding design (Guerriero, *et al*., 2017 cited in Bertelsen & Nielsen, 1997). As well, the cost of rework on site has also a significant impact (Guerriero, *et al*., 2017 cited in Love & Li, 2000).

The implementation of Lean Construction principles on construction sites, have shown their efficiency in reducing several kinds of waste:

- Quality improvement from 50% of defect rate to 10%, and reduction of the throughput time of steel beam by 37% using 5S and Just-In-Time delivery (Guerriero, *et al*., 2017 cited in Berroir, *et al*., 2015).

- Delivery reliability optimization (i.e. rework in connection with material issue, waiting time of the workforce, looking for material / equipment, several handling time) increased productivity of the labor force on construction site by up to 25 minutes per person and per day (Guerriero, *et al*., 2017 cited in Vol & Final, 2005).

In order to reduce wastes on construction sites, several actions can be applied such as Kanban, Heijunka, 5S, among others.

For instance, Kanban systems can help to realize the required work type on construction sites (i.e. material, production, maintenance or safety checks etc.), this means, where, when and by whom the work is required.

At the same time, Heijunka boards are used to level demand and to control variability in production, material, equipment uses on the construction sites.

On the other side, 5S is a systematic workplace structuring and organization methodology that can help to have visual information of workplace elements such as materials, space, machinery, equipment, tools, gadgets, personnel on the construction sites and refers to and acronym for the ‘’sorting’’, ‘’setting-in-order’’, ‘’sweeping’’, ‘’standardizing’’ and ‘’sustaining’’ steps.

According to Salem, *et al*. (2006) as cited in Bajjou, *et al*. (2017), the most advanced and the most appropriate Lean Construction tools are the Last Planner System, 5S, Visual Management, Error-proofing (Poka-Yoke).

Regarding to the 5S process, Ogunbiyi (2014) has defined that it can be used as follows:

- 5S and value stream mapping while Six Sigma is the least used technique for enabling sustainability.
- 5S and value stream mapping are commonly noted for environmental improvement.
- 5S helps companies to look at their workplace in a new dimension.

The implementation of the 5S process on the construction site can help create a well-organized environment, which can contribute to the production of a high-quality product and its implementation requires a low financial outlay.

5S process is defined by Gapp, *et al*. (2008) as cited in Li, *et al*., (2017) such as comprehensive management method of on-site personnel, materials, and equipment. At the same time, Johansen & Lorenz (2007) in their research have said that the use of a site logistic tool such as 5S process has been proofed helpful.

2.2. Construction Supply Chain

Despite recent improvements of Lean Construction to reduce the wastes on construction sites, managing a seamless information flow between multiple stakeholders involved in a construction project is still a challenge. Construction work is often characterized by errors, rework, lack of understanding of the project and processes, and conflicts. Rapid and convenient access to relevant construction information, through improved awareness of user context can lead to significant cost and time savings due to the accuracy and immediacy with which relevant project information can be made available (Tezel & Aziz, 2017). Therefore, BIM can be strongly beneficial for construction sites management through platforms collecting data and providing analytics. These can be used to manage and control the people, materials and vehicles flows which create the complex organization of a medium and big construction site (Tagliabue & Ciribini, 2018).

Regarding to the construction sites, BIM can help construction managers to visualize the design and environment of the site in order to define storage areas, cranes positions and accesses to the construction site during the entire project.

In addition, BIM can provide users with a record of construction progress, which allows construction managers to compare the "planned version" with the "built version". As well as, with the daily report they can evaluate the planning and on the other hand it provides feedback for future projects.

Regarding to the construction supply chain, BIM can help to integrate interfaces chains and cooperative coordination of the parties involved with an overall perspective on the flow of information and material, which means, that BIM allows the creation of information and its use in any other circumstance during the life cycle of the project. BIM can support various operations, facilitate collaboration and provide a database platform that can be used for site management during the execution of a project.

Shin, *et al*. (2011) as cited in Vrijhoef & Koskela (2000) insisted that the application of the SCM concept for the construction industry is necessary in order to eliminate uncertainties in the construction supply chain, to improve efficiency in time and money by increasing prefabrication of building components and materials, and to build an integrated system between supply chain and the construction site to react to design changes more effectively and efficiently.

The construction supply chains are characterized by:

- The involvement of many companies from a wide variety of trades (O'Brien, *et al*., 2002 cited in Cheng, *et al*., 2010).

- The construction projects are involved by a diverse group of participants including contractors, architects, engineers, laborers, and developers (Issa, *et al*., 2003 cited in Cheng, *et al*., 2010).

- The projects of medium to large scale typically are involved by hundreds of different companies supplying materials, components, and a wide range of construction services (Dainty, *et al*., 2001 cited in Cheng, *et al*., 2010).

The traditional way in which the information of the project is acquired during the inspections of the construction sites and the data, is registering them in paper documents to share with the supply chain (Getuli, *et al*., 2016 cited in Garcia, *et al* ., 2014). Therefore, Getuli, *et al*., 2016, as cited in Saidi, *et al*., 2002, exclaimed that nowadays the technology is used on the site to acquire and process data. The use of technology improves information management and increases operational efficiency (Getuli, *et al*, 2016 cited in Son *et al*., 2012).

Knowing that companies use a wide range of hardware platforms and software applications for their own operations, therefore, the integration of the construction supply chain is difficult, however, there are many software packages such as BIM programs which allow the extension of functionality through the application programming interface.

As mentioned earlier, the implementation of the construction supply chain during the execution of a project can bring several benefits, such as: improving the flow of information, the interface between site activities, the supply chain itself, site transfer activities to the supply chain; save costs and reduce the duration, especially those related to logistics, delivery time and inventory, as well as support the business strategy that improves revenue.

However, there are still many problems in the application of supply chain management in the construction industry that must be addressed, such as: the way in which the industry is organized generates high fragmentation, bringing with it a lack of mutual trust because there is not a single system for the exchange of information in the management of the construction supply chain; the supply chain includes many participants that are distributed geographically in different locations, which makes each participant use a different software or hardware system and stores the information in their own way.

Therefore, nowadays, the construction industry has put all efforts to minimize waste and generate new value, for effective management of information, logistics and cost in the chain of construction supply, hand in hand with technology (Cheng, *et al*., 2010), some of the research in this area carried out in recent years will be mentioned below.

- Irizarry, *et al*. (2013) as cited in Williamson, *et al*. (2004) said that the authors conducted research on the use of information systems within supply chain management and the application of the Internet in the monitoring of deliveries.

- Irizarry, *et al*. (2013) as cited in Tserng, *et al*. (2006) explained how the authors developed an information system tool to optimize the inventory cost of the entire supply chain or only one of the supply chain members and also to reduce the integrated inventory of construction materials.

- Irizarry, *et al*. (2013) as cited in Navon & Berkovich (2006) stated that the authors developed an automated IT model to improve material management and control.

The automated IT model developed by Navon & Berkovich (2006) generates list of materials to order, report the status of materials on site, and alerts when the material quantity on the site is less than the defined minimum.

2.3. Construction Progress Monitoring

Nowadys, construction projects require sufficient planning and management of resources to become successful, the core issues are tasks that deal with material logistics on construction sites such as procuring materials, guaranteeing the supply chain, controlling the work status, and monitoring safety and quality.

Therefore, several case studies have demonstrated the successful application of these technologies in construction such as defect detection, rapid 3D and 4D BIM modelling, progress monitoring, geo-referencing existing project level information, simulation, visualization, real-time resource tracking and data visualization, virtual design and augmented reality, and worker safety and performance (Teizer, 2015).

For instance, during the execution of a project, monitoring the progress of the construction is an indispensable tool to have a good management of the project. On-site progress monitoring is essential to track work in progress on construction sites, as it provides professionals with the information they need to detect performance deviations and decide on control actions that can prevent or minimize them its impacts.

Despite the fact that the progress monitoring on construction sites is an essential process during the execution of a project. In recent years, different authors through research have found out similar conclusions regarding this topic in the construction industry and its that current methods for measuring project status or progress are mostly based on manual assessments. This task is a manual, time-consuming activity, costly, prone to error, performed intermittently and, in real operation, frequently out of date (Braun, *et al*., 2015, Han & Golparvar-Fard, 2015, Teizer, 2015).

For instance, Turkan *et al*. (2012) as cited in Kiziltas & Akinci (2005) explained that the typical practice for progress tracking mostly depends on foremen daily or weekly reports which involve intensive manual data collection and entail frequent transcription or data entry errors. These reports are then studied by field engineers and/or superintendents along with 2D as-planned drawings, project specifications and construction details to review the progress achieved by that date. After that, they study the construction schedule to identify the work planned to be done by that date. This requires a significant amount of manual work that may impact the quality of the progress estimations.

Besides, Bosche, *et al*. (2015) as cited in Schaufelberger & Holm (2002) said that the traditional progress tracking practice depends on visual inspections, and daily or weekly reports created based on those inspections. The inspectors' duty is to ensure that work meets contract specifications and schedule. They use checklists during inspections and logs to report deficiencies that are discussed at follow-up weekly meetings and Bosche, *et al*. (2015) concluded that this traditional practice relies heavily on the inspectors' personal judgment, observational skills, and experience which come with a high probability of incomplete and inaccurate reports.

In recent years, in the construction industry, numerous relevant studies and commercial developments have addressed construction site management problems. Specifically, in semiautomatic o fully automatic approaches to capture the progress on construction sites, to process and share this data among the project team and stakeholders, and thus be able to compare this data such as those as-built with the planned works.

These studies have focused on the use of commercially available technologies to capture the actual state of the construction project, for this different methods can be applied, however, there are two dominant methods of collecting visual detection data to monitor the progress of construction, such as laser scanning or photogrammetric methods.

These methods have shown potential to save time and costs by recording the current status of the project, while promising to increase the efficiency and accuracy of this process.

In addition, they can be linked to information models, which can be updated in a timely and accurate manner during construction, making it possible to align progress with the schedule. Therefore, BIM can be a very suitable basis for automated construction progress monitoring. Below the methods mentioned above, will be explained in depth.

- **Laser Scanning**

Currently, the most popular 3D reality capture method for progress monitoring during the execution of a project in the construction industry is laser scanning. According to Turkan, *et al*., (2012) laser scanning is a key technology for feedback information flow because it provides fast, accurate, comprehensive and detailed 3D as-built information about the scene being scanned and produces vast point clouds of data, these 3D data is stored as dense point clouds and each point in these point clouds is defined as a "x, y, z" coordinate triplet in the scanner's coordinate system.

According to different authors, laser scanning is probably the best technology adapted to detect the 3D status of projects accurately and efficiently, therefore, a summary of some of these researches will be presented.

Research	Conclusion	Authors
Investigated the use of 3D laser scanning data to monitor project progress	Schedule-based scanning facilitates a detailed definition for partially completed construction work, and also provides as-built proof for geometric measurement and visualization	Shih, N.J., Wu, M.C., Kunz, J., 2004
Developed of a formal methodology for active construction quality control using laser scanning, embedded sensors and integrated project models	These reality capture technologies can be employed for accurate as-built data collection on construction sites, and they can be leveraged to improve quality control processes	Akinci, B., Boukamp, F., Gordon, C., Huber, D., Lyons, C., Park, K., 2006
Proposed a simulation-based framework to model information flow processes from a job site to a field office to measure and highlight existing deficiencies, and to model and demonstrate the effect of using laser scanners and radio frequency	The time spent on non-value adding activities in the information flow can be reduced significantly by utilizing these automated reality capture technologies	Akinci, B., Kiziltas, S., Ergen, E., Karaesmen, I.Z., Keceli, F., 2006

identification in streamlining the data collection process for the same project		
Proposed an approach to automate the generation of as-built BIMs of constructed facilities by using hybrid video and laser scan data as input	Having access to an as-built model of an existing facility can enhance project planning, improve data management, support decision making, and increase the productivity, profitability and accuracy of a construction project	Brilakis, I., Lourakis, M., Sacks, R., Savarese, S., Christodoulou, S., Teizer, J., Makhmalbaf, A., 2010
Investigated the potential benefits of using laser scanning on transportation projects	Laser scanning can be very effective for the purpose of safe and accurate construction measurement	Jaselskis, E., Gao, Z., Walters, R.C., 2005

Table 2. Research summary related to laser scanning technology.
[1] Turkan, et al., 2012

➢ Photogrammetric methods

One of the most economical ways to track progress automatically is by recording video or taking images. For instance, Teizer (2015) as cited in Teizer, *et al*. (2005) said that it is possible to reliably track multiple resources with images or videos in order to reproduce the daily workflow of activities associated to a worksite.

In another hand, Han & Golparvar-Fard (2015) commented that nowadays, the availability of inexpensive point-and-shoot and time-lapse cameras and also smartphones have significantly increased the number of photos that are being captured on construction sites on a daily basis.

However, the main challenge in vision-based approaches is precisely the automated extraction of progress information from extended time-lapse photographs (Teizer, 2015). Therefore, some researches that have focused on improving the automated extraction of progress information are mentioned below.

- Turkan, *et al*. (2012) as cited in Golparvar-Fard & Pena-Mora (2007) and Golparvar-Fard, *et al*. (2009a, b) commented that the authors proposed an alternative image-based method for progress monitoring using daily photographs taken from a construction site. In that research, they

[1] Turkan, Y., Bosche, F., Haas, C. & Hass, R., 2012. Automated progress tracking using 4D schedule and 3D sensing technologies. *Automation in Construction,* Volume 22, pp. 414-421.

calibrated (using internal and external calibrations) series of images of the site, and consequently reconstructed a sparse 3D as-built point cloud of that site. This allowed them to visually compare as-built data with 3D as-planned data and monitor the progress.

- As well as, Turkan, *et al*. (2012) as cited in Wu, *et al*. (2010) explained how the authors proposed another image-based approach to estimate project status information automatically from construction site digital images. They developed an object recognition system to recognize construction objects of interest successfully from their construction site digital images. The approach exploited advanced imaging algorithms and a three-dimensional computer aided design perspective view to increase the accuracy of the object recognition, and thus enabled acquisition of project status information automatically.

2.4. Tracking Materials

Nowadays, emerging technologies, which have continuously been better integrating with each other, hold the potential to overcome some of the current limitations of the construction industry through the partial automation of processes.

For instance, Stefanic & Stankovski (2019) developed a mind map that summarizes the advances of technologies in the construction industry, where some applications were created in different areas to address construction problems and then some of them are explained in detail.

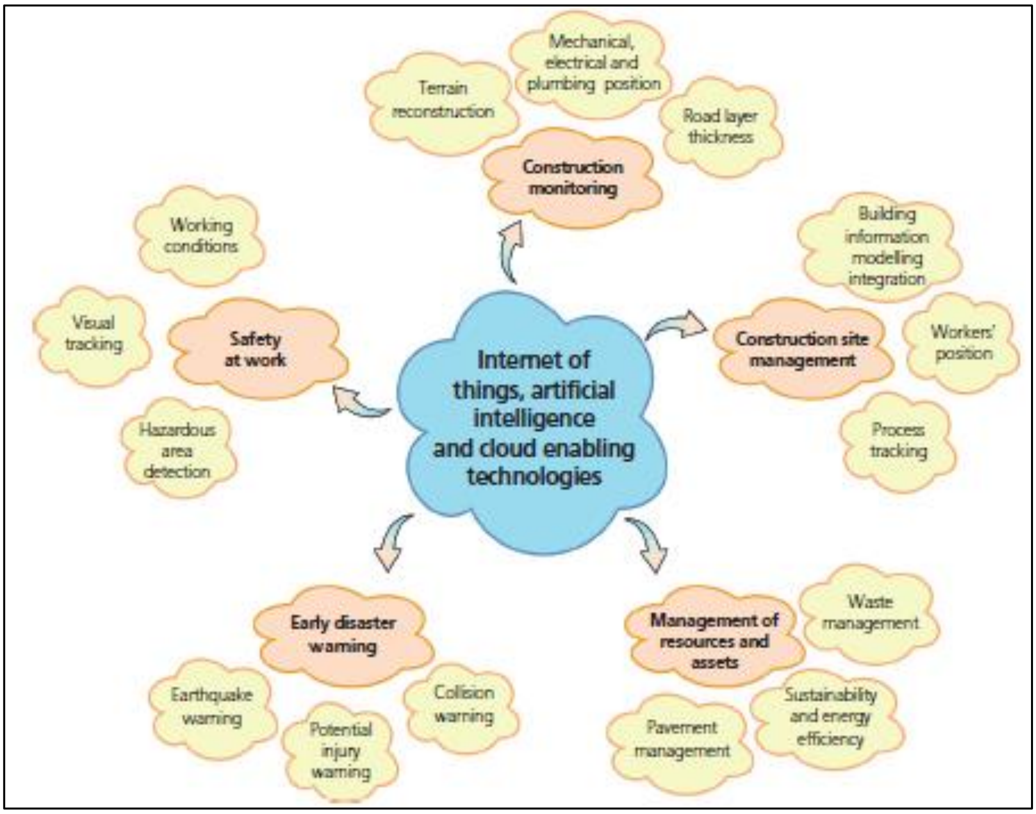

Figure 3. Converging internet of things, artificial intelligence, cloud fog and edge computing technologies will provide the necessary dependability to time-critical smart construction applications.
[1] Stefanic & Stankovski, 2019

➢ RFID

According to Kasim (2018), automatic identification technologies are referred to as automatic data capture for identifying items and gathering data without human intervention or data entry.

Being able to track or have a real-time access to the locations workers, materials, and equipment on construction sites can significantly help the management of materials in the construction because it improves the productivity and efficiency of a construction project. As well as, it can help project managers improve safety, security, quality control, worker logistics and maintain local ordinances for a construction project.

Zhai, *et al*. (2009) have found out in his research that integrating technology to automate the monitoring and analyses is a way to reduce the human component and increase accuracy and reliability and, projects with higher automation and integration of information technology improved between 31% and 45% in productivity.

As mentioned before, the automation of the identification and tracking materials with technologies, such as RFID, bar-coding, GPS, improve the productivity and efficiency of a construction project.

[1] Stefanic, M. & Stankovski, V., 2019. A review of technologies and applications for smart construction. Proceedings of the Institution of Civil Engineers-Civil Engineering, 172(2), pp. 83-87.

However, according to Costin, *et al*. (2015) as cited in Ergen, *et al*. (2007) and Grau, *et al*. (2009), RFID technology has been shown to have a multitude of benefits from the implementation within various construction sites including asset tracking, inventory management, and on-site security upgrades.

On the another hand, the same authors (Costin, *et al*., 2015) as cited in a previous research Costin *et al*. (2012a) concluded that the implementation of RFID has been shown to be feasible and cost effective. Therefore, RFID technology will be explained in detail below.

RFID is a method of communication that uses radio waves. The system is composed of a tag, which is read by an RFID Tag reader, and a computer that receives the data from the reader. This technology is rapidly becoming more capable and complex, helping to track materials, workers, and equipment in real time as well as produce a visual of the locations and resources on a construction site (Costin, et al., 2015).

The fact of being able to safely track the materials, workers and equipment that enter and exist at all times on the construction site allows the project team to increase the efficiency of work planning. Different research has been developed regarding to RFID technology and it has been found that this technology has multiple benefits, some of them will be mentioned below.

- Prevents the materials or equipment from being misplaced or lost, which could potentially be a negative impact on the project's cost and schedule (Costin, et al., 2015).

- The use of RFID technology has been found to enhance the user's ability to locate materials that have been tracked by the RFID readers with an improvement ratio of 8:1 over manual tracking (Costin, *et al*., 2015 cited in Grau *et al*., 2009).

- RFID technology has been even further utilized by successfully pairing with Building Information Modelling (BIM), this link between the virtual models and the physical components in the construction process can improve the information handling and sharing in construction and building operation management (Costin, *et al*., 2015 cited in Sørensen, *et al*., 2010).

➢ **UWB**

Apart from automatic identification technologies, there are other technologies to track or have real-time access to the location of workers, materials, and equipment on construction sites, such as wireless technologies. According to Kasim (2008) as cited in Wood & Alvarez (2005), the term wireless refers to any type of electrical or electronic operation which is accomplished without the use a 'hardwired' connection. Wireless technologies include phones, personal digital assistants, and wireless networking to transfer the information over distance without the use of electrical conductors or 'wires'.

Deploying wireless networks can potentially improve the management of materials in the construction site, it is for this reason that some of these benefits are mentioned below:

- The wireless networks can provide an automatic tracking and give real-time information (such as status ad location) of materials, suppliers, and tools. By accessing the materials management system on a mobile, computer, supervisors and employee will be able to locate materials and suppliers and also reduce time spent searching an entire site (Kasim, 2008).

- Labors productivity and lower labor costs are also improved by ensuring the crews in the field have the correct materials to execute work as planned. This will also reduce the cost of replacing materials that have been lost or misplaced (Kasim, 2008).

There are multiple wireless technologies such as, UWB and WLAN. Each technology has its own inherited advantages and disadvantages, accuracy, cost, coverage range, deployment requirements and scalability. However, UWB technology has demonstrated unique advantages for precision localization applications (Saidi, et al., 2011). Therefore, this technology is explained in detail below.

UWB uses short (nanosecond) bursts of electromagnetic energy in the form of short pulse radio frequency (RF) waveforms over a large bandwidth (N500 MHz). UWB provides an ability to precisely measure the time-of-flight of a signal between a transmitter and a receiver. This capability provides a means for creating a localization system using multiple receivers by measuring the time-difference-of-arrival (TDOA) between them from multiple moving transmitters (tags) (Saidi, et al., 2011).

Several researchers have studied UWB applications to track or have real-time access to the location of workers, materials and equipment on the construction sites. Some of the findings are mentioned below:

- Teizer, *et al*. (2007) proposed a rapid automated monitoring of construction site activities using UWB and, Teizer, *et al*. (2008) suggested a UWB for automated real-time three dimensional location sensing for workforce, equipment, and material positioning and tracking. Both investigations found that tracking the location of people, equipment, and materials on the construction sites could improve the work zone safety and work task status monitoring (Saidi, et al., 2011).

- On the other hand, Teizer, *et al*. (2007) recommended a real-time three-dimensional occupancy grid modelling for the detection and tracking of construction resources, Rueppel & Stuebbe (2008) proposed a BIM-based indoor-emergency-navigation-system for complex buildings, and Khoury & Kamat (2009) studied the high-precision identification of contextual information in location-aware engineering applications. These studies found that UWB has a higher localization accuracy of approximately < 1m (Ibrahim & Moselhi, 2015).

III. Application of Tools for the Supply Chain Process in Civil Engineering Projects

3.1. Construction Site Management

Following the methodology outlined above, approximately between 15 to 20 sources were evaluated in order to find the most appropriate technology, principle, method, among others, in relation to the construction site management. Some of those works can be found below:

- Bajjou, *et al*. (2017) conducted a synthesis of the most reliable research in the field of safety management in order to study the contribution of Lean Construction practices in the promotion of safety.

- Li, *et al*. (2017) evaluated the extent of implementation of lean construction in China and explore the influencing factors of lean construction in China's construction firms.

- Sarhan, *et al*. (2017), investigated the current state of lean construction implementation in the construction industry in the KSA.

- Nowotarski, *et al*. (2016) introduced Lean Management methodologies in chosen construction processes and the purpose of the study is to show how Lean Management can influence the total cost of selected process of managing storage area on the construction site.

After leading a very detail and extensive research, it was possible to determine that the implementation of 5S process and Visual Management on the construction site not only improves productivity, quality, but can also help to improve safety and provide environmental benefits, some of the benefits are cited below in the following table:

Benefits	Citations
Reduce displacement, falls, movements	Bajjou, *et al*., 2017 cited in Nahmens & Ikuma, 2009
Reduces clutter and diminishes or eliminates non-value-added time that is often spent in locating tools or equipment needed for construction tasks	Forbes & Ahmed, 2010
Helps reduce waste, improve productivity and safe management, and encourages employees to operate with an eye on constant improvement	Li, *et al*., 2017 cited in Gapp, *et al*., 2008
Improve building processes	Nowotarski, *et al*., 2016
Improves safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times,	Ogunbiyi, 2014 cited in Spoore, 2003

cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (kaizen activities)	
Reduces waste of outdated components, reducing vehicle emissions, and reusable packaging	Ogunbiyi, 2014 cited in Ross & Associates, 2004
Potential significance in terms of productivity, service delivery and quality which ultimately results in substantial cost savings within a company	Ogunbiyi, 2014
Increases the productivity of the project since it reduces the time spent searching for supplies, tools, and equipment	Sarhan, *et al*., 2017 cited in Umstot, 2013

Table 3. Benefits of implementing the 5S process on the construction site, according to different authors.

Therefore, that 5S process and Visual Management as part of the foundation of Lean can be implemented as a strategy to increase the productivity, quality and morale by having a safe and efficient site.

Then, detailed information about the 5S process and Visual Management can be found, in order to explain how it works and how it can be applied. It is important to note that the following information was developed based of the following sources:

- A Guide 6S created by Creative Safety Company in 2018.
- Practices recommendations for the application of Lean Construction methods to building new Australian LNG capacity created by Engineers in Australia Company in 2012.

3.1.1. 5S process

5S is a system of creating workplace organization to reduce/eliminate waste created by clutter, lack of information, duplication, underutilized space, inconsistency in process.

At the macro level this includes site layout, access points, laydown area positioning, work fronts and crib rooms. At the micro level it may include positioning of grinding tools in a storage container, color coding welding equipment or sorting a computer filing system in the office.

Therefore, the following steps should be done by the work team who use the workplace, as they are the best judges of how their work area should be organized.

Sort (Seiri)

Sort is the process to eliminate all the unneeded tools and materials and thus create a work area free of clutter.

The implementation of this phase can help solve the following problems:

- Tools and materials impeding workflow
- Wasted time looking for parts, tools, and products
- Stockpiling unnecessary and expensive inventory
- Safety hazards resulting from clutter

In order to do this, unneeded parts and tools must be identified, and a tool called Red Tags can help this sorting process, identifying objects that need to be removed from the workplace.

When there is a possibility that something needs to be removed, a Red Tag needs to be put on it, in order to let people, know that this item needs to be evaluated.

On the Red Tag, the action that should be taken must be indicated, for instance:

1) Leave the item where it is
2) Relocate the item
3) Dispose of the item
4) Recycle the item
5) Place in “Red Tag Holding Area”

The Red Tag Holding Area is a location where items are placed until its value is determined.

When a tool is in the Red Tag Holding Area and after one month no one has used it, the tool can be removed from the workplace.

On the other hand, when the item is still needed, the Red Tag must be removed and the most appropriate location to store the item must be found.

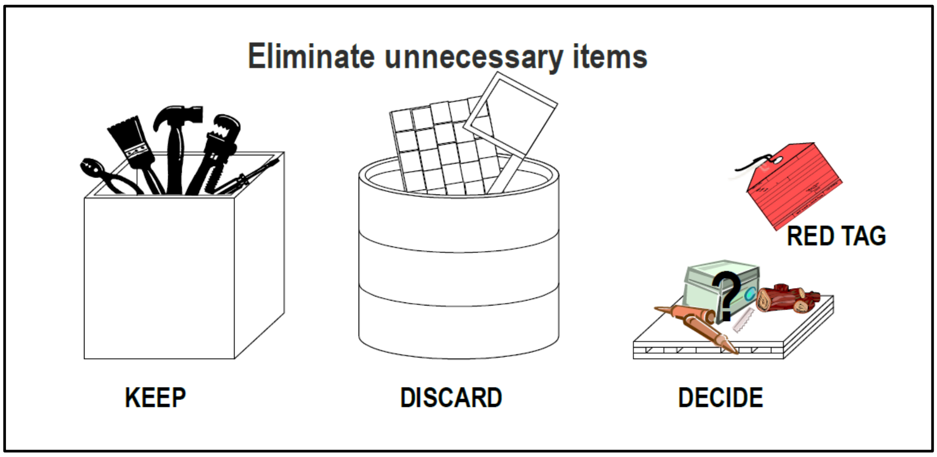

Figure 4. Example of the Sort process
[1] Engineers Australia, 2012

➢ Set in Order (Seiton)

Set in Order is the process of putting everything in a place that is easy to get, the idea is to create a standardized and consistent way to store and retrieve tools and materials.

In order to achieve that the following parameters have to be taken into account:

- The user must develop a system based on how often the tools and materials are accessed and the process that uses them.

- Set in Order phase can begin only when the Sort phase has been completed.

In the Set in Order phase, a general layout of the workplace is designed in order to accommodate in the safest most efficient way the items that can still be used, taking into account the following parameters:

- If items are used together, store them together.
- Place frequently used items closest to the user.
- If possible, devise a let-go system in which tools are attached to a retractable cord and automatically go back to the stored position.
- Place items so the user does not need to bend or twist much to access them.
- Arrange tools and materials in order of use.

➢ Shine (Seiso)

The goal for Shine is to keep everything in great working order so it lasts as long as possible and does not break down.

[1] Engineers Australia, 2012. *Recommended practices for the application of Lean Construction methods to building new Australian LNG capacity,* West Perth: Engineers Australia.

The implementation of Shine brings some benefits such as:

- Employees can work in a clean environment.
- Increased productivity and reduced costs, due to the decrease in injuries and equipment breakdowns.

Cleaning is everyone’s responsibility, however, in order to achieve this goal, some measures must be taken, such as:

- Standardize the cleaning program.
- Train employees to do the cleaning program properly.
- Use checklists and diagrams for consistency.
- Damage inspection of tools and machinery.
- Perform routine periodic maintenance.

➢ **Standardize (Seiketsu)**

The Standardize phase involves the creation of a system of tasks and procedures so that the principles of 5S are performed on a daily basis.

For this, a set of schedules and checklists can be followed.

As well, in order to ensure that the 5S pillars are carried out consistently and correctly, the following steps must be followed:

- Make sure each employee knows his responsibilities, its means, their responsibilities must be clearly written out on a checklist or a chart so that they can be easily accessed throughout the day.

- Make it a part of their daily routine, training the employees correctly in order to make sure they execute the steps of 5S without even thinking about it.

- Periodic evaluation, creating a committee made up of employees from different departments or assign evaluation to department supervisors. Either way, a system must be created to ensure tasks are consistently.

Figure 5. Example of an office minimum Standard.
[1] Engineers Australia, 2012

➢ Sustain (Shitsuke)

The goal of Sustain is to keep the staff motivated and on track, therefore, the following suggestions can help keep the program functioning well.

- Assign the time to do the tasks.
- The application of 5S pillars must be carried out from the highest position of the company.
- Create a reward system.
- Get everyone involved.
- Let employees visualize the importance of 5S around them.

➢ Safety

The 6th S is not part of the original concept of 5S developed at Toyota, however, since one of the guiding principles of all Lean methodologies is to eliminate waste, it makes perfect sense that safety issues that cause delays, damage, or worse, injuries to employees, would need to be eliminated.

Safety issues cause delays in production and cost companies a lot of money, therefore, the implementation of 6th S can help protect workers from injury, improve productivity, and eliminate waste.

In order to achieve the goal, the following tips can be followed:

- Use visual communication like floor and wall signs to alert workers and visitors of hazards.

[1] Engineers Australia, 2012. *Recommended practices for the application of Lean Construction methods to building new Australian LNG capacity,* West Perth: Engineers Australia.

- Use floor marking material to communicate danger.
- Displaying safety processes and posters in break rooms to remind workers of safety programs.
- Include safety policies in training and orientation for new employees.
- Make sure first aid equipment is functional and clearly marked.

3.2. Construction Supply Chain

Following the methodology outlined above, approximately between 10 to 15 sources were evaluated in order to find the most appropriate technology, principle, method, among others, in relation to the construction supply chain. Some of those works can be found below:

- Wang, *et al*. (2007) demonstrated the effectiveness of a RFID-based supply chain management application called the mobile construction RFID-based dynamic supply chain management (M ConRDSCM) system in construction projects, demonstrating that it responds efficiently and enhances the information flow among offices and sites in a construction supply chain environment.

- Cheng, *et al*. (2010) described the overall architecture of a system called SC Collaborator and its features.

- Xue, *et al*. (2004) analyzed the problems in construction supply chain and designed an agent-based framework for construction supply chain coordination.

All these sources have a large number of citations in the academics' databases, as well as, an impact of Q1 journal, however, Irizarry, *et al*. (2013) integrated BIM and GIS to improve the visual monitoring of construction supply chain management, whose main focus of its research was on the procurement phase of a project in which information pertaining to the location of supply chain assets was visually monitored.

On the other hand, this Master Dissertation consists in finding possible improvements by the combination of Lean Construction and BIM, and this article improves the current practices of CSCM by taking advantage of BIM to create objects with the maximum level of detail in geometry.

Although, the research made by Irizarry, *et al*. (2013) mainly concentrates on the flow of materials from the supplier to construction site, it also addresses some aspects of Lean Construction in terms of efficient use of resources and cooperative SCM.

In addition, being 106 times cited in academic databases, with an impact on the Q1 journals in categories such as Construction & Building Technology and Civil Engineering. Therefore, this study was selected as the most appropriate regarding to the Construction Supply Chain. Following, it will be explained how it works and how it can be applied. It is important to note that the following information was developed based on the article published by Irizarry, *et al*. (2013).

3.2.1. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management

The role of BIM in this CSCM model is that the system concentrates on creating objects with the maximum level of detail in geometry and GIS are applied to analyze the objects, which already exist around. The benefits of each system are listed below.

- **BIM**

  - Improves the visibility of the supply-network and accurate information concerning the status of material at different stages.

  - Allows defining discrete quantifiable elements to show detailed material and component properties, as well, export them to a spreadsheet or an external database.

  - Generates reports and alerts graphically.

  - Provides scheduling functionality and simple functions to link construction schedule to the 3D model, allowing visualization of the sequential construction of the building.

  - Provides a visual report that shows the availability of materials and their final locations, which ultimately facilitate monitoring and properly provides process transparency.

- **GIS**

  - Maps the entire supply chain process.
  - Provides an ideal solution to manage costs of transportation.
  - Map the physical flow of goods and to reduce overall costs and lead times along the extended supply chain.

The CSC workflows outlined in this model is described below:

- Pre-Design Decisions: The availability of materials is evaluated in this phase.

- Sourcing: Is the process of finding suppliers of goods and the impact of supplier's location on cost and schedules for a given construction project.

- Logistics: Is the management of the flow of materials between the suppliers to the construction site in order to meet the requirements of a given project.

- Performance Management: Provides visibility into key performance indicators (KPIs) across the supply chain.

- Monitoring & Inspection: Deal with available and accurate information concerning the status of material at different stages within the construction supply.

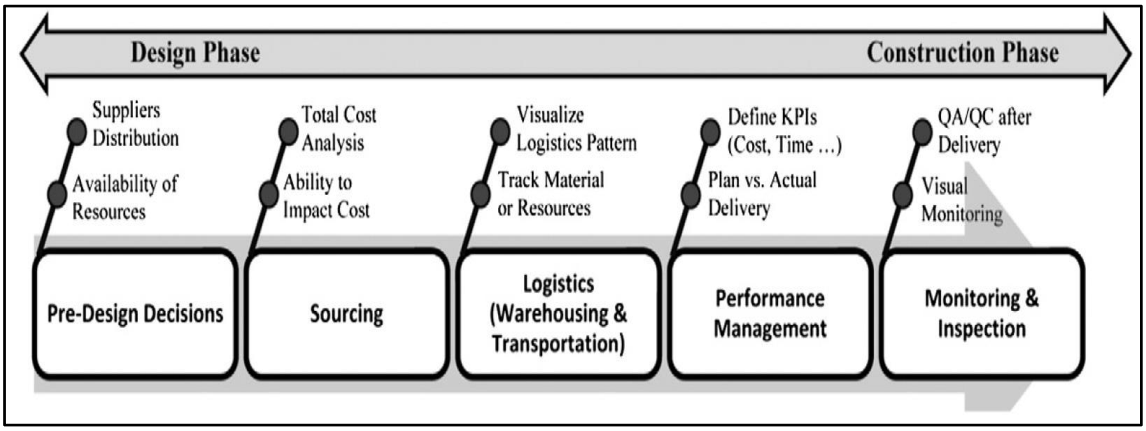

Figure 6. Model framework of Construction Supply Chain.
[1] Irizarry, et al., 2013

In the proposed model, it is important to highlight the following information:

- In order to enhance the exchange of geographic information in GIS with the IFC schema IFG can be used.

- The latest IFC 2×4 release was used as the data repository for addressing the geometry, relations, and attributes.

- In order to accurately locate the building within GIS context, spatial coordinates were defined and transformed from local coordinate systems to the real word coordinate system (i.e. georeferenced) at the beginning of the process.

- MS Access was used as a central all BIM and GIS data can be exported/imported as 3D objects into the database.

➢ **Description of the BIM-GIS model**

1. BIM Module: define building elements and properties.

The building's elements are defined at this stage, and the type of each element is determined based on the material being used. The required amount of building information is provided as an IFC file.

[1] Irizarry, J., Karan, E. & Jalaei, F., 2013. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction,* Volume 31, pp. 241-254.

Construction products such as ETO, MTO, ATO, MTS are defined in objects classes (or object family) to address how they are structured and how they are edited, since each of these has its own supply chain.

2. BIM-GIS Module: develop visual model representing the availability of materials.

This step involves identification of all available resources defined earlier in the BIM model and recognition of their relative distance to the construction site. Since buildings elements in BIM identity what needs to be purchased, it is possible to extract all information directly from the BIM tool.

Following the previous steps, most information like schedule of material delivery, the components of the building and their installation locations, and schedule of their relevant activities are available in GIS database. Each component is annotated with its delivery time and installation/consumption time; thus, storage duration of each component can be calculated in this step. This option is used in the BIM module of the model to calculate order due dates and demand forecasting. While demand forecast is obtained from the construction schedules, it should be borne in mind that date and duration of activities are uncertain due to the existence of various constraints.

3. GIS Module: total cost analysis

In this step, GIS-based spatial analyses such as network analysis and attribute analyses have been used to provide an optimal solution to manage costs of supply chain logistics. In order to achieve logistics' aim of reducing costs.

Cost of transportation is considered as one of the deterministic factors in choosing suppliers. In this essence, the main requirements of GIS module are inventory costs (capital, storage, taxes, insurance and obsolescence), vehicles characteristics (vehicle costs, vehicle capacity, vehicles available, vehicle travel time), average fuel price and product unit. Each vehicle starts from its corresponding supply point, forwards materials to a given customer (e.g. construction site) according to the demand less than the capacity of the vehicle.

Regarding to the integration with GIS module, transportation mode(s), warehouse capacity, and product characteristics are utilized to identify optimum transportation cost and the facility that is used to fill the order. Ordering costs depend on the number of material orders and the quantities. In addition, real-time transportation information generated by the GIS module can be compared with the expected (or as-planned) data in order to assess the delivery performance. With the aid of network analysis function in the GIS module, various modes of transportation can be considered.

Figure 11 shows the input variables used in the GIS module to calculate transportation time and cost. To select the alternative with least cost or time of logistics, the associated time and cost should be assigned to each input variable.

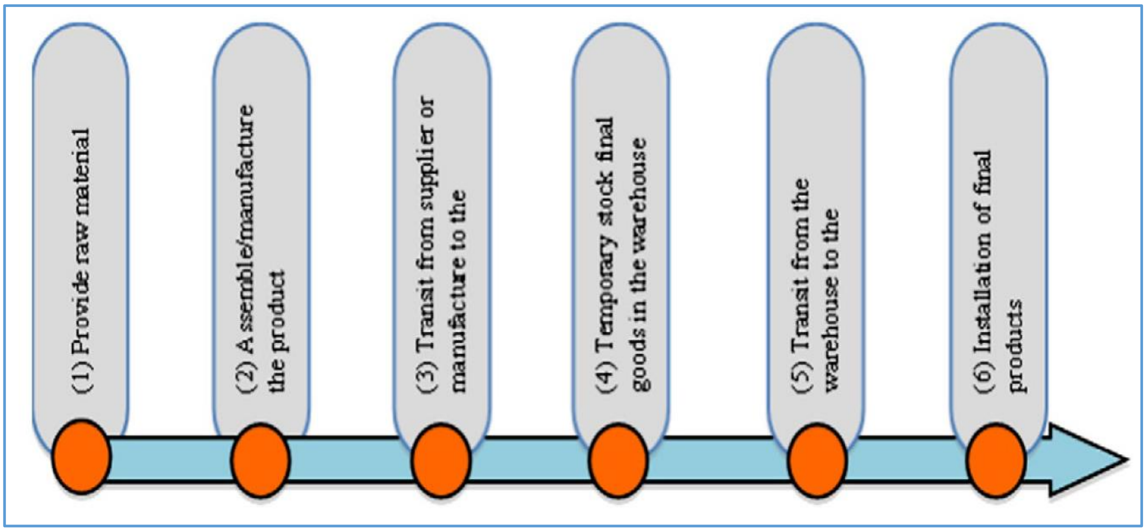

Figure 7. Input variables and their sequences in the GIS module**.**
[1] Irizarry, et al., 2013

4. GIS Module: Visualize Logistic Pattern

GIS can be applied for logistics management to provide accurate and up-to-date information on the status of materials and resources. GIS need dynamic and instance location information of resources to map the status and issue warning, which enable managers to respond immediately if the resource arrives to the site at the wrong time.

The present model does not include automated real-time data tracking of the location and identification of new materials. However, this area will be addressed later when discussing tracking materials.

5. BIM Module: monitoring and graphical representation of material status

The objective of the BIM monitoring module is to overcome the main challenge in supply chain process of material tracking; to provide the managers with reliable information on material status, whether the inventory is located at the site or elsewhere along the supply chain. The status of material availability is established by tracking the building materials that are identified with corresponding ID in the BIM model and registered into the tracking system. Also, there is a link between these IDs and schedule activities, so the material needed for a given activity along with the time can be determined. When materials arrive at or their delivery date obtained from previous step, the respective material availabilities can be visualized in the BIM model. The BIM solution can be used for field inspection and quality control of materials, as a last component of supply chain. The QC department needs to know the up-to-date status of materials to monitor the status of a work order and to plan ahead. A major portion of quality inspection requires checking the material properties of various products at the construction site, which are available in the BIM model.

[1] Irizarry, J., Karan, E. & Jalaei, F., 2013. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction,* Volume 31, pp. 241-254.

As a part of quality inspection process at jobsite, each component (e.g. material ID) is scanned (or automatically tracked) by the field personnel, so the updated status can be gathered and updated. The QC management system has three main components, a PDA, tracking device (e.g. barcode scanner, RFID), and a portal. While the BIM database is on the portal side, field personnel can update BIM attributes using the PDA equipped with systems software (e.g. Vela systems). PDAs display the material properties; thus, field personnel can check the relevant items with their specifications and enter quality and inspection results into their PDAs. This information will be transferred between the PDA and portal by real-time synchronization, enabling the managers to check the process and monitor inventory status on the BIM model. The material status is created as instance parameters in the BIM model and assigned to all categories like walls, windows, doors, and columns.

As could be seen above, the quality inspection process at jobsite is carried out with human presence, which means that a lot of time is being consumed and time means spending money, to address this issue, a semi-automated approach to monitor the construction progress will be presented later.

The overview of CSCM information flow among the various applications in the proposed system is shown in Figure 12.

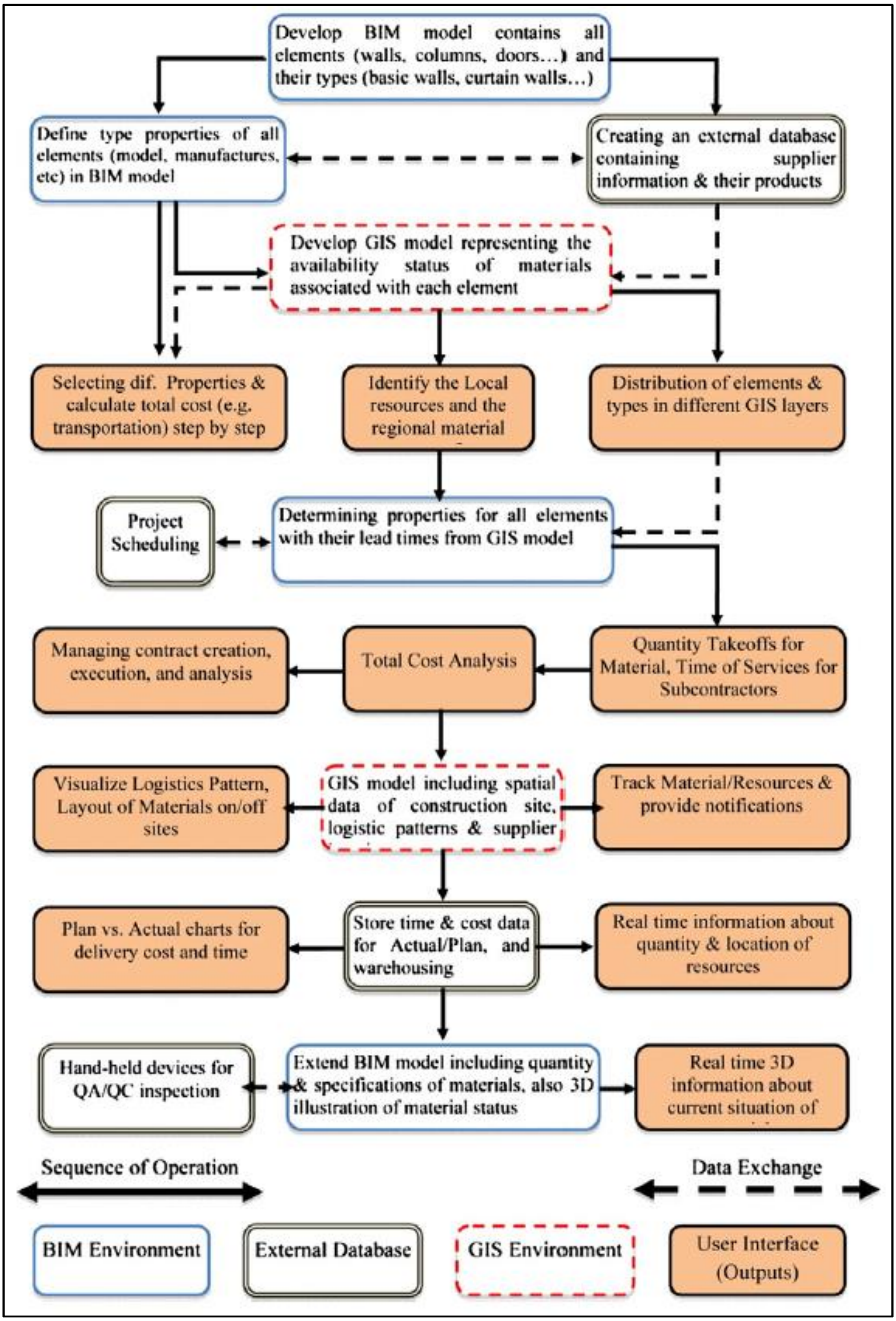

Figure 8. Information flow in the Supply Chain model.
[1] Irizarry, et al., 2013

[1] Irizarry, J., Karan, E. & Jalaei, F., 2013. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction,* Volume 31, pp. 241-254.

➢ Case Study

In order to validate the applicability of the proposed model, a case study was developed and will be explained below.

Highlights

- In order to support and facilitate interoperability with the GIS application, the BIM model has been developed based on the IFC standard.
- Autodesk Revit Architecture 2012 was used as the BIM software application.
- Autodesk Revit has a.NET framework application-programming interface (API), which makes it possible to use any of the .NET compliant programming languages (C#, VB.NET, F#, etc.) to develop a plug-in. The plug-in has been developed in C# with the .NET Framework 3.5.

1st. Step

BIM models of building elements were defined according to the element class or family and product specifications.

The building elements were categorized into ETO, MTO, ATO and MTS products.

As soon as the quantifies specific materials were modeled into Revit. The properties for objects selected by the user could be exported to a central database (e.g.MS Access©).

The schedule date (e.g. installation/consumption date) was extracted from the construction schedule, while detailed information about materials (e.g. size, weight) was obtained directly from the BIM model.

2nd. Step

All descriptive and geographical information in the central database were exported to the GIS module of the system in order to map the availability of resources.

The location of each supplier and the construction site were represented as a set of 2D points having x and y coordinates.

The geographic distribution of resources was analyzed by means of spatial statistical methods.

GIS measures the degree to which suppliers were concentrated or dispersed around the construction site (or project location).

The distance between the construction site and the suppliers was limited 100, 200 and 500 miles. The distance can be measured using two main methods: straight-line distance from each cell to the source (i.e. construction site) and travel distance through a given route (i.e. transportation network).

3rd. Step

GIS was used to explore the optimal way to transport materials from a given supplier to the construction site (i.e. number and time of orders, order quantity, and transportation methods) and the associated cost of transportation.

The data for logistics costs were obtained from the contractor annual Reports, cost center reports, and financial team of the project suppliers.

Transportation cost was calculated along with the vehicle cost and the fuel price cost, which depend on the type and number of trucks, the travel distance between suppliers and construction site, and material properties (i.e. size and weight).

In order to find the shortest path, travel distance and travel time, a network analysis of ArcGIS was used, as well, the optimal number of orders, along with the order quantity and time were determined using the python language module available in ArcGIS.

4th. Step

The visualization process was based on the information regarding material quantities, delivery scheduling, and the major player (e.g. suppliers, customer, owner, etc) executing logistic processes and activities, which were already in the database of the model.

The GIS maps of work sequence logistics were depicted using value stream mapping symbols. The technique was used to map material and information flow required to bring a material to the construction site and summarizing them visually.

The data related to the arrival of materials and their dispatch was exchanged between the engineering company, material suppliers and construction site using the IFC data standard.

All these parameters for the construction products were defined as a Date-Time variable and had two entries; one for schedule and one for actual date. The user had to enter all schedule entries either manually or by using a direct link to the project schedule. On the other hand, actual entries were updated based on the element's latest status. Each element was identified and tracked using barcode assigned to the corresponding ID in the building information model.

After that, the actual dates were compared with the schedule dates in order to alter an elements' appearance. In order to alert the user of the delivery of materials the aforementioned color codes (blue, green, yellow, and red) were used.

The quality inspection was performed at the time of delivering the materials to the construction site. The inspector checked products to ensure that they are consistent with the quantities and specifications defined in the BIM. The updated status of materials was transferred to the file-hosting portal and all information was further used to visualize the material status for managers.

Some figures related to the present case study can be found in the annexes.

3.3. Construction Progress Monitoring

Following the methodology outlined above, approximately between 20 to 25 sources were evaluated in order to find the most appropriate technology, principle, method, among others, in relation to the construction progress monitoring. Some of those works can be found below:

- Bosche, *et al*. (2009) presented a new approach that allows automated recognition of three-dimensional (3D) computer-aided design (CAD) objects from 3D site laser scans.

- Bosche, *et al*. (2015) combined laser scanning and BIM in a unified approach for more robust automated comparison of as-built and as planned cylindrical MEP works, thereby providing the basis for automated earned value tracking, automated percent-built-as planned measures, and assistance for the delivery of as-built BIM models from as designed ones.

- Golparvar-Fard, *et al*. (2009) proposed visualization of performance metrics that aims to represent progress deviations through superimposition of four-dimensional (4D) as-planned model over time-lapsed photographs in single and comprehensive visual imagery.

- Teizer (2015) presented an overview to vision-based sensing technology available for temporary resource tracking at infrastructure construction sites, then provided the status quo of research applications by highlighting exemplary case and finally, he discussed the existing advantages and current limitations of vision based sensing and tracking.

- Turkan, *et al*. (2013) examined a four-dimensional model recognition-driven automated progress tracking system that transforms objects to their earned values, through the analysis of data from the construction of a steel reinforced concrete structure and a steel structure.

- Wang, *et al*. (2013) proposed a conceptual framework that integrates BIM with augmented reality (AR) so as to enable the physical context of each construction activity or task to be visualized in real-time.

- Wang, *et al*. (2014) proposed an interface system that uses the BIMs ability with regard to quantity take-offs of required materials (such as steel, forms, and concrete) to support site-level operations simulation, ultimately leading to the generation of a project schedule.

- Zhang, *et al*. (2009) explored the potential of using computer vision technology in assisting the project management task.

As seen above, research has mainly focused on facilitating the process through the use of terrestrial laser scanning, however, this method still has some challenges to face to detect processes at the operation level such as:

- Lack of detail in Plan model: The level of development (or detail) in BIM used in many projects for pre-construction coordination or constructability reviews is not sufficient enough for tracking progress on an element-by-element basis.

- High-level work breakdown structure (WBS) in construction schedules: In many projects, for project control, the construction schedules remain at the contractor-level.

- Static and dynamic occlusions: Occlusions result in incomplete data and challenge reasoning under limited visibility.

Han & Golparvar-Fard (2015) named the challenges outlined above and proposed a new appearance-based material classification method for monitoring construction progress deviations at the operational-level in order to address them.

Therefore, his research was selected as the most appropriate technology regarding the construction progress monitoring and the following information is based on his research in order to explain how it works and how it can be applied.

3.3.1. Appearance-based Material Classification for Monitoring of Operation Level Construction Progress Using 4D BIM and Site Photologs

➢ **Method Overview**

The method proposed by Han & Golparvar-Fard (2015) can be seen in Figure 13 and consists of:

First, it takes a 4D Plan BIM and a collection of overlapping images of a construction site as the inputs.

Then, the input images form a dense 3D point cloud representing the as-built status of the construction.

Finally, with a few user input (3) on point correspondence between the 3D point cloud and BIM, the up-to-scale point cloud is transformed into the BIM coordinate system and the images, registered to the point cloud, are brought into alignment with the BIM elements (Figure 13.a).

In order to infer the state of progress for all BIM elements, the following steps are conducted automatically:

1. A depth map of all BIM elements is generated for every camera viewpoint to reason about the occlusions. This allows the specific image regions that see a BIM element be extracted from each image (Figure 13.b).

2. From each image region that corresponds to a BIM element, several smaller squared-shape patches are sampled.

3. Each patch is placed into an appearance-based method to classify the construction material that is associated with each BIM element.

4. A vector-quantized histogram of all observed construction materials is formed per element (Figure 13.c).

5. The material with the highest frequency of observation is returned as the most updated operation-level state of progress for that BIM element (Figure 13.d) and the state of progress for BIM elements is color-coded according to the observations.

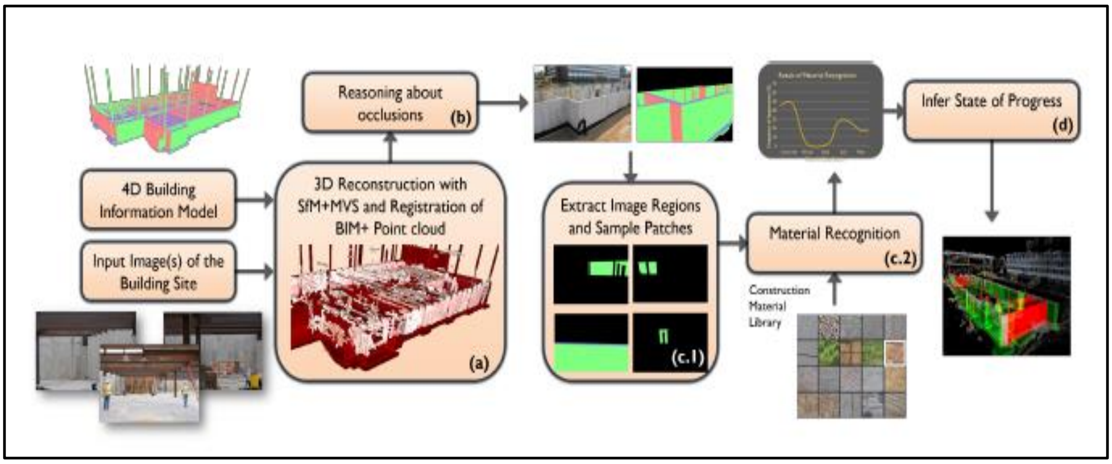

Figure 9. Method overview.
[1] Han & Golparvar-Fard, 2015

[1] Han, K. & Golparvar-Fard, M., 2015. Appearance-based Material Classification for Monitoring of Operation-Level construction progress using 4D BIM and site photologs. *Automation in Construction,* Volume 53, pp. 44-57.

In order to successfully perform the above method, it is necessary to develop some procedures whose explanation is developed below.

- **Generating as-built point cloud models**

The SfM procedure is mainly used to calibrate the images with respect to a sparse 3D point cloud models and feed in the calibration information into the MVS procedure to produce a denser point cloud model.

The MVS dense reconstruction procedure is mainly used to enhance the as-built 3D visualization and help a user with more accurate selection of the corresponding points for the point cloud-vs.-BIM registration.

- **Integration of the as-built model and 4D BIM**

An image-based 3D point cloud produced from uncalibrated site imagery is up to scale.

In order to recover scale and transform the point cloud into the BIM coordinate system, a newly developed web-based interface allows a user to select at least three correspondences (3D vertices) between a BIM and a point cloud.

Using these user-selected correspondences, the point cloud is scaled and transformed into the BIM coordinate system by solving the least square registration problem of absolute orientation for seven degrees-of-freedom (7DOF) - one uniform scale, three rotations and three translations.

- **Reasoning about occlusions and sampling image patches**

Once the point cloud is transformed into the BIM coordinate system, the 3D BIM elements can be back projected onto the site-registered 2D images.

In order to find the exact relevant 2D regions in the calibrated images that correspond to each BIM element, one needs to reason about the occlusions from every camera viewpoint.

Here, a depth-based reasoning can show which BIM elements are visible, and what parts of each image can be used as their representations.

Once the relevant 2D image regions corresponding to each element are extracted, their appearance is analyzed for progress monitoring purposes.

- **Material Classification**

The material classification method was introduced by Ibrahim, *et al*. (2009) and the following explanation show how this method was adapted for appearance-based recognition of construction progress.

It takes a squared-shape image patch as an input and returns the material category with the highest classification score by using a group of discriminative one-vs.-all classifiers that are trained separately for different categories of construction materials.

Each group of features (texture and color) found in the samples of all material categories are separately grouped using k-means clustering algorithm.

Using the resulting cluster centers, two separate histograms of texture and color are vector quantized for each image sample. These histograms are then concatenated to form codebooks.

Once the texture and color histograms are concatenated, the formed codebook is placed into the multiple classifiers and the material class that returns the highest classification score is returned.

- **Case Study**

For validation, four case studies of “different levels of construction progress” were formed from two real world projects.

First, point cloud models were generated from the construction site images using a pipeline of SfM and MVS image-based 3D reconstruction procedures.

Then, these models were superimposed with 4D BIMs and the BIM elements were back-projected onto each site-registered image for extracting relevant image patches.

The extracted patches were then tested against multi-class material classification method that was pre-trained using the extended CML dataset.

Achieving an average accuracy of 95.6% on appearance-based recognition of progress.

From the different stages, the following information can be highlighted:

- **Progress monitoring datasets**

IFCs that were originally created by the contractor for constructability review purposes were exported and used as the basis for model-based reasoning process.

A large set of overlapping photographs were taken by various teams on these job sites on a daily basis during the construction.

The Figure 14 shows in its first row, images used for 3D reconstruction; second row, snapshots of the point cloud; and third row, views from the registered images.

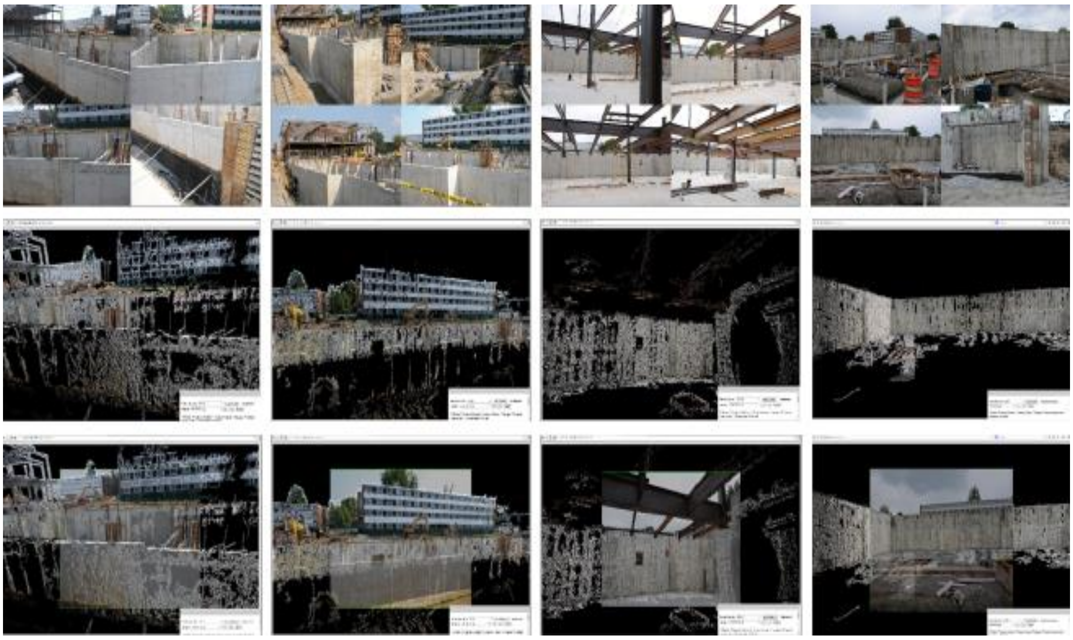

Figure 10. Image-based 3D reconstruction.
[1] Han & Golparvar-Fard, 2015

- **Construction material library for appearance-based recognition**

An extended version of the CML from research conducted by Ibrahim, *et al*. (2009) was put together to include material categories that represent different operation-level activities of concrete placement.

The Figure 15 shows in its first row, registered image + point cloud + BIM from the camera views; second row, only showing BIM from the same views; and third row, registered image + point cloud + BIM from the different views.

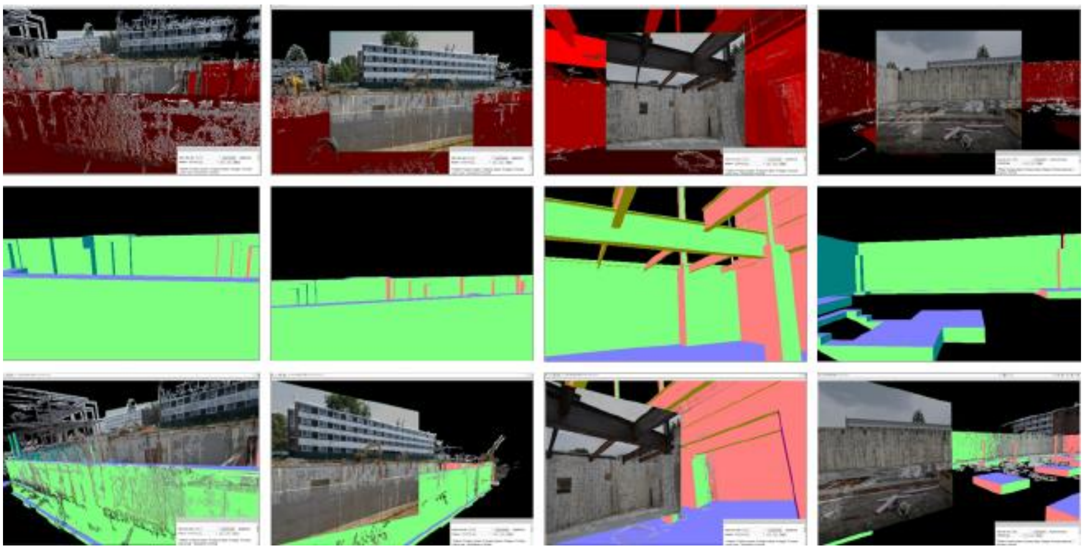

Figure 11. Point cloud and BIM superimposed.
[1] Han & Golparvar-Fard, 2015

[1] Han, K. & Golparvar-Fard, M., 2015. Appearance-based Material Classification for Monitoring of Operation-Level construction progress using 4D BIM and site photologs. *Automation in Construction,* Volume 53, pp. 44-57.

- **Web-based point cloud modeling, point cloud-vs.-BIM integration, and procedures**

For each collection, a 3D image-based point cloud model is generated, using the collected images.

Then, using several inputs from the user, the model is transformed into the relevant BIM coordinate system.

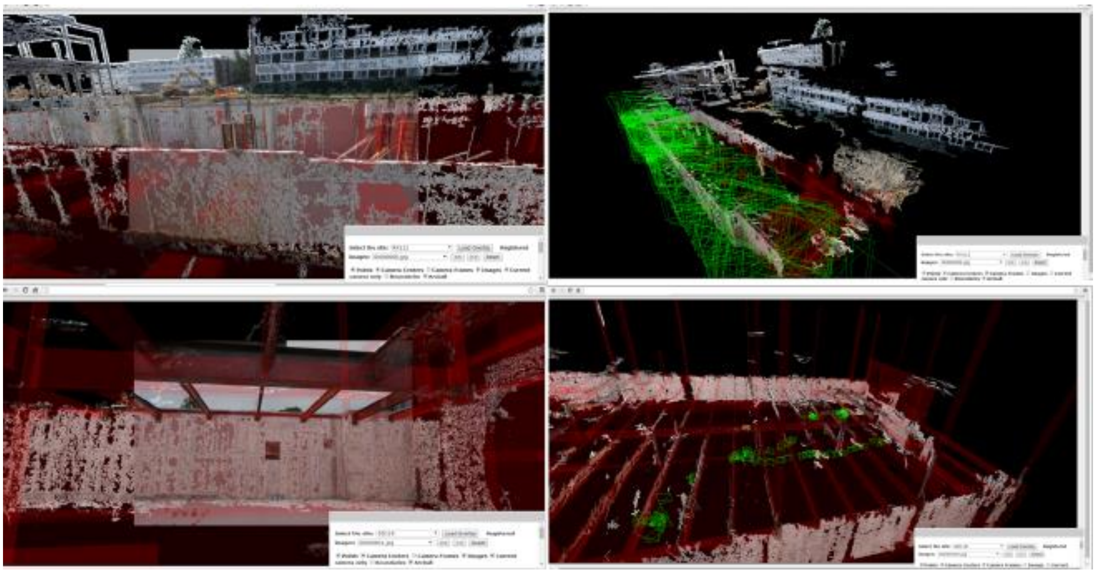

Figure 12. Point cloud vs BIM integration via web-based project viewer.
[1] Han & Golparvar-Fard, 2015

- **Processing BIM-registered imagery**

Due to the presence of static and dynamic occlusions some of these squared-shape patches are expected to be irrelevant to the surfaces being inspected.

The number of image patches that are from the relevant surface material are expected to dominate compared to the occluding element, thanks to the multiple images or viewpoints that are extracted in the scene.

Taking an advantage of having multiple views minimizing occlusions, it is hypothesized that the correct maximum frequency of observations will infer the correct state of progress.

[1] Han, K. & Golparvar-Fard, M., 2015. Appearance-based Material Classification for Monitoring of Operation-Level construction progress using 4D BIM and site photologs. *Automation in Construction,* Volume 53, pp. 44-57.

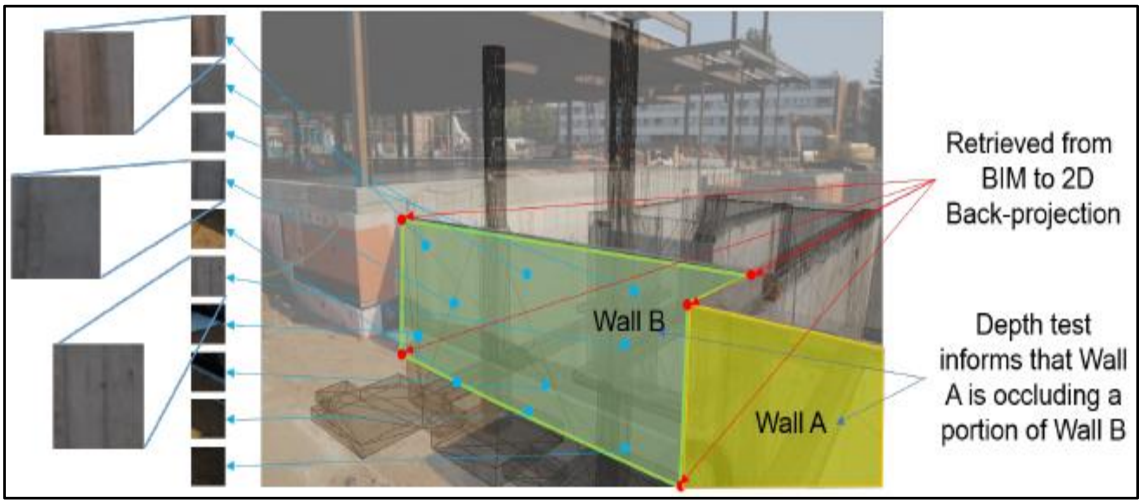

Figure 13. Illustration of extracting sample patches for material classification.
[1] Han & Golparvar-Fard, 2015

3.4. Tracking Materials

Following the methodology outlined above, approximately between 10 to 15 sources were evaluated in order to find the most appropriate technology, principle, method, among others, in relation to the tracking materials. Some of those works can be found below:

- Yagi, *et al*. (2005) proposed a new concept of "parts and packets unified architecture.
- Montaser & Moselhi (2014) presented a low cost indoor location identification and material tracking methodology for construction projects using Ultra High Frequency (UHF) passive Radio Frequency Identification (RFID) technology.
- Lu, *et al*. (2011) investigated various scenarios that can illustrate the uses of RFID technology in construction project management.
- Ergen, *et al*. (2007) provided a vision of intelligent components, which know their identities, locations and history, and communicate this information to their environments.
- Saidi, *et al*. (2011) presented a study for evaluating the static and dynamic performance of a commercially-available ultra wideband (UWB) tracking system in free space and under realistic construction environments.

Despite all these sources have a large number of citations in the academics' databases, as well as, an impact of Q1 journal, in general terms, they focused more on the material tracking system using RFID for the supply chain or for real-time tracking of personnel on construction site.

[1] Han, K. & Golparvar-Fard, M., 2015. Appearance-based Material Classification for Monitoring of Operation-Level construction progress using 4D BIM and site photologs. *Automation in Construction,* Volume 53, pp. 44-57.

Therefore, real-time monitoring of materials has been difficult to develop due to the disadvantage of ADC to record data on bulk materials, since, barcodes and RFID cannot be attached to them.

Despite this, Navon and Berkovich (2006) developed an automated model for materials management and control, this article being selected to be the most appropriate technology for tracking materials, because this article describes the arrival of the materials to the site and their movement about the site, its consumption, among others.

The main benefits of using the model were:

- The increment availability of materials on site and resulting higher productivity.

- Availability of up-to-date and accurate information regarding the inventory of available materials on-site.

- Reduction surplus and waste of materials and real-time control information comparing the planned vs. the actual consumption of materials.

- Reduction the time spent searching for materials, assessing inventory levels and tracking purchase orders.

Therefore, detailed information about this method can be found below, in order to explain how it works and how it can be applied. It is important to note that the following information was developed based on the article published by Navon and Berkovich (2006).

3.4.1. An automated model for materials management and control

➢ **General considerations**

Before beginning to explain the model, it is important to mention the different considerations that must be taken into account in order to develop the model, and are listed below:

- The model should be an integral part of the company's managerial process, meaning that the model should be flexible enough to fit all managerial styles.

- Tracking, monitoring and controlling materials require large and complicated databases, which should be organized in such a way that it is easy to store, organize and analyze the data, as well as present them in a way that will support decision making.

- The model should be able to check and verify data entry for completeness, consistency and integrity to reduce errors to a minimum. This can be done by comparing each data entry with a standard database or by automated data collection technologies (such as barcode and RFID).

- The model should be updated frequently to enable real-time operation.
- The model should be able to compare planned to actual values to alert about discrepancies and enable corrective measures to be taken on time.

➢ Model description

The model is composed of five units and can be seen in Figure 18 and Figure 19 below:

1. Input Unit

The data used is stored in the PD. The PD includes data regarding the schedule of the project, the planned quantities and inputs associated with each activity, as well as catalogues of construction materials.

This unit periodically calculates the materials needed for pending activities ('PD Interface'). The pending activities are all the activities whose predecessors are completed and the ones whose early start falls within a specified time duration (defined by the user).

The result of this calculation is recorded in the Required Materials file, which lists the activities in the specified time duration, the quantities of materials, the time when the material is scheduled to arrive, or be used, etc.

2. Purchasing Unit

In this unit, the materials that must be ordered are determined, based on the data in the required materials file, Decision Rules and the inventory of the materials on the site.

The unit initiates issuing PO for pending activities, meaning that the materials required for these activities are calculated by the Input Unit and stored in the Required Materials file.

The Unit initiates an order if one of the following situations occurs:

- A new activity is scheduled to start.
- When the inventory level of materials required for activities in progress reduces below minimum.

Then, the PO is issued on the strength of logical rules stored in the Decision Rules database.

The rules in the Decision Rules database relate to items such as:

- Lead times for supply.
- Minimal inventory for the various types of materials.
- Minimal quantity per PO to avoid ordering small batches, which increases transportation cost.
- Maximal time between arrival to the site and dispatch for use.

Once the system initiates it, a PO is issued manually. This operation requires knowing the potential suppliers, the local current market conditions and the history of suppliers in other projects of the company.

In order to make sure that the PO is received by the supplier and s/he understands the order and has the materials available to be supplied on time, the Unit requires confirmation from the suppliers. If the supplier has not confirmed, another manual operation is required (verifying the reasons for not confirming) as a result of which the PO may be re-issued.

3. Tracking Unit

This unit tracks incoming materials and their dispatch for use. The data relating to the arrival of materials and their use are collected with ADC, specially PDA technology. This technology is suitable for all types of materials, but it requires some manual data inputting. The incoming materials data are compared to the relevant data in the PO in real-time and transferred to the desktop computer.

As soon as materials arrive to the site their quantity, specification and expected date of arrival, are compared to the relevant data in the PO. If all of these meet the specification in the PO, the materials are accepted, and the data are logged. If they do not meet the specifications, a decision is made whether to accept the materials, or return them to the supplier.

All accepted materials are added to the Inventory file. Materials that are dispatched for use, either upon their arrival or later, are also registered and their quantity subtracted from the inventory.

4. Analysis Unit

This unit receives data from the Purchasing and from the Tracking Unit and generates the data for the Output Unit. The unit compares between the planned and the actual quantities of materials and, based on this, makes recommendations.

The unit calculates, or compares the following:

- Planned vs. ordered quantities. This monitors the function of the Purchasing Unit.
- Ordered materials compared to the ones actually supplied to the site, as recorded by the Tracking Unit.
- Planned vs. actually used quantities.
- Ordered vs. the actually used quantities.
- Standing Inventory, meaning materials that were not taken for use for a long time.

5. Output Unit

This unit generates various types of output: reports, warnings and historical data.

The reports provide information regarding the flow of materials to the site and around it, the main reports are:

- A comprehensive list of all the materials needed in the project, their quantities and their planned time of usage. This list is useful for planning purposes and for negotiating.
- List of materials to be ordered, this list includes the materials that are needed to be ordered in the near future.
- A detailed list of materials flows. This list includes all the materials that arrived in the site, the ones dispatched for use, and the ones remaining in stock.
- A cumulative list of materials flows. This list includes the same items (arrival of materials, departure for use and inventory) in a cumulative format.
- A list of all open PO and the materials in each PO.

The warnings alert about differences between the plans and the actual performance, the main warnings are:

- PO not confirmed by supplier.
- A list of materials that should have been ordered but were not.
- A list of expected materials that were not supplied.

- Materials arriving to the site that are incompatible with the PO.

- A deviation between planned and actual quantities.

The historical data are gathered for use both in the current and in future projects, the model focuses on two items: suppliers and actual quantities.

- All problems with the suppliers, such as late supply, or deviations in quantities or quality, are logged in the historical database.

- The actual quantities of materials, and the materials waste, in each project, broken down to activities, are indispensable for future cost estimating.

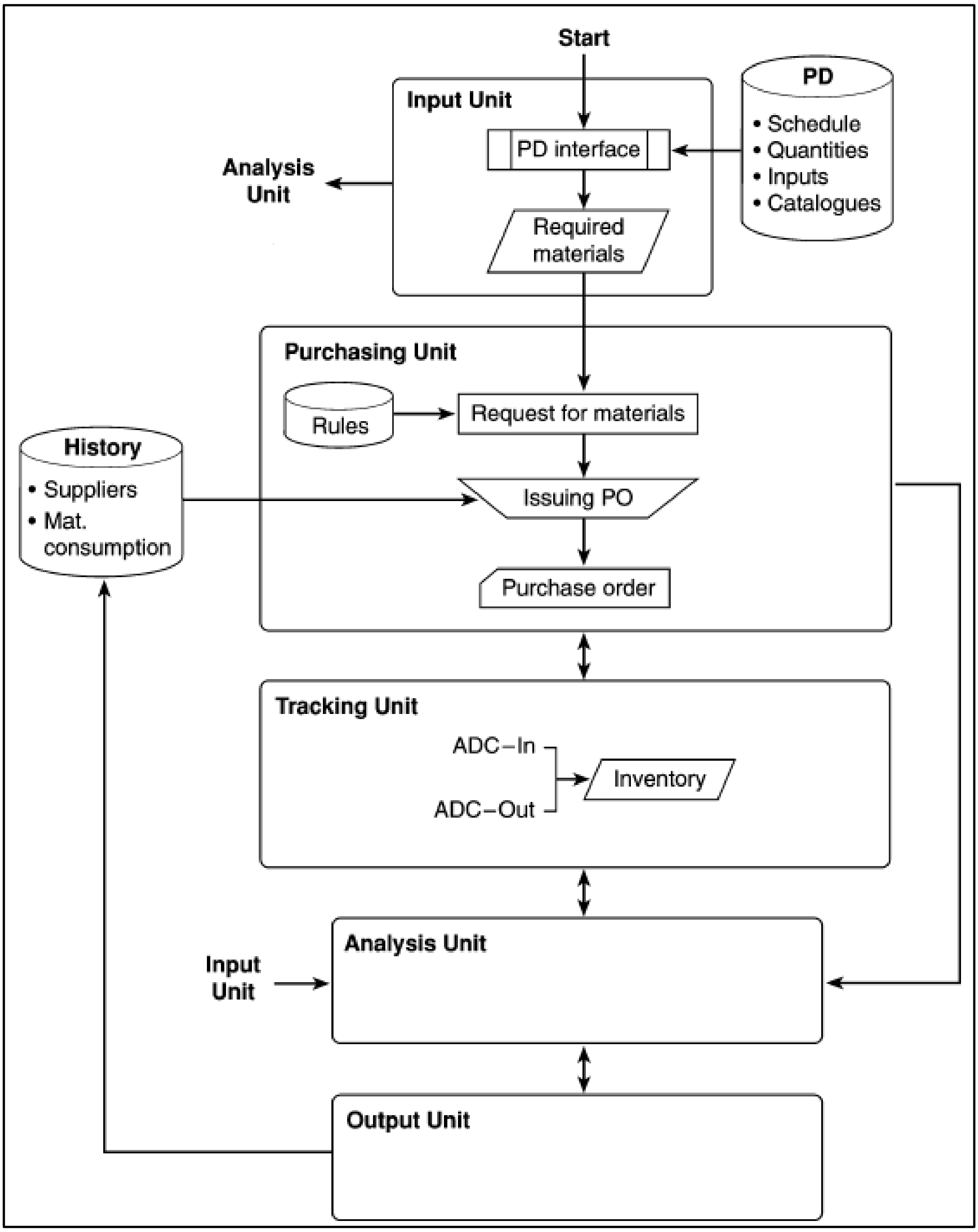

Figure 14. Model Architecture.
[1] Navon & Berkovich, 2006

[1] Navon, R. & Berkovich, O., 2006. An automated model for materials management. *Construction Management and Economics,* 24(6), pp. 635-646.

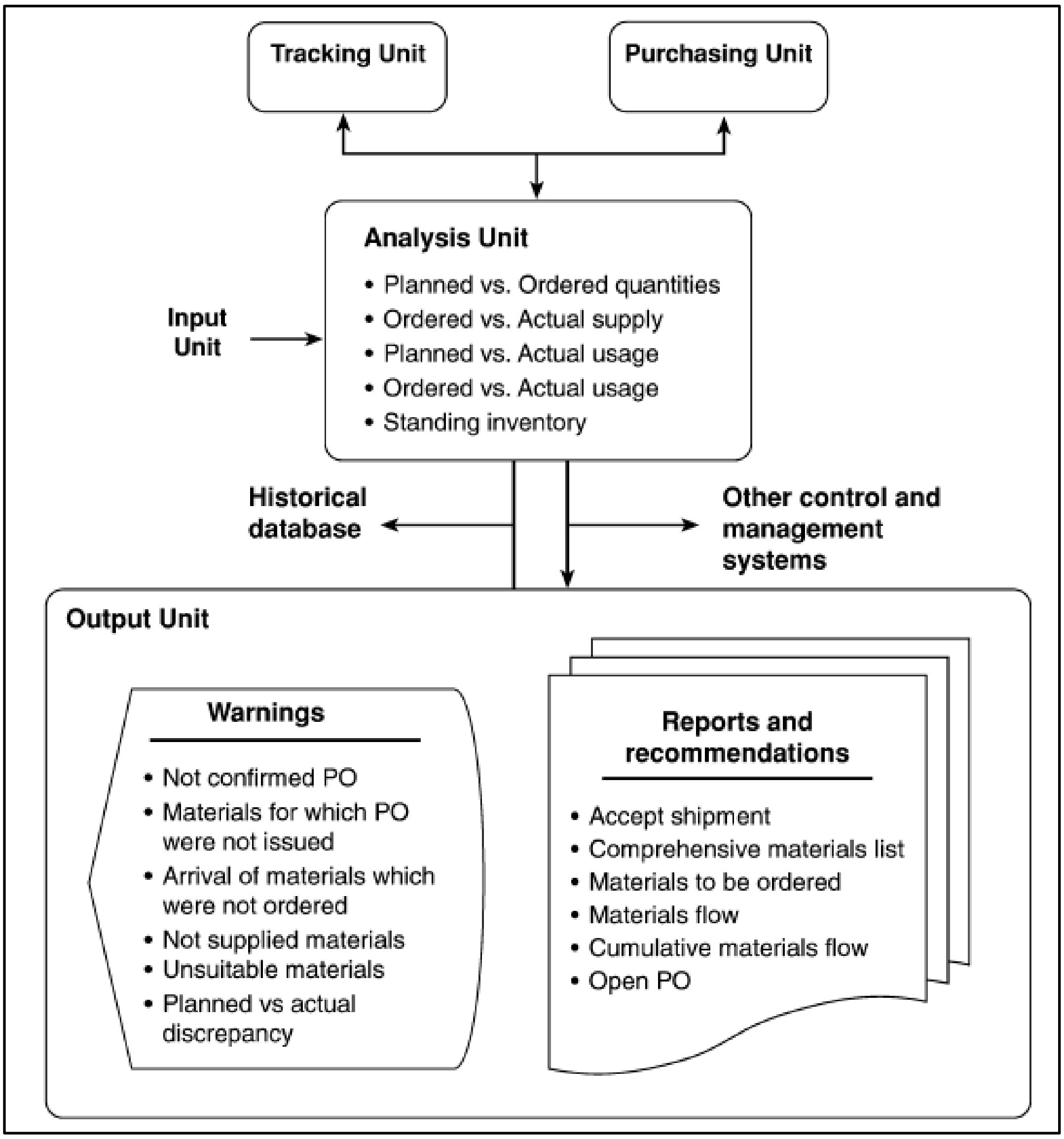

Figure 15. Model Architecture (continued).
[1] Navon & Berkovich, 2006

➢ Case Study

The demonstration and evaluation were carried out on an ongoing project in real conditions and the highlights were:

- The model was implemented in a computer program using Access© for the algorithms and the databases, and a PDA for the data collection.
- The Access© forms were used to input all the general data relating to the project itself, the suppliers and other data necessary for efficient operation of the model.

[1] Navon, R. & Berkovich, O., 2006. An automated model for materials management. *Construction Management and Economics,* 24(6), pp. 635-646.

- The incoming materials and the ones dispatched for use have to be logged automatically, or semi automatically.

- The data in the PDA and those in the Access© database were synchronized frequently (at least once a day).

From this project, it was possible to conclude that the implementation of the model confirms that it is possible to develop an automated system for materials management and control, and that this system has many advantages over customary methods of materials management.

In order to gain the most out of such a system, detailed planning of the project's progress and the use of materials is needed.

Additionally, the plans have to be up-to-date and to reflect all changes in the actual progress of the project and in the design.

IV. LOCATER: New process for Supply Chain Management in Construction

LOCATER: Lean cOnstruction Chain mAnagemenT cubERos

As it was already pointed out, Lean Construction and BIM bring several improvements in construction projects, however, emerging technologies that mostly come from the Industry 4.0, have been applied in the construction industry and have shown huge improvements in areas as quality, safety, efficiency and productivity.

However, there are still issues that must be faced, for instance in the execution phase the problems regarding to materials logistics on construction site such as transportation, inadequate storage and delay in material delivery, as well, still having human labor to control the progress monitoring of a construction project.

Many researchers have focused on develop and applying tools in order to improve the processes of a construction project, some of them precisely solve the problems concerning the materials. Therefore, the literature review was focused in four (4) main areas that from the point of view of the author are related to the material logistics on construction site, such as construction site management, construction supply chain, construction progress monitoring and tracking materials.

Knowing that the aim of this Master Dissertation was to find the most adequate technologies, principles or methods in order to face the challenges related to the material logistics on construction site, four (4) case studies were selected following the methodology established in order to explain how the they work and how they can be applied.

The four (4) case studies have shown several improvements regarding to material logistics on construction site, however, all of them were not related to each other. For instance one was to have a good storage management applying a Lean Construction principle called 5S process, then a process between BIM a GIS was developed in order to improve the supply chain, on another hand, the technology based on photographs plus a method to register this photologs in a Revit program and in the end show the status of material progress, as well as, a semi-automated process was developed to track the materials on construction site, all these case studies, shown several benefits, but on the other hand there still needs work to be done.

However, all those case studies evaluated different areas or processes, that in the end, all are related to the material logistics on construction sites, therefore, after presenting all the literature review and the case studies, it is possible to define a new method for supply chain management in construction, having these case studies as an example, that some of them use technologies coming from the Industry 4.0, another follows the Lean Construction principles and almost everybody uses a platform supported by BIM to exchange information between all stakeholders.

This entire process is called ''LOCATER'', this will be explained in detail below and can be visualized in the Figure 16.

4.1. Level 1 Stakeholders

It is composed by all the people involved in a construction project. According to the Project Management Institute (2013), the term project stakeholder refers to "an individual, group, or organization, who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project.

4.2. Level 2 Tools

Level 2 is composed by different technologies that can easily interact with LOCATER but the most important things are the tools to help in the different processes of construction site, for instance:

- Spatial or geographic data

In order to collect spatial or geographic data GPS can be used to improve fleet and equipment tracking, more accurate site surveying, enhances safety, demonstrates progress and makes construction projects more efficient and improves security of a site.

On the other hand, GIS can be used as well to improve construction planning and design by integrating locational and thematic information in a single environment.

- Building Information Modelling

A 3D model can be developed in order to define the type and properties of all elements by using a BIM tools.

In order to know which materials are required based on the project plan, 4D model can be used to see the project scheduling, quantities, etc.

When a language program needs to be used, a visual programming tool that works with BIM tools can be utilized.

- Wireless Grid

UWB or WLAN are wireless technologies that can be applied for real time location and progress tracking of materials, equipment and workers on construction site.

- Automatic Identification and Data Capture

Automatic identification technologies are referred to as automatic data capture for identifying items and gathering data without human intervention or data entry, it can be done by using RFID, bar-coding in order to improve the productivity and efficiency of a construction project.

- Collecting Visual Detection Tools

Semiautomatic or fully automatic approaches to capture the progress on construction sites, to process and share this data among the project team and stakeholders, and thus be able to compare this data such as those as-built with the planned works such as 3D laser scanning or photogrammetry.

4.3. Level 3 Information Platform (Open Source)

LOCATER is an open source that in any moment, for any reason, etc can be used as a historical database that keeps information regarding construction progress monitoring, tracking, material procurement, storage management, supplier information and their products, among others.

4.4. Level 4 Supply Chain

Level 4 is referred at the three (3) main areas that the author thought that these were really related to the supply chain process, and they are:

- Construction progress monitoring

In order to replace the human labor controlling the progress monitoring of a construction progress, 3D laser scanning and photogrammetry can be used in combination with Revit in order to infer the status progress of the activities and to have a good control and management system.

- Tracking materials

When the material arrives on the construction sites, a semi-automated process can be carried out in order to determine if the material is needed or not. The materials can be accepted on the construction site and automatically be added to the system and update it.

- Storage Management

Regarding to the inventory, in order to have a properly storage management, 5S process can be used, JIT can help the process of procurement and Kanban can be useful to determine when the material has gone and when a new one is needed.

- Procurement

To realize the material procurement is possible to use an automated process to identify potential suppliers, negotiating price, awarding purchase order to supplier and billing processes, it can be made by using a ERP software due to its potential to exchange information with BIM.

When the material is required, an analysis of cost must be carried out that mostly depend on the decision rules or the mechanism that each company uses for the procurement phase.

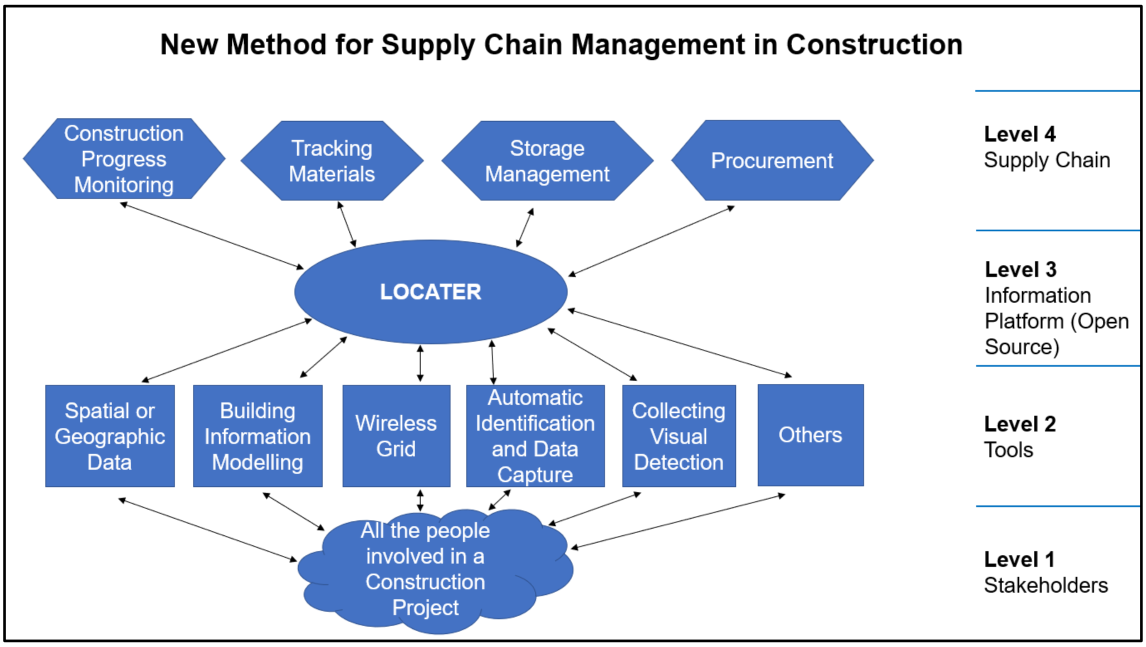

Figure 16. New method for supply chain management in construction.

In the end, the new method for the supply chain in construction, helps anyone involved in a construction project by using emerging technological tools through an open source information platform in order to improve the different areas of the supply chain, for instance, spatial or geographic data, wireless grid or automatic identification and data capture can help to have a real time location and progress tracking, as well as, collecting visual data can help to have an automatic or semi-automatic progress control about the status of the activities in order to help the human labor improve the supply chain process. Providing benefits such as quality, safety, improving productivity and efficiency, reducing the costs associated with the materials, meeting the projects schedule, among others.

All the information mentioned above include different areas that were researched in different ways, however as a benefit or output of this Master Dissertation, it was possible to define a new method for supply chain management in construction that include all these areas that have already been applied and shown benefits.

However, the author could find some lack of these technologies, methods or principles and the information mentioned below, will open a door for future research:

Regarding to the supply chain, it could be possible to develop a system similar to DHL to track the material from the supplier to the construction sites, the GIS and BIM methods mentioned above help to realize the date of each delivery based on the projects scheduling, however, having a real-time tracking of the material, the construction site manager could know the exact moment that the material will arrive, in order to prepare for the arrival, as well as if the material is delayed or will not arrive in the day expected, the construction site manager can make decisions on base of this information.

Regarding to the material when it arrives to the construction sites or when the material goes out from the inventory, it could be possible for instance to use an automated data collection such as RFID to add automatically the material that get into the construction site and goes out from the inventory, without the human labor process.

It could also be possible due to the improvements in the Industry 4.0 and technologies such as IoT, AI or sensor, that as well as the workers nowadays can be tracked on the construction site either for security or safety. It should be possible to do the same with tracking the materials on the construction site.

V. Conclusion, Recommendations and Future Work

The application of Lean Construction in the Construction Industry has brought several improvements regarding to efficiency and productivity, as well as new approaches are focused on bringing safety benefits.

On the other hand, there is BIM that has done a big step to be a platform to exchange information between all the parts implicated in a construction project and also the process.

The world is changing, the construction industry as well, during decades, the construction industry was behind the industries such as mobile phone, automotive and so on. However, nowadays, it was possible to find out that in construction some processes are the same all the time. This led to the possibility that standards can be applied, as well as the implementation of new technologies.

The project is composed of different phases such as design, planning, execution, control and monitoring and management, regarding all of them the industry is trying to improve each phase by using new methods and technologies that in the end are tools to improve efficiency, productivity, quality and safety, among others.

Focusing on the execution phase, there are still some issues that must be faced such as transportation, inadequate storage on site, delay in material and component delivery, supply of low quality material, poor coordination among material planning team, inability to forecast activity period with accuracy, inaccuracies in material delivery and an increased waiting time between activities are the main issues of material logistics in the process of construction sites that undoubtedly leads to the higher cost and delayed time schedules.

Many researchers have focused on develop and applying tools in order to improve the processes of a construction project, some of them precisely solve the problems concerning the materials.

Therefore, the aim of this Master Dissertation was to find the most adequate technologies, methods or principles in order to improve the material logistics on the construction site, following the Lean Construction principles, using technologies coming from the Industry 4.0 and having an open source platform supported by BIM to exchange information.

After an extensive literature review, it was possible to find out that there are four (4) areas such as construction site management, construction supply chain, construction progress monitoring and tracking materials that in the end when they are well managed, they can improve the material logistic on construction sites.

Only case studies have been chosen for this master dissertation that have used BIM as platform, follow Lean Construction principles and used technologies from the Industry 4.0. In addition to this these chosen case studies have also shown good benefits and were recognized in the academic field. Some of the highlights of the chosen case studies for this work are the following:

- Construction Site Management: a Lean Construction principle was applied in order to manage the storage on construction site.

- Construction Supply Chain: a method between BIM and GIS was developed to improve the visual monitoring of construction supply chain management.

- Construction Progress Monitoring: an appearance-based material classification for monitoring of operation level construction progress using 4D BIM and site photologs was developed to infer the actual status of the construction.

- Tracking materials: an automated model for materials management and control was created to track materials on construction site.

All these case studies have shown good benefits, as well some issues that must be improved, however none of them were a part of a process. It is therefore, that a new method for supply chain management in construction called ''LOCATER'' was defined in order to create an entire material logistics process that take those case studies as a base, where some principles of the Lean Construction are followed, technologies from Industry 4.0 were used, and BIM was the tool to support the platform in order to exchange information in the whole process.

In the end, the new method for the supply chain in construction, helps anyone involved in a construction project by using emerging technological tools through an open source information platform in order to improve the different areas of the supply chain, for instance, spatial or geographic data, wireless grid or automatic identification and data capture can help to have a real time location and progress tracking, as well as, collecting visual data can help to have an automatic or semi-automatic progress control about the status of the activities in order to help the human labor improve the supply chain process. Providing benefits such as quality, safety, improving productivity and efficiency, reducing the costs associated with the materials, meeting the projects schedule, among others.

Some recommendations for future works regarding to the supply chain management could be to develop a system or method that can track the material in real-time from the supplier to the construction site, as well as using the technology to track the material in real-time on the construction site. On another hand, the new method for supply chain in construction can be made step by step in a logical sequence in order to carry out the whole process, such a computer program.

It is important to realize that despite high part of the construction industry is making a huge effort to adapt to those new trends, methods and technologies. In the end everything depends on how open minded the people are to implement them and also if the company is able to afford the investment. Therefore, a first important step is to start educating students and professionals, among others, in order to create in them a conscience towards these new technologies and show them the many benefits that brings the application of the technologies, principles and methods. The idea behind this is that everybody involved in the construction industry will be able to easily apply them and make an industry competitive with high quality results, safety, sustainability, reducing cost and fulfilling the projects on time.

VI. References

Ahmed, S., 2019. A review on using opportunities of augmented reality and virtual reality in construction project management. *Organization Technology and Management in Construction,* 11(1), pp. 1839-1852.

Al-Aomar, R., 2012. Analysis of lean construction practices at Abu Dhabi construction industry. *Lean Construction Journal,* pp. 105-121.

Andersen, B., Belay, A. & Seim, E., 2012. Lean Construction practices and its effects: A case study at St Olav's integrated Hospital, Norway. *Lean Construction Journal,* 20(12), pp. 122-149.

Asgari, Z. & Rahimian, F., 2017. *Advanced Virtual Reality Applications and Intelligent Agents for Construction Process Optimisation and Defect Prevention.* Primosten, Elservier Science Bv.

Babalola, O., Ibem, E. & Ezema, I., 2019. Implementation of lean practices in the construction industry: A systematic review. *Building and Environment,* Volume 148, pp. 34-43.

Bajjou, M., Chafi, A. & En-Nadi, A., 2017. The potential effectiveness of Lean Construction tools in promoting safety on construction sites. *International Journal of Engineering in Africa,* Volume 33, pp. 179-193.

Bosche, F. et al., 2015. The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components. *Automation in Construction,* Volume 49, pp. 201-213.

Bosche, F., Haas, C. & Akinci, B., 2009. Automated Recognition of 3D CAD Objects in Site Laser Scans for Project 3D Status Visualization and Performance Control. *Journal of Computing in Civil Engineering,* 23(6), pp. 311-318.

Braun, A., Tuttas, S., Borrmann, A. & Stilla, U., 2015. A concept for automated construction progress monitoring using BIM-Based geometric constraints and photogrammetric point clouds. *Journal of Information Technology in Construction,* Volume 20, pp. 68-79.

Cheng, J. et al., 2010. A service oriented framework for construction supply chain integration. *Automation in Construction,* 19(2), pp. 245-260.

Costin, A., Teizer, J. & Schoner, B., 2015. RFID and BIM-enabled worker location tracking to support real-time building protocol control and data visualization. *Journal of Information Technology in Construction,* Volume 20, pp. 495-517.

Creative Safety Supply, 2018. *Guide 6S.* Oregon: Creative Safety Supply.

Dallasega, P. & Rauch, E., 2017. Sustainable construction supply chains through synchronized production planning and control in engineer-to-order enterprises. *Sustainability,* 9(10).

Engineers Australia, 2012. *Recommended practices for the application of Lean Construction methods to building new Australian LNG capacity,* West Perth: Engineers Australia.

Ergen, E., Akinci, B. & Sacks, R., 2007. Life-cycle data management of engineered-to-order components using radio frequency identification. *Advanced Engineering Informatics,* 21(4), pp. 356-366.

Forbes, L. & Ahmed, S., 2010. *Modern Construction: Lean Project Delivery and Integrated Practices.* 1st ed. Florida: CRC Press.

Getuli, V., Ventura, S., Capone, P. & Ciribini, A., 2016. *A BIM-based construction supply chain framework for monitoring progress and coordination of site activities.* Budapest, Elservier Science BV.

Golparvar-Fard, M., Pena-Mora, F., Arboleda, C. & Lee, S., 2009. Visualization of Construction Progress Monitoring with 4D Simulation Model Overlaid on Time-Lapsed Photographs. *Journal of Computing in Civil Engineering,* 23(6), pp. 391-404.

Guerriero, A., Kubicki, S., Berroir, F. & Lemaire, C., 2017. *BIM-enhanced collaborative smart technologies for Lean Construction processes.* Portugal, IEEE.

Han, K. & Golparvar-Fard, M., 2015. Appearance-based Material Classification for Monitoring of Operation-Level construction progress using 4D BIM and site photologs. *Automation in Construction,* Volume 53, pp. 44-57.

Hinkka, V. & Tatila, J., 2013. RFID tracking implementation model for the technical trade and construction supply chains. *Automation in Construction,* Volume 35, pp. 405-414.

Ibem, E. & Laryea, S., 2014. Survey of digital technologies in procurement of construction projects. *Automation in Construction,* Volume 46, pp. 11-21.

Ibrahim, M. & Moselhi, O., 2015. *Enhanced localization for indoor construction.* Krakow, Elservier Science Bv.

Ibrahim, Y. et al., 2009. Towards automated progress assessment of workpackage components in construction projects using computer vision. *Advanced Engineering Informatics,* 23(1), pp. 93-103.

Irizarry, J., Karan, E. & Jalaei, F., 2013. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction,* Volume 31, pp. 241-254.

Johansen, E. & Lorenz, W., 2007. Lean construction: Prospects for the German construction industry. *Lean Construction Journal,* 3(1), pp. 19-32.

Kasim, N., 2008. *Improving Materials Management in Construction Projects.* PhD Dissertation, Loughborough University.

Li, S., Wu, X., Zhou, Y. & Liu, X., 2017. A study on the evaluation of implementation level of lean construction in two Chinese firms. *Renewable & Sustainable Energy Reviews,* Volume 71, pp. 846-851.

Lu, W., Huang, G. & Li, H., 2011. Scenarios for applying RFID technology in construction project management. *Automation in Construction,* 20(2), pp. 101-106.

Montaser, A. & Moselhi, O., 2014. RFID indoor location identification for construction projects. *Automation in Construction,* Volume 39, pp. 167-179.

Navon, R. & Berkovich, O., 2006. An automated model for materials management. *Construction Management and Economics,* 24(6), pp. 635-646.

Nowotarski, P., Paslawski, J. & Matyja, J., 2016. *Improving construction processes using lean management methodologies - cost case study.* Prague, Elservier Science Bv.

Ogunbiyi, O., 2014. *Implementation of the Lean Approach in Sustainable Construction: A Conceptual Framework.* PhD Dissertation, University of Central Lancashire.

Olatunji, J., 2008. *Lean-in- Nigerian Construction: State, Barriers, Strategies and "Go-Togemba" Approach.* Manchester, International Group for Lean Construction.

Project Management Institute, 2013. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide).* Fifth ed. Newrown Square: Project Management Institute.

Saidi, K., Teizer, J., Franaszek, M. & Lytle, A., 2011. Static and dynamic performance evaluation of a commercially-available ultra wideband tracking system. *Automation in Construction,* 20(5), pp. 519-530.

Saidi, K., Teizer, J., Franaszek, M. & Lytle, A., 2011. Static and dynamic performance evaluation of a commercially-available ultra wideband tracking system. *Automation in Construction,* 20(5), pp. 519-530.

Sardroud, J., 2012. Influence of RFID technology on automated management of construction materials and components. *Scientia Iranica,* 19(3), pp. 381-392.

Sarhan, J., Xia, B., Fawzia, S. & Karim, A., 2017. Lean Construction Implementation in the Saudi Arabian Construction Industry. *Construction Economics and Building,* 17(1), pp. 46-69.

Shin, T., Chin, S., Yoon, S. & Kwon, S., 2011. A service-oriented integrated information framework for RFID/WSN-based intelligent construction supply chain management. *Automation in Construction,* 20(6), pp. 706-715.

Shi, Q., Ding, X., Zuo, J. & Zillante, G., 2016. Mobile Internet based construction supply chain management: A critical review. *Automation in Construction,* 72(2), pp. 143-154.

Stefanic, M. & Stankovski, V., 2019. A review of technologies and applications for smart construction. *Proceedings of the Institution of Civil Engineers-Civil Engineering,* 172(2), pp. 83-87.

Tagliabue, L. & Ciribini, A., 2018. A BIM based IoT approach to the construction site management. *In Bo-Ricerche e Progetti per il Territorio la Citta e l Architettura,* 9(13), pp. 136-145.

Teizer, J., 2015. Status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites. *Advanced Engineering Informatics,* 29(2), pp. 225-238.

Tezel, A. & Aziz, Z., 2017. From conventional to IT based visual management: A conceptual discussion for Lean Construction. *Journal of Information Technology in Construction,* Volume 22, pp. 220-246.

Tezel, A., Koskela, L. & Aziz, Z., 2018. Lean thinking in the highways construction sector: motivation, implementation and barriers. *Production Planning & Control,* 29(3), pp. 247-269.

Tserng, H., Dzeng, R., Lin, Y. & Lin, S., 2005. Mobile construction supply chain management using PDA and bar codes. *Computer-Aided Civil and Infrastructure Engineering,* 20(4), pp. 242-264.

Tunji-Olayeni, P., Afolabi, A., Eshofonie, E. & Ayim, B., 2018. Dataset for material logistics on construction sites. *Data in Brief,* Volume 20, pp. 1142-1147.

Turkan, Y., Bosche, F., Haas, C. & Hass, R., 2012. Automated progress tracking using 4D schedule and 3D sensing technologies. *Automation in Construction,* Volume 22, pp. 414-421.

Turkan, Y., Bosche, F., Hass, C. & Haas, R., 2013. Toward automated earned value tracking using 3D imaging tools. *Journal of Construction Engineering and Management - ASCE,* 139(4), pp. 423-433.

Wang, L., Lin, Y. & Lin, P., 2007. Dynamic mobile RFID-based supply chain control and management system in construction. *Advanced Engineering Informatics,* 21(4), pp. 377-390.

Wang, W., Weng, S., Wang, S. & Chen, C., 2014. Integrating building information models with construction process simulations for project scheduling support. *Automation in Construction,* Volume 37, pp. 68-80.

Wang, X. et al., 2013. A conceptual framework for integrating building information modeling with augmented reality. *Automation in Construction,* 34(SI), pp. 37-44.

Xue, X., Li, X., Shen, Q. & Wang, Y., 2004. *An agent-based framework for supply chain coordination in construction.* Langkawi, Elservier Science Bv.

Yagi, J., Arai, E. & Arai, T., 2005. Parts and packets unification radio frequency identification application for construction. *Automation in Construction,* 14(4), pp. 477-490.

Zhang, X. et al., 2009. Automating progress measurement of construction projects. *Automation in Construction,* 18(3), pp. 294-301.