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Exploiting the fusion between BIM and IoT

A study on available innovative technologies and their economic assessment for investment decision-making.

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This project is dedicated to the investigation of technological complementarities of Building Information Management (BIM) and Internet of Things (IoT). In this respect, several aspects of construction management were identified as being critical to project's performance, thus having priority in being addressed: project planning, defects and health and safety.

Three innovative technologies built on the digital workspace of Internet of Things were argued to represent viable solutions in mitigating risks and errors, therefore enhancing project's performance within the chosen critical aspects: Drone Laser Scanning, Photogrammetry and RFID. Consequently, scenarios were created for the implementation process of these technologies within the BIM methodology, showing case of the incremental value brought to the construction project.

The present project accounts for the reluctance of the decision makers in adopting these technologies, as a result of both the financial investment in hardware and software and the operational change within the current exiting business structure to accommodate new concepts and means of reporting. A cost benefit analysis is therefore conducted for the investment decision-making, which shows that even though the financial commitment is not modest, it will become profitable starting with the second year of operation at the most.

By signing this document, each member of the group confirms participation on equal terms in the process of writing the project. Thus, each member of the group is responsible for the all contents in the project.

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2D	2 Dimensions	**IP**	Internet Protocol
3D	3 Dimensions	**IPD**	Integrated Project Delivery
4D	4 Dimensions	**IR**	InfraRed
5D	5 Dimensions	**IT**	Information Technology
6D	6 Dimensions	**KPI**	Key Performance Indicator
7D	7 Dimensions	**LED**	Light Emitting Diode
AEC	Architecture, Engineering and Constructions	**LEED**	Leadership in Energy and Environmental Design
AOA	Angle of Arrival	**LiDAR**	Light Detection and Ranging
API	application programming interface	**LTE**	Long-Term Evolution

BIM	Building Information Modelling	**M2M**	Machine to Machine
BLE	Bluetooth Low Energy	**MC**	Main Contractor
BREEAM	Building Research Establishment Environmental Assessment Method	**PSLP**	Phase Comparison
CAD	Computer Aided Drawing	**R&D**	Research and Development
CBA	Cost/Benefit Analysis	**RF**	Radio Frequency
CEO	Chief Executive Officer	**RFID**	Radio Frequency Identifications
DGNB	German Sustainable Building Council	**RSS**	Radio Signal Strength
DoD	Department of Defence	**RTOF**	Round Time Of Flight
EU	European Union	**SARD**	Surplus And Recitative Data
GDP	Gross Domestic Product	**SM**	Site Manager
GNSS	Global Network Satellite System	**TDOA**	Time Difference Of Arrival
GPS	Global Positioning system	**TNU**	Taiwan National University
H&S	Health and Safety	**TOA**	Time Of Arrival
HKD	Hong Kong Dollar	**UAV**	Unmanned Aerial Vehicle
HPP	High Precision Positioning	**UI**	User Interface
HSE	Health and Safety Environment	**UK**	United Kingdom
HVAC	Heating, Ventilation and Air Conditioning	**UUID**	Universally Unique Identifier
ICMP	IoT control and monitoring platform	**UWB**	Ultra Wide Band
ID	Identification	**WLAN**	Wireless Local Area Network
IMU	Inertial Measurement Unit	**WRA**	Work Related Accident
IoT	Internet of Things		

1. Introduction

1.1 Background and justification of research

Through construction, human needs relating to accommodation, infrastructure and services are satisfied by the supply of appropriate structures in which, activities relating to these needs can be conducted. The construction industry is seen by many countries as an important part of the economy. Yet, the construction industry, when compared to other industries it is seen as being wasteful, in regard to resources allocation, and behind at adoption and implementation of advanced solutions. (Department for Business, Innovation and Skills , 2013)

According to Christensen, et al., (2015), the construction industry is characterized by a reluctance to change that comes from a rooted tradition of knowledge transfer. It argued that, in the construction industry, information is passed from one entity to another following a preset set of rules, such as “learning by assisting” or “learning only for the team”. Christensen, et al., further argues that this allows for data produced in one project to be lost when another project is started, leading to a re-invention of the wheel.

Building Information Modelling is considered as an innovation in the construction industry worldwide, and it is seen by researchers and professionals as a way for the industry to become efficient. The core of ethos of BIM focuses on collaboration between project stakeholders. This contradicts the traditional methods of project management and moves to a new, completely changed method of working. Sharing of information and resources, and consequently sharing of risks, is expected to increase efficiency, performance, resource allocation and further client satisfaction.

With the advancement of Information Technology, new solutions that make use of internet have appeared for the construction market. Looking at smart thermostats, smart taps and indoor environment meters and controls, the term of Smart Buildings has appeared. This lead to the development of a new concept, Smart Cities. Within Smart Cities, all elements are connected between each other, produce and transfer information and are aware of each other. The interest that corporations and government bodies place on these systems concentrates on an efficient use of available resources for maximization of productivity, profitability and use satisfactions. The communication between the elements, sub-systems and systems is conducted through internet, where the notion of Internet of Things comes from. (Alavi, et al., 2017)

1.2 Research problem

Researchers and professionals within the construction industry, such as IBM (2017), argue that a collaboration between BIM and IoT would lead to positive results for construction projects as data produced on the site by various technologies can be transferred via a connectivity bridge to a central system for processing and storage. Using the two technologies, data would be available to all stakeholders faster and easier, leading to a reduction in errors and incidents.

One part of this project is dedicated to reviewing and exploring means in which BIM and IoT can communicate to one another through sensors, and what type of metrics and applications are attributed to this process. The other part is projected for exploring potential costs and benefits of employing the proposed technologies, from a main contractor's perspective; this latter analysis is intended for the investment decision making of construction companies in order to balance out the input with the output.

For these two major directions of the project, the investigation will be structured according to the following research question:

How can frameworks of BIM and IoT be aggregated and conceptualized, to improve project's performance areas and what are the costs and benefits of employing these technologies?

1.3 Objectives

The intent of this report is to explore existing technological frameworks that address critical aspects in a construction project and how these innovative technologies can be employed by a company.

The report will commence by analyzing the available innovations in the construction industry under the form of Building Information Modelling and Internet of Things and the challenges and benefits associated with working with these solutions. The report will study the conditions under which these two technologies can work together by looking at available technologies that make use of both concepts.

Furthermore, data from available market reports in the construction industry will be analyzed to observe the critical areas where there is need for better management and improvement.

As there are various limitations that apply to this report, not all the technologies available under the BIM and IoT umbrellas will be used in the analysis. Similarly, when looking at areas of great importance in construction project, a selection of three areas for examination will be done in order to observe the manner in which these will be affected by adoption and implementation of innovative solutions.

The second biggest objective of the report is to conduct a cost-benefit analysis of employing these technologies, for the purpose of investment decision-making, which is expected to deliver a result for solutions prone to yield best deliverables.

2. Methodology

2.1 Theory and research strategy

When conceptualizing the holistic methodological process for the research project, noteworthy is the direction for theory and research. Depending on the type of the theory, one can view the steps of the process as iterative, thus allowing a flexible approach of going back and forth with the findings, so as to refine and revision the theory which will lead to greater validity of the findings.

Bryman & Bell (2015) distinguishes between deductive and inductive theory. Although with a more technical nuance, the authors of this project posit that the *deductive theory* is the one made used of. 'Deductive theory is the most common view of the relationship between theory and research. The researcher, on the basis of what is known about a domain […] deduces a hypothesis that must be subjected to empirical scrutiny.' (Bryman & Bell, 2015)

In these lines of thought, the process of the present project followed the same structure: after careful consideration and synthesis of the literature review, the authors have come up with a new concept – embedded site connectivity measure, which will be further subject to scrutiny. The main difference here is that the scrutiny will be made within empirical context, but rather tested with a feasibility study, including a Cost Benefit Analysis within the business usage.

As mentioned earlier, the implications of knowing the direction of theory and research are related to the iteration of the steps involved. If the findings of the feasibility study do not meet the conditions of the technical concept, further investigation will need to be undertaken. This process will involve the use of inductive theory, whereas the researchers infers the implications of the findings upon the initial work that fostered the entire concept. (Bryman & Bell, 2015)

2.2 Research design

The deductive study will be framed in the project as an explorative design study. The explorative design study infers the studying of the phenomenon in order to come up with more precise details of its constituents (Kuada, 2010); this implies that the studying of the new technical concept, together with its feasibility results will lead to a better visualization of the components, be they physical - technical components, financial – price, logistical – distribution channels or social – workers' training, or legal – liabilities.

'An exploratory case study is usually recommended for studies in which the investigator anticipates that there are many more variables of interest than possible data points. It is also found useful when the researcher expects to rely on multiple sources of evidence with unpredictable information […] Such a case study helps to define the questions and hypotheses of a subsequent study or at determining the feasibility of the desired research procedures. They therefore serve as precursors to a more comprehensive study that may use a functionalistic/analytical methodology.' (Kuada, 2010)

Exploring through the literature review about the IoT, BIM and KPIs, many data points have been identified as useful in creating the new technical concept. The data points were only taken under consideration if the technologies were deemed as being complementary.

2.3 Data Collection

The data collected for conducting this project is secondary data. 'In business and management, secondary analysis is of increasing interest to researchers. Traditionally, it has been the province of economists to analyze secondary data and draw conclusions about how it relates to the world of business.' (Bryman & Bell, 2015)

Amongst the first ones to consider the advantages of using secondary data are Dale, Arber & Proctor (1988), who took note of the needs of the students conducting undergraduate or graduate projects. Their observations make referral to the cost and time, allowing the prospect access to high quality data, the opportunity for a longitudinal analysis as it is the case for this project where innovative concepts are being revealed throughout time and more time for data analysis. (Bryman & Bell, 2015) The sources of information for data collection varied, and includes: Google Scholar, ProQuest (access via AAU), Academia, Research Gate, American Society of Civil Engineers (ASCE Research Library), Science Direct, Emerald Insight, ICONDA and ARCOM databases for scientific and journal articles, specialty magazines and articles with regards to the embedded site connectivity, web content for competing technologies and last minute developments, methodology books such as Bryman & Bell (2015) and Kuada (2010).

With all the benefits that the secondary data brings to the students for conducting their projects, worth mentioning in these regards are the limitations it infers to the project. However, this aspect will be covered in the Project's Limitations Chapter.

2.4 Data analysis

For employing and institutionalizing a new technology in the market, Munir & Phillips (2005) used discourse analysis on the Kodak case study. This project makes use of the discourse analysis as well, as this type of analysis is ideal for exploration a new concept. (Munir & Philips, 2005)

Built on the Kodak case, Munir & Phillips (2005) have defined discourse analysis as 'an interrelated set of texts that brings an object into being, along with the related practices of text production, dissemination and reception.' This type of data analysis includes 'structured and systematic study of texts – including their production, dissemination and consumption – undertaken […] to explore the relationship between agents and the production of social reality'; the systematic study of texts is a reference to any type of registered communication, either written or spoken words, pictures or videos. (Munir & Philips, 2005)

Along with this type of data analysis, there three constructs associated: concepts, objects and subject positions (Munir & Philips, 2005). Applicable to the topic of this project, the authors have identified the concept as the embedded site connectivity, whereas it is inferred that the site has the ideal conditions for adopting such technology. The object will be the drone, whose mainframe supports a chip for internet connectivity and data transmission. The subject positions will be correlated with their generality for site adoption, which will result from the feasibility study.

In the framework analysis proposed by Munir & Phillips (Munir & Philips, 2005), there is distinction between several discourse strategies: embed technology in existing practices, create a new role for an existing actor (in Kodak's case – the photographer), new institutions, and modifying new institutions within the field. This project adopts the first discourse strategy, embed technology into existing practices.

The subject positions are very important in this type of analysis, as they allow the agents to participate in the process in a certain way; this has great implication in the overall strategy, as the agents can influence how the object is being created. Thus, another important dimension added to this type of analysis is the perspective of the agents; in this case, the agents assume the role of manufacturers.

In order to obtain a better visualization of the creation process, the discourse analysis will be complemented by *a contextual design*, where scenarios will be built for prototyping the usage of the object – the drone. Following the contextual design, a *feasibility study* will be conducted within the business context to reveal the implications this new technology will bring to the markets. These complementary processes to the analysis do not make the claim that discourse analysis is always prone to include either the contextual design or the feasibility study, but rather adding an extension to it in light of the technical degree of the project.

3. Thematic literature review

3.1 Search protocol

For the construction of this report, the authors have employed a thematic search protocol focusing on a specific topic and area in the construction literature.

When comparing to the systematic literature review, where the researcher must conduct a thorough investigation of the literature and extract the research problem following his perusal, the thematic literature review starts from an already existing research problem and focuses on finding literature that aids in the analysis of the research statement.

The following lines will explain the employed methods for the search of literature used in the creation of this report.

Availability of research literature on Building Information Modelling and Internet of Things is relatively scarce as these technologies are considered rather new and constraints associated with each of them has hindered the creation of data through intensive analysis.

Keywords like “Internet of Things”, “IoT”,” innovation”, “BIM”, “Building Information Modelling”, “Business”, “adoption”, “challenges and benefits” and “cost-benefit analysis” were used in the formation of search strings.

Gathering literature resources was done with the use of various journal article databases like Google Scholar, ProQuest (access via AAU), Academia, Research Gate, American Society of Civil Engineers (ASCE Research Library), Science Direct or Emerald Insight. These ones were the most used databases for obtaining secondary data literature for research purposes in creating this report.

Search strings were created through combinations of keywords and phrases resulting in the following strings: “BIM AND IoT”, “BIM AND IoT AND Construction Businesses”, “Innovation AND Construction Businesses”, “IoT OR BIM AND Adoption”.

The search strings above are just a small number of the ones employed in the search for literature. Some search strings employed the full term of the technology instead of the abbreviation term resulting in strings like “Building Information Modelling AND IoT” or “Building Information Modelling AND Internet of Things”.

As the construction of the report advanced and the search for literature shifted from general literature on the technology to more in-depth and thematic literature, the search strings changed to accommodate the investigated area or subject. As such, the team used specific terms found in the first search for literature and created new search strings such as "Laser scanning AND Construction projects", "Drone scanning AND Construction projects", "RFID AND Construction projects", "RFID AND Health and Safety AND Construction projects" and other.

It should be noted that using a thematic literature review can be considered a slightly "relaxed" process of finding information and as such, a listing of all the used search strings in finding literature for this report would consume too many resources to create. The above search strings are the ones that have produced the largest number of available resources.

Screening of resulting literature in every search was done in steps by first choosing the articles or journals that have been reviewed by peers. As technology is changing rapidly, we have focused on articles that have been released after 2000 and up to 2017, this being the second stage of literature screening. Very few articles that were released before 2000 and were considered of high value, were considered for use in the first part of the report to explain general trends of the technology or to elaborate on the history of the technology

For the third stage of the screening process, articles that were not relevant for the construction industry but were relating to BIM and IoT technology (e.g. "Using BIM in hospital facility management" or "Advancement of IoT in the manufacturing industry") were discarded as the report focused on the construction industry and construction projects.

Search engine Google was used to inquire for various information sources on the researched topics in the form of reports, technical articles, periodicals and the like that would offered different views on the topics.

With the use of Google, two other journal databases emerged and produced few valuable articles for this report: ICONDA and ARCOM.

3.2 Literature synthesis

3.2.1 Building Information Modelling

3.2.1.1 Definition and understanding

Available literature does not give an exact date when the concept of Building Information Modelling has first appeared, but we can understand that the basic thinking behind today's version of BIM was available at the start of the 60's when research engineer D.C. Engelbart prepared a report for Headquarters Air Force Office of Scientific Research in US. In his report, Engelbart has described a fictional situation in which an architect would use his work computer:

“the architect next begins to enter a series of specifications and data – a six-inch slab floor, twelve inch concrete walls eight feet high within the excavation, and so on. When he has finished, the revised scene appears on the screen. A structure is taking shape. He examines it, adjusts it, pauses long enough to ask for handbook or catalog information from the clerk at various points, and re-adjusts accordingly. He often recalls from the "clerk" his working lists of specifications and considerations to refer to them, modify them, or add to them. These lists grow into an ever more detailed, interlinked structure, which represents the maturing thought behind the actual design.” Engelbart (1962)

So far, researchers have not managed to establish an universal agreed definition for building information modelling and as such, each researcher or specialist in the field tends to use its own definition of BIM when working with this technology; the definition defers from one specialist to another and also from one industry to another.

For example, according to Alshawi and Ahbabi (2015), building information modelling is just a software tool that allows for better management of design and construction procedures due to continuous breakthroughs in the field of CAD. This understanding of BIM differs from what other scholars’ view of BIM which is considered to be a disruptive innovation pushing for a shift in the methodology and processes in the architecture, engineering and construction industry. (Poirier, et al., 2015) and supported by (Crotty, 2011).

Everett Rogers (2003), argues that the term innovation portraits “an idea, practice or object that is perceived as new by an individual or other unit of adoption” and the spread of innovation represents the “process through which an innovation is communicated through certain channels and adopted over time among the members of a social system”.

Few disruptive innovations have affected the construction industry throughout time and it concentrated mostly on technology. Gladson (2005) advocates that building information modelling cannot be considered a disruptive innovation as it gradually evolved from the need to reduce and further to eliminate scheduling errors in project management.

The leaders of the construction industry view BIM with good eyes and fully understand the challenges and benefits of its adoption in an organization and in the industry.

HOK, a multinational design, planning and construction company, considers that:

"BIM is the first truly global digital construction technology and will soon be deployed in every country in the world. It is a 'game changes' and we need to recognize that it is here to stay – but in common with all innovations, this presents both risks and opportunities" **Patrick MacLeamy, HOK CEO.**

Per the Construction Industry Council in UK, their view upon BIM is that:

"BIM will integrate the construction process and, therefore, the construction industry. But it will also have many additional benefits for the nation. It will enable intelligent decisions about construction methodology, safer working arrangements, greater energy efficiency leading to carbon reductions and a critical focus on the whole life performance of facilities (or assets)." **Graham Watts, OBE, CEO CIC.**

The above statements and the analyzed studies and research for this paper, pushes for the idea that BIM is a cooperative method of working, supported by the existing technology that allows for a more systematic way of designing, constructing and managing assets of facilities. Building information modelling brings together valuable information about product and asset and also a 3D CAD model that can aid to properly manage the gathered information for the entire length of a project's life, from inception to commission and operation. (HM Government, 2012)

According to Sanchez et. al. (2016) and supported by Shou et. al. (2015), BIM can also represent a methodology that organizes project design and information in a digital format during the life span of a project and incorporates a series of linked guidelines, procedures and components.

At the basis of building information modelling lies computer aided design which is used for the representation of the model in digital format and for the diffusion of knowledge between partners of the project.

Perusing the available literature, the authors of this paper have concluded that Building Information Modelling can be considered a technological innovation in the construction industry due to its characteristics of collaborative work, knowledge sharing and diffusion, multiple dimension modelling and extensive use of IT technology. These characteristics are in contradiction with the traditional layout of construction project contracting as they promote goal sharing and overall objective focus rather than individual profit and responsibility. Building Information Modelling comes in the form of a methodology of work to be used in conjunction with a software solution capable of covering BIM tasks. This description follows the conclusion of

Gladson (2005) that BIM is an innovation, but not a disruptive one. We consider that Building Information Modelling developed out of the need to reduce wastage of resources in the construction industry and increase quality, safety and client satisfaction, as there is a general view that the construction industry, at an international level, is one of the least efficient industries and in one article from Themidnightlunch.com (2015) has even been named as "the last craft industry".

For the rest of the paper, we will consider that Building Information Modelling is an innovation that comes in the form of a methodology for management of produced data in a construction project, from the inception phase of a project to commissioning and further to operation and maintenance phases.

3.2.1.2 Computer-Aided-Design Modelling

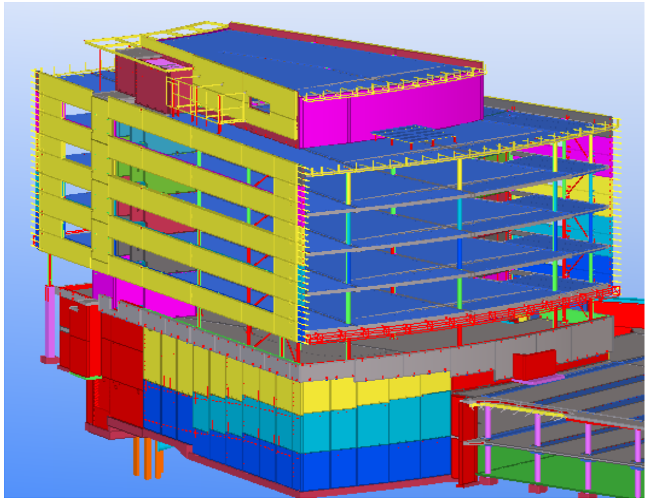
CAD modelling tasks were able to be handled as early as 1970s when models were represented digitally in 2D formats leading to a great appreciation by production and construction industries leading to an increase in productivity. Today, some of the software solutions developed then are still the basis for the new software products that are being released today. (Cohn, 2010)

Drafting of construction projects is done in engineering and architectural offices through the use of 2D and 3D CAD representations that later will be exported to the required format, either digital, for use in conjunction with other software solutions, or paper for use in various activities, for example: on site works management.

The advancement of information technology which led to the production of sturdier electronic devices has permitted specialists the use of 3D representations of the project for various onsite activities, allowing them to easily observe issues in the project before proceeding with the works.

Unfortunately, particularities of the construction industry make it a highly conservative one and as such the use of technology for onsite activities is still at minimum levels, when comparing to the use in drafting offices, as the condition present on a construction site are harsh. Workers rely heavily on the use of 2D printed representation of the construction model.

Specialist vendors advocate for the use of 3D models over 2D models as they consider these as being, to some extent, obsolete. 3D CAD models are portrayed to contain all the required information to build an object – information about sizes and shape, cross sections and connecting to other elements. The use of 3D models can bring a better understanding of the requirements of the physical model and issues that can pose a financial burden later in the project can easily be observed at an early stage. (Tekla Structures, 2016)



Picture 1: 3-D Model by Tekla Structures (Tekla Structures, 2016)

Building information modelling in not only about the 3D models that are used. A building information modelling model starts with the first 3 spatial dimensions (X, Y and Z) and as the requirements for information increases, the number of dimensions that the model has will increase, leading to a 4D, 5D, 6D (and so on) model. In this context, the term dimension does not refer to physical dimensions, but it refers to layers of information.

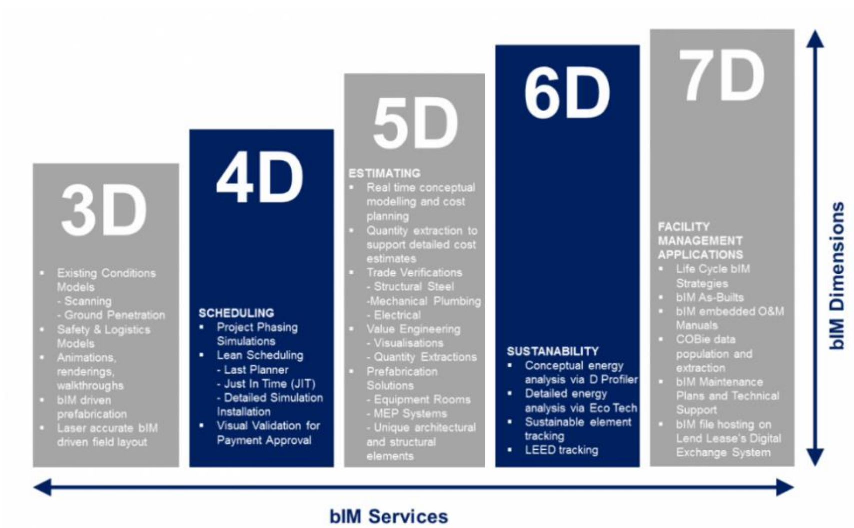


Figure 1:Dimensions of BIM (Waldeck Consulting, 2016)

With every dimension that is added to the BIM model, so the strains on the model increase as currently there is no software capable of handling all dimensions represented in Picture 2. Accommodating many dimensions, for example 7, will require the use of several software solutions.

It should be noted that, when working with multiple dimensions, one requires a clear definition of the parameters for each the dimensions. The first 3 dimensions provide the standard information that defines the shape and size of the element to be represented virtually while the following two dimensions represent the cost and time requirements to build the required element. The 4th and 5th dimensions take information from the construction industry where studies on the time required to erect the required type of element and the costs associated with it have been conducted and benchmarked against countless number of projects. Looking at the 6th and 7th dimensions, one can argue that these have yet to be considered full dimensions of BIM and that these add to the marketing campaign of a company.

If we are to look at the 3-main green building rating systems, LEED, DGNB and BREEAM, a comparative study on these three shows that the weight of the evaluation criteria in each is different. There is not definite, standard form to express sustainability and facilities management and as such, working with dimensions, that represents information on these, differs from project to project and from company to company. (Hamedani & Huber, 2012)

Interoperability allows applications to move amounts of data from one software solution to another easing the workflow and promoting automation. For example, a 3D model can be created in one software and then exported to another software for conducting the planning analysis and cost analysis of the project. There are various vendors that offer software products with various specification and for different areas of the project. Interoperability requires that all vendors, regardless of their area of expertise, use an Industry Foundation Class data model (IFC) which is a neutral data model allowing the use by all vendors and permitting the exchange of basic information about the project. (Solibri, 2016)

3.2.1.3 Collaborative work

The construction industry worldwide is highly reluctant at adopting innovation and many consider that the industry is still highly conservative where the use of "this is how it was done before, this is how we will do it now" is still considered a general rule. Due to the fragmented feature of the industry, many organizations tend to repeat mistakes in every project as information

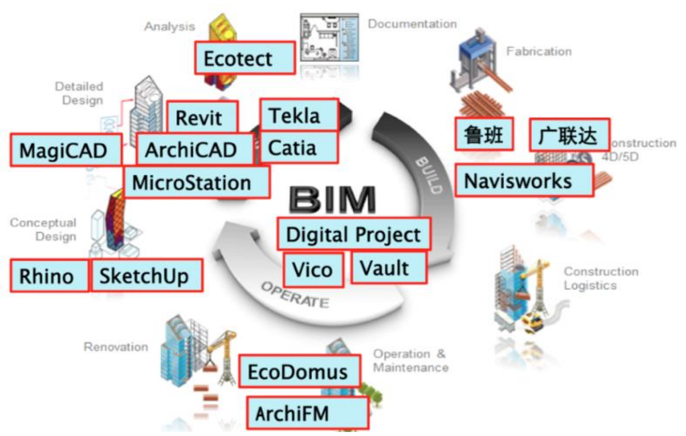


Figure 2: BIM Solutions **Invalid source specified.**

is not properly diffused from one project to another and from organization to industry and vice versa. (Christensen, et al., 2015).

A basic requirement of BIM is the use of collaboration between the parties involved in the design, build and operation of the project. The collaborative feature of BIM can be considered a strain for the project as there is a high level of inter-organizational collaboration and inter-personal collaboration required.

Through communication and collaboration, a “culture of sharing” is promoted in the projects where BIM is present and the traditional layout of contracts to be changed. Through the new layout, partners in projects are looking towards saving costs, improving quality and client satisfaction, improving efficiency and promoting innovation while still maintaining the targets of each of the parties. Collaboration has also pushed for the creation of a more flexible and fluid approach of responsibilities and also for new procurement methods, such as IPDs. (Alshawi & Al Ahbabi, 2015)

BAM Construction (2016), a large player on the construction industry in the United Kingdom and specialist in the use of building information modelling argues that the involvement of parties as early as possible in the conception and design of the project can have a positive result on the end-product as specialist can easily collaborate and identify issues early in the conception phase or design phase, thus reducing number of work hours spent on re-works and also increasing the quality of the project and client satisfaction.

Amongst many existing gaps in the proper adoption and implementation of Building Information Modelling in an organization, personnel management and information and communication have been rated as the highest threats to a good adoption and implementation of this solution. (Murphy, 2014)

Eadie et al. (2015), in a study on the level of BIM adoption for the United Kingdom, have concluded that, although having great levels of understanding and knowledge on the benefits and challenges of adopting and implementing BIM, the construction industry in this country is highly fragmented, leading companies to work on different standards, thus reducing the percentage of BIM implementation.

Applicable to BIM and to any innovation that has the potential to introduce efficiency and increase productivity, change of methodology and processes is required in great amounts to secure the success of the new technology or innovation. Change management is considered of great importance to any organization or industry searching for introduction of new solutions.

3.2.1.4 Value for stakeholders

A shift from a 2-dimensional design to a 3-dimensional design would allow the organizations involved in the phases of the project to work with vaster amounts of information and to easily transfer knowledge from one stakeholder to another. Working with 3D models would allow them to better design and calculate, make the correct solution choices and control the safety and quality in a project.

A shift from a traditional way of working and contracting can be seen as daunting, however, BIM can bring to the participants in a project, increased benefits while adding value to the project.

3-Dimensional design v. 2-Dimensional design

As stated above, a change from the traditional 2D design would allow the designers to create better representations of the project while enhancing the visualization and understanding of the elements. (InfoComm International, 2016)

A case study from the municipally of Manchester, United Kingdom, showed that implementing BIM for the Central Library project, gave the participants in the project the chance to reduce costs of up to £250k by better understanding, visualization and diffusion of knowledge through the use of 3D representation of the project. Part of the saving was attributed to a reduced number of meeting hours. (BIMTask Group, 2016)

Incompatibility detection and Area calculation

Analysis of needs and specifications of every element employed in the project can be done with easy by the drafting teams. Conducting an incompatibility detection analysis, the architectural and engineering teams can spot elements that are misplaced within the space of the project in the early phases of the project, thus reducing resources spent on re-design and re-work that can amount of up to 10% of a contract value. (Guangbin, et al., 2012)

Construction Information bases

Using a variable 3D model gives the stakeholders the opportunity to create databases for the project, that can be shared during the lifetime of the project.

If created at the start of a project and populated during its design, construction and commissioning phase, will allow the facility management teams to better operate and maintain the project once it is finished and transferred to the client.

With the adequate information, facility management teams can increase the quality and client satisfaction while bringing down operational costs. (InfoComm International, 2016)

Health and Safety

Protection on the construction site is a major factor to consider when designing and construction a project. Business can be disrupted by any work-related accidents and the repercussions can affect all the stakeholders.

Introducing info on critical areas of a project into a 3-dimensional model, project managers can better understand and coordinate on-site activities and consider appropriate solutions to reduce, remove or mitigate the risks.

Making use of Building Information Modelling for the Manchester Town Hall Complex Refurbishment project, the municipality of the city of Manchester, UK, has increased the safety of the site activities, reduced work-related accidents and improved workmanship. Feedback provided by participant sub-contractors showed that the workers respond better to 3-Dimensional representations than to 2-Dimensional representations. (BIMTask Group, 2016)

3.2.1.5 BIM and the Business

Innovation in construction

For a long time, it has been a known fact that the construction industry, national or international, runs in a very conservative manner, basing itself on procedures and methods that have been developed and analyzed in the past, producing documented results that have been tested over and over.

Time estimating and management in the construction processes is one of the factors of the project planning that affects the overall performance of the project. “Planning is performed in order to decide upon organizational goals and project means and solutions.” (Gladson, 2005).

The traditional way of planning a project and passing the info from one stakeholder to another progressed with increasing complexity of projects and increasing demands from the clients. Computer-Aided-Scheduling software allowed project managers to better manage and sequence work procedures for various projects and create better results, but with increasing number of tasks so does the complexity of creating accurate project schedules, pushing decision makers to question existing solutions and look towards new technologies. (Gladson, 2005).

As stated in the previous pages, the construction industry holds a great portion of an economy's GDP, however, when comparing to other industries, for example: manufacturing or services, the construction industry can be characterized as being wasteful and lagging back in productivity. (Designing Buildings Ltd. 2016, 2016).

A report issued by the government of UK in 2013, it showed that the construction industry, when benchmarked to other industries in the economy, has had the lowest level for Research and Development spending. Looking at the figures, while other industries have recorded an average expenditure of £500m, the construction industry recorded about £22m. (Department for Business, Innovation and Skills , 2013)

Having a history of over 20 years in the construction industry as an omnipresent term and being defined by Oslo Manual as being a technological novelty, Building Information Modelling is constrained by the limitations in the construction industry towards innovation.

From the same report released by the United Kingdom's government, it could be observed that around 25% of organizations do not invest in innovation and implementation of it as the general feeling is that there is no requirement to do it, while around 40% of non-innovating firms argue that the barriers in the construction industry are to be blamed for the low score in R&D. Firms that have made investments in research and development and allocated funds for innovative solutions have acknowledged that R&D plays a critical role in maintaining the market share but do argument that the low scores recorded by this country for innovation implementation are due to little demands from the client, limited availability of founding and unstable market environment. (Department for Business, Innovation and Skills , 2013)

As agreed upon by Olatunji (2011),Murphy (2014), Poirier et al. (2015) and other researchers, amongst the variety of factors for which innovative solutions, such as Building Information Modelling, in the construction industry are hindered in their way to implementation, the below ones can be considered the general ones:

- Little collaboration and communication between organizations due to the fragmented nature of the construction industry
- Procurement and the ways to do it
- Little data creation, implementation and delivery

- Little cost/benefits analysis for construction innovations
- Limited client spending

On a similar note, Department of Business, Innovation and Skills in the United Kingdom (2013) argues that the top three factors that have influenced the growth and implementation of innovation in this country are:

- Low Return on Investment for innovation funding organizations
- Low levels of collaboration between stakeholders, and
- Low levels of available data (Department for Business, Innovation and Skills , 2013)

Innovation in organizations

In a study by Brynjolfsson and Hitt (1996), the authors have observed that investment in information technology is directly proportional to the development of the firm and its procedures and business, thus arguing that improvements in the productivity in an organization is linked to the investments that the organization has made in its information technology systems.

Investments made in organizations are drawn up, analyzed, proposed and promoted by the management of any organization as a response to the external market stimuli and to the internal stimuli. The liability for selecting the adequate measures that will ensure the organization will maintain or even increase its market share lies with the upper management of any firm. (Simpson, 2012)

Wisdom et al. (2014) are defining the adoption process of any solution as a complicated procedure to proceed with a limited or a whole implementation of a solution. The adoption procedure requires the identification of a need in the organization, the move towards an answer and last with a decision to execute the found solution.

Olatunji (2011) insists that the acquiring of Building Information Modelling solutions for firms and projects has a great prospective to increase the productivity and performance while, at the same time, improving the contentment of all the parties involved in the construction process, a prospective that hasn't been met in the construction industry before.

As a core characteristic of BIM is extensive collaboration between the participants in a project, it is considered that this innovation will reduce the fragmentation that currently exists in the construction industry by promoting shared mentality, shared resources and interoperability between organizations and systems. (Olatunji, 2011)

“Effective communication is a significant factor in any successful project” (Gorse & Emmitt, 2007). Existing literature on Communication is great and offers a myriad of models and explanation for every communication channel. An overall agreement stands forth that “communication effectiveness relies on the success of closing the transactional distance between parties” (Gladson, 2005). Moore (1997) has developed one of the most famous and important diagrams that explains transactional distance as a “psychological distance” present between persons that engage in communication activities.

Gladson (2005) explains that one of the positive aspects of using BIM solutions is the increase in the level of product information quality and the reduction of transactional distance between project stakeholders.

Eadie et al. (2015) supported by Gould (2010) and Deutsch (2011) affirm that BIM can be seen as a product directed towards the management aspects of a project that is placing together the technological and social issues of the construction process. They view BIM as having an overall perspective.

As with any existing technological innovation on the market today, BIM adopters and implementers face opposition from additional need of education, different skills and key personnel and a new approach. These aspects are expected to be drivers for BIM and enhance its results. (Olatunji, 2011).

A different perspective on the adoption and implementation of BIM is offered by sceptics of this innovation. They see it as just being a “overhyped product” that is only valuable to large-scale projects and that it can be put in place by large organizations capable of considerable investments (Bruning, 2011). Others view BIM as being a design tool that has been developed from the existing CAD systems, allowing the user to add data to the elements in the model. (Crotty, 2012)

Building information modelling brings to the construction industry the advantage to increase the staff recruitment rate by opening new positions in the organizations. Critical staff is required for a good implementation of the methodology, as this staff will be trained and educated in the implementation, use and maintenance of the Building Information Modelling systems. New positions of BIM managers, facilitators and operators will appear in the organizations with the adoption of the new methodology. These roles can be occupied by new employed personnel or by existing one. If using outside personnel, organizations will aid the economy at reducing the unemployment rate. By using existing personnel in the organization, there is a risk that with poor management, the employees taking the additional tasks of BIM will be close to flat lining.

Challenges and Benefits of BIM

As stated above, one of the reasons for which the construction market in the United Kingdom has a low rate of innovation growth is that there is limited knowledge on the Costs/Benefits of adopting an innovation for the organization and the project.

To make sense for investors to allocate funds for adopting and implementing a solution, they need to be provided with a solid economic foundation for their decision. In the same manner, end-users who are to make use of the innovation need solid evidence of the benefits the innovation will bring to their work.

A thorough Economic Analysis is needed for any organization considering adopting a new technology to maintain its competitiveness. Analyzing the studied literature for this report, it could be observed that the available data on the adoption and implementation of BIM, as well as, on the Costs and Benefits of it, is scarce due to the unwillingness of companies and clients to invest in innovative solutions as a result of limited data to prove the benefits of it. This can be seen as a vicious circle of Building Information Modelling.

This report is constrained by several resource limitations that did not allow the team to conduct primary data gathering from professionals in the construction industry. In order to understand what it means to adopt, implement and use BIM from a financial point of view; the team will make use of secondary data available through research by specialists in the field, under the form of case studies and analysis.

In a research by Lu et al. (2014) on the CBA analysis of BIM it was observed that, comparing to the traditional methods of construction, where the distribution of effort was concentrated in the construction phase, with the use of Building Information Modelling, the distribution of effort was shifted to the design phase.

Figure 3 offers an understanding on the impact of this shift has on the cost of changes in a project. The possibility of design change is decreasing with the advancement in the project while the cost of the change increases with time.

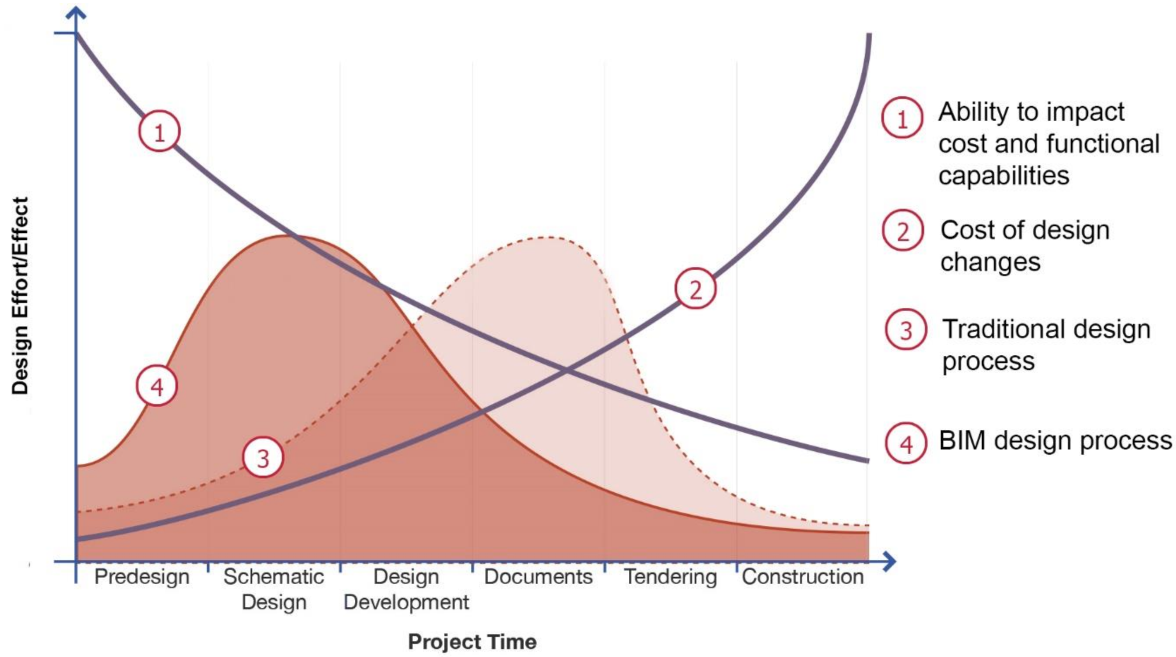


*Figure 3: Time-effort distribution curve (*MacLeamy Curve*) between BIM and Traditional projects. (Lu, et al., 2014) adaption from (Macleamy, 2004)*

	Non-BIM Project	**BIM Project**
Location/ District	Cheung Sha Wan, Kowloon	Wong Tai Sin, Kowloon
Type of building	Non-standard domestic building	Non-standard domestic building
Contract sum (Foundation stage, HK$m)	102343	N/A
Contract sum (Building stage, HK$m)	505,3	384,0
Gross site area (m^2)	10.188	12.000
Gross floor area (m^2)	53.184	42.480
Starting date	Feb. 2007	Sep. 2008
Design stage	Aug. 2009	Jun. 2010
Progress	Completed	Accomplished 85%
Completion date	May 2013	Continuing

Table 1: Project basic information, adaptation from Lu, et al., (2014)

In their study, Lu et al. (2014) have analyzed two construction projects from the Hong Kong area, one that has had BIM implemented and another that has followed the traditional AEC processes. The two projects, as similar in size and shape followed the same construction technology and the same Design and Build procurement process. Table 1 offers a comparison between the two projects.

In their study, Lu et al. (2014) have concluded that the shift in the time-effort curve has pushed for an increase in costs of over 45% for the design phase when compared to the traditionally built project. They have attributed the additional costs to the requirements of Building Information Modelling for hard and soft resources, as well as educational resources. The 45% increase in costs represented a little over 100HKD/ m^2.

The analysis for the two projects case study showed that the increase of 45.9% in the design phase has created a decrease in the construction phase of the BIM project of around 8.6%. This decrease, although considerable smaller that the increase in costs, accounts for a little over 590HKD/m^2 saving in costs. (Lu, et al., 2014)

As an overall, comparing to the traditionally built project, the BIM project allowed for a decrease in costs for the design and build phases, of 6.92% which translates in 490.86HKD/m^2. (Lu, et al., 2014)

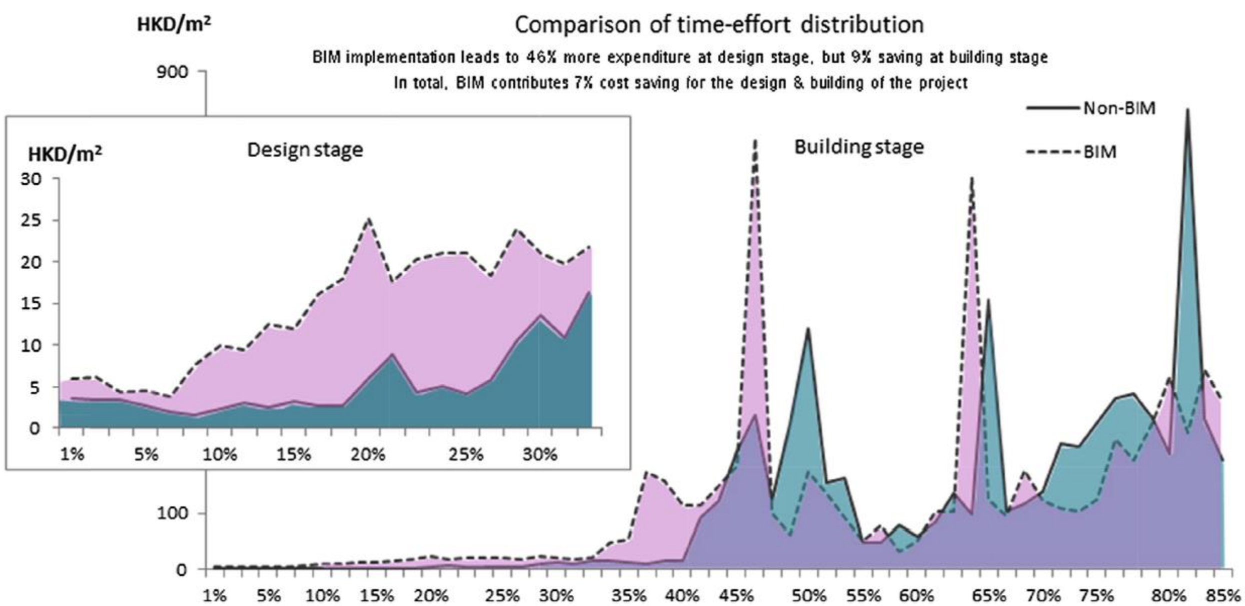


Figure 4: Graphic Summary of CBA of BIM vs. Non-BIM (Lu, et al., 2014)

3.2.2 Internet of Things

3.2.2.1 Definition and understanding

In recent years, the number of research papers and articles available on the topic of Internet of Things (IoT) has considerably increased. Looking at searches in the search engine ProQuest, the number of released papers exceeded 16000 in 2016, in comparison with almost 400 papers in 2010, showing an increased attention towards this topic (ProQuest, 2017). The high number of papers focuses on new and existing technologies, that, through the use of an internet connection have allowed specialists to make use of them in areas of the industry where these were not previously considered. Looking at Figure 5 we can observe the distribution of the research papers on Internet of Things, from 2010 until 2016, in just one search engine, ProQuest.

Today, many industries are taking advantage of IoT in the manufacturing, supply chain management, delivery and safety. With the advancement in the technology and development of IoT's fields, IoT umbrella is covering much more industries and processes, now it is considered difficult to present a specific definition on it. However, a well acknowledged definition, describes IoT as a dynamic network of devices erected on communication protocols to facilitate some services or processes. In the other words, in a platform of telecommunication protocols, mostly internet, a number of machines are interacting with each other (Lee & Lee, 2015). As a result, devices should have both virtual and physical identities and they must permanently be connected to common platform (He, W & Li, 2014). This is a definition that justifies "smart things", which is commercially and academically of high interest. Similarly, in this report, IoT is defined as a network of machines, sensors and data collectors as well as computers that are connected to each other via internet to process, analyze and store data in a cloud-based server for different types of clients.

Nevertheless, Internet of Things is still in its early stage and in many cases, applications of IoT have remained in the limited pilot projects. (Miorandi, et al., 2012) and (Xu, 2011)

To have a quick understanding about evolution of IoT, the concept of IoT was initiated in 80s when the internet had recently emerged. (Carnegie Mellon University, 1998). IoT gradually grew and linked with the concept of "21th century computers" (Friedemann & Floerkemeie, 2010) while Raji (1994) supplied the concept of controlling and linking of appliances, "connected appliances".

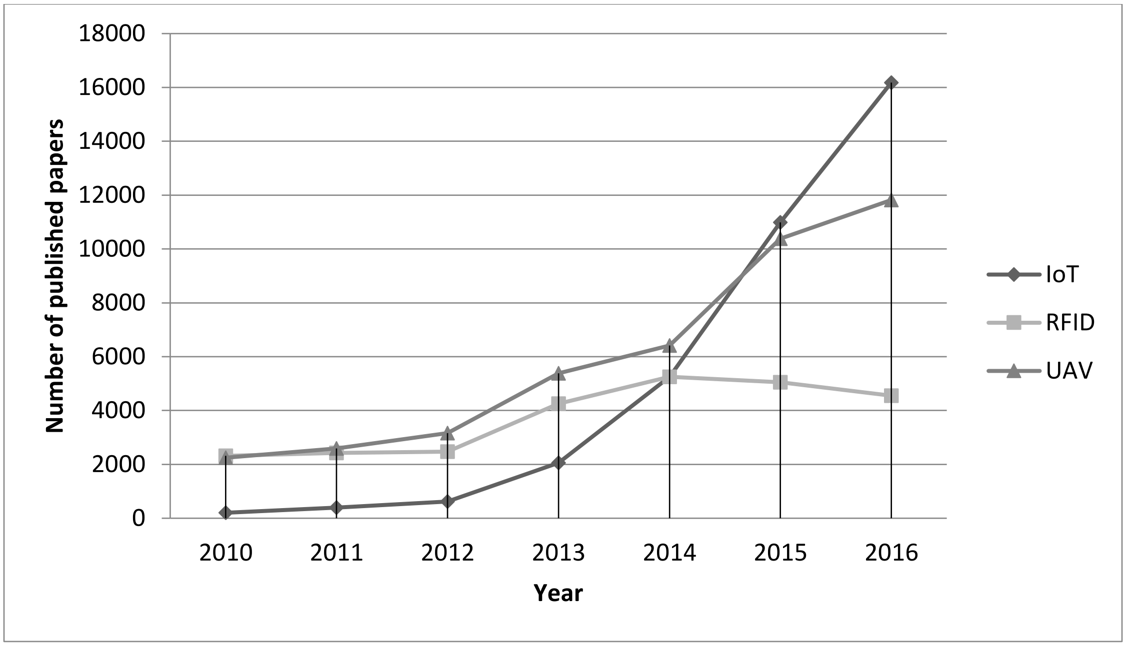


Figure 5 - Number of published papers on IoT, RFID and UAV technologies by 2016, Figures provided by Proquest (ProQuest, 2017)

Integrated with Internet of Things, Radio-frequency identification (RFID) was known as the backbone of this new concept and soon scholars embraced, this being observed from the increased number of articles on this topic (He, W & Li, 2014). Gradually, the idea of IoT has thoroughly developed and transformed and it currently comprises many new technologies such as WLAN, UWB, iBeacon, machine learning and artificial intelligence. (Wigmore, 2014)

3.2.2.2 IoT structure and layers:

To better understand the concept of Internet of Things, different paradigms should be connected. A case study by Atzori (2010) proposes a trinary paradigm consisting of a middleware, sensors and actuators network and finally knowledge based system. On the other hand, a specialty article published on Opentechdiary (2015), on a platform for IoT block looks at four layers of sensors, processors, gateways and applications. Similarly, to the article on Opentechdiary (2015), He and Li (2014) proposed four layers which encompass almost all of the aforementioned layers.

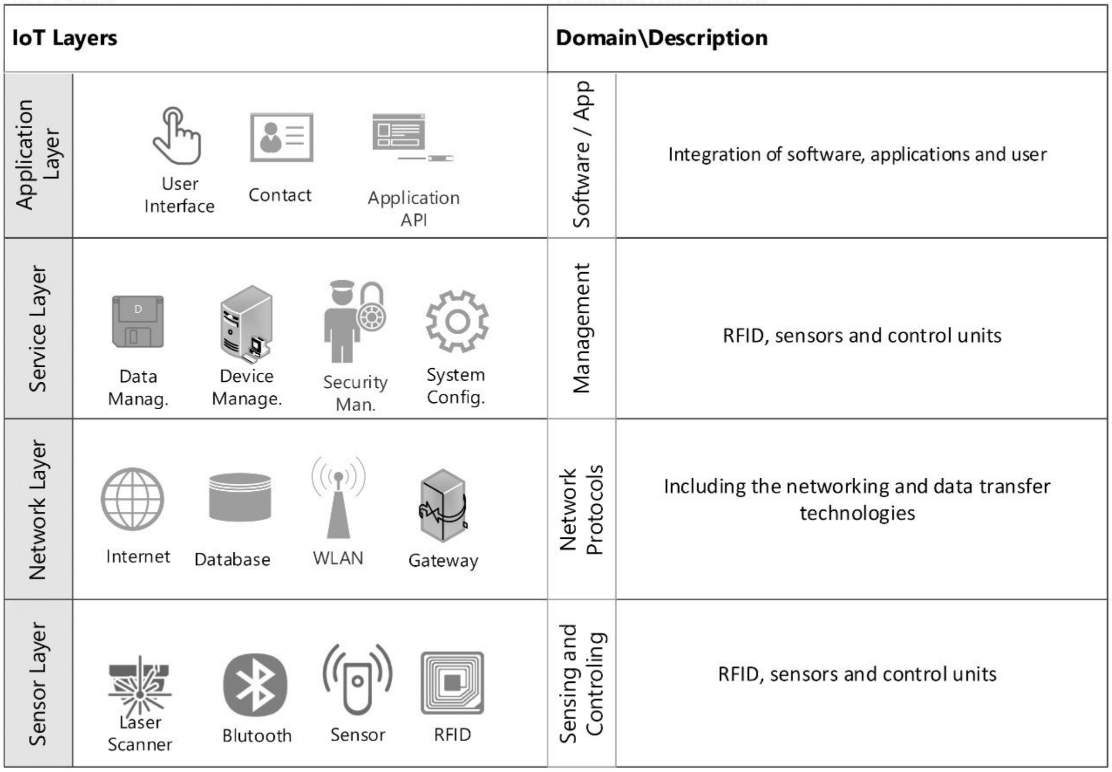


Figure 6: Layout of IoT layers, Adapted from: (Opentechdiary, 2015) & (He, W & Li, 2014)

3.2.2.2 Internet of things – available technology

Built on so many technologies, Internet of Things has moved from being a simple concept to being considered an umbrella for technologies meant to communicate with each other.

In the following lines, a synthesis is presented on the available technologies that have gone from working independently to working in a connected environment where interaction between “smart things” and exchange of information is the core of Internet of Things.

Radio-frequency technologies

Radio-frequency identification (RFID)

Built on radio frequency protocols, RFID is one of the most important technologies in IoT field for data acquisition. RFID is not a newly emerged technology and its precedence dated back to WWII era when this technology was used for detecting airplanes and distinguishing friend from foe. After WWII, RFID technology was considered for civil industries, such as automobile and airplane engineering and facilitating the automation processes of manufacturing (Domdouzis, et al., 2007).

However, it is only that in the past two recent decades this technology has been blooming. For example, RFID is one of the most popular technologies, proposed for tracking assets in the industries like food and construction (Samuel, et al., 2009).

Structure of RFID technology is simple as it utilizes radio frequency for two-way data transmission and this data is stored in RFID tags and also it can be sent to an analyzer or external storage. The RFID system consists of three parts as seen in Figure 7. Firstly, a **transponder** or **tag**, which is used for identification of asset and storing data communicates with a second component is **interrogator** or **reader**. Likewise, the interrogator will communicate with a terminal for data processing, analyzing and storing, which sometimes is called middleware.

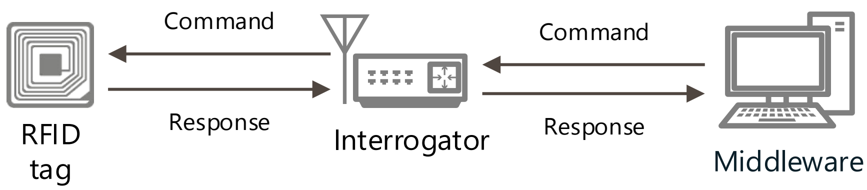


Figure 7: Components of a simple RFID system, Source: (Jia, et al., 2012)

The tags can be taxonomized, according to their power source and data storage abilities into three types as Active, Passive and Semi-active.

Active tags are powered by a battery built inside the tag. Battery can guarantee the continuously data transmission through radio waves. Powered by battery, transmission range of active tags is much higher than passive tags. Although different manufacturers claim different transmission ranges, they are located in a spectrum between 20 meters and 100 meters. Due to complexity in manufacturing, the storage size and the battery, they are more expensive than other types. (Meadati, et al., 2002)

Second group are Passive tags which they aren't supplied by battery and instead, they are dependent on the external power. In other words, the radio waves transmitted by the reader can supply the energy for transmitting data. In passive tag, the range of transmission is limited to around 15 meters, however, in the most of models it barely exceeds 3 meters (Meadati, et al., 2002). Easy to produce and inexpensive make them as the most popular type of tags. Similarly, the size of memory in the passive tags is so limited and for storing large quantities of data, they are dependent of external database. In terms of memory type, the passive tags are divided into read-only tags, write-once tags and read-and-write tags (Datamax, 2009).

Semi-active tags have recently been introduced in specialty literature without a clear definition being introduced and accepted yet. Motamedi (2016) stated that these tags inherit properties of both active and passive tags as they are assisted by an external power unit. Maedati, et al., (2002) describes them as Semi-passive tags and defines them as a tag assisted by a battery which this battery is used to emit the radio waves only when the reader located in the responding range of tag. As a result, data transmission in this type of tags is not instantaneous.

Although there is no consensus about different properties of tags, table below gives a comprehensive perception about them.

Feature	**Active Tag**	**Passive Tag**	**Semi-active Tag**
Duration	10 years	Unlimited	Over 5 years
Data storage	64 to 128KB	128B to 256B	Vary/ around active tag
Data rate	128 Kb/s	1 to 5 KB/s	Uo to 16 KB/s
Power	Battery	Depends on Reader	Battery- On by signal
Responding	30m (up to 100 m)	Up to 15 m	Up to 80 m
Cost	$20	$0.1	>$20

Table 2: RFID transponders comparison- Adapted from: (Goodrum, et al., 2006), (Valero, et al., 2015)

Wireless local area network or WLAN

WLAN is another radio frequency (RF) - based technology which is extensively used in Internet of Things applications. Wireless Local Area Network, is a local network that uses Ethernet/Wireless Protocol to transfer and receive data wirelessly. Although this technology is currently used in the outdoor localization and communication between machines, however, it shows its better performance for indoor purposes. Costs of establishing an IoT-based WLAN is much lower than of other technologies like UWB or even RFID. Accessibility of internet, 4G/LTE and gateways, caused this technology to be more broadly applied in many industries. The results of WLAN studies show that the level of precision fluctuates depending on WLAN antenna, localization algorithm and access point strength (Bahl & Padmanabhan, 2000) (Elnahrawy, et al., 2004). WLAN usually calculates the location of assets by using RSS (Radio Signal Strength) and trilateration techniques as seen in Figure 8.

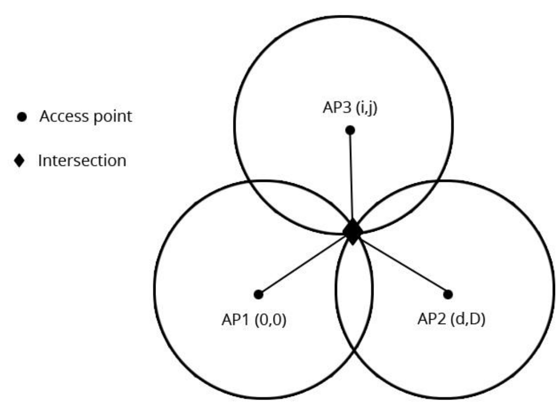


Figure 8: Localization by RSS of WLAN – Source: (OnkarPathak, et al., 2014)

In a case study by Woo, et al. (2011) , WIFI-based localization in a construction project in China is used to locate the labors' position. In this study, the received signal strength method (RSS) is utilized to increase the precision of WLAN by locating access points. Taneja, et al. (2012), in a case study about indoor localization of assets, has managed to increase the precision of WLAN to 1.5m from 4.5m. As a hybrid solution for increasing the positioning algorithm, a mix of WLAN and Bluetooth has been utilized for indoor localization, with great results (Altini, et al., 2010).

Ultra wide-band or UWB

Ultra wide-band is a radio frequency technology for transmitting data in short ranges using very short pulses over very high band frequencies. Although, UWB in the beginning was applied for radio imaging, other industries start using this technology for localization and tracking of the assets. Recently, a wide spectrum of applications related to UWB are provided, such as high precision positioning (HPP), tracking assets in short distances and wireless data gathering transmitted by sensors (Liu, et al., 2007). Higher level of accuracy in this system obtains due to the UWB inherent ability to be read without need for direct line of sight and higher signal penetration. (Cho, et al., 2010)

Infra-Red (IR)

Infrared is an electromagnetic radiation which its wavelength is located between Ultraviolet and radio waves. Since its radiation length is higher than visible lights, it is not visible for human eyes. Relied on emission of IR radiation by all objects on Earth, IR technology is mostly used for sensing and detection. An infrared- based tool require clear line of sight for localization and has a limited range of approximately 6 m. Infrared is used for short-range communication in indoor area and the system perform very poor in outdoor purposes especially in sunlight. (Hightower, et al., 2000)

Ultrasound

Ultrasound positioning systems are developed based on ultrasound signals and locating the assets is done by calculating time of transmission and time of arrival of signals (TOA). Priyantha, et al., (2000), mentioned the idea of Cricket for indoor localization. Cricket is an ultrasound positioning system using TOA and triangulation for finding the location of assets. Application of Ultrasound positioning is very limited because Ultrasound signals cannot penetrate the objects. Besides the signals in proximity with the metal objects can be reflected or conflicted. However, few applications for inspecting the structural elements in construction industry can be found. (Priyantha, et al., 2000)

Sensors

Sensors are one of the main sources of gathering information in IoT-based solutions. Sensors are electronic components designed to measure changing parameters in an environment, such as temperature, motion, humidity. Sensors are vital for monitoring, tagging, localization and sensing and inspection pyramid around us, particularly in closed area (Falke & Fairgrieve, 2011).

In the building industry, especially for maintenance purposes, sensors are widely used for measuring and monitoring the indoor features, the HVAC systems and the structural health. For e.g., crack and deflection of the steel columns can be monitored by sensors and amount of distortion and deformation can be reported instantaneously through an IoT structural system (Samuel, et al., 2009). The application of sensors in the construction industry revolves around structural health quality control, safety, and infrastructure and energy consumption in the buildings.

Data gathered from sensors can further be used by integration in BIM models through software solutions such as Autodesk Revit. It is possible to store and visualize data in Revit by an external API (application programming interface).

Recently, a considerable number of research papers is embracing the newly-emerged WSNs (Wireless Sensors Network). Assisted by wireless ability, a network of sensors is established to measure and process data without any manual interference. The data gathered from sensors has ability to be visualized in the BIM models for example in Autodesk Revit through an external API (application programming interface). A case study on the geothermal results of bridge deck deicing were visualized in the IFC model through a .NET API.

In another case study, accomplished in Surrey University, a real-time solution for visualization of operations and energy consumption is proposed. In this study, a network consisting of around 200 sensors installed to measure different performance of an office building, such as lighting, noise and temperature in regard to the occupants' point of view. The main goal was to visualize real-time data in Revit, as BIM software in integration with IoT (Wang, et al., 2013).

GPS

Global Positioning System is one of the most applicable and popular technologies for tracking and localization of assets. GPS is a ubiquitous technology consists of 32 satellites orbiting twice a day around the Earth. Since each satellite transmits unique orbital coordination, receiver devices and utilize this data to find position. By trilateration methods, receiver can measure distance from a set of received satellites. For a 2D positioning, your device should receive at least

3 satellites signals, while with more than this number, 3D positioning, including the altitude and 2D directional positioning, is accessible. (Integrated Mapping Ltd., 2014)

In the industries, GPS can be used in numerous ways. Currently, there is a great number of companies that, commercially, offer positioning services for tracking and monitoring the materials, vehicles and human recourses. For example, Track-Your-Truck, Inc. offers a set of services including defining the location of your fleet, the fuel waste management and monitoring of the driver behavior and the speed limit. (Track-Your-Truck, 2017).

In the construction industry, GPS is used along with other technologies to track and handle traffic of vehicles in site, positioning the labors, material and machines and fuel reduction. For instance, integrating GPS with other technologies can reduce the fuel consumption in a project by modifying the routes and TOA (Time of Arrival) and ETC (Estimated Time of Completion). With common GPS receiver, positioning might entail in 10-meter error, nevertheless, still for off-road tracking GPS is one of the cheapest and trustable solutions. The accuracy of positioning, however, can be improved by mobile networks, such as LTE. In indoor positioning, GPS is assisted by other methods like WLAN and RFID (Hildreth, et al., 2005).

iBeacon

In 2013, Apple introduced a protocol for data transmission on base of Bluetooth Low Energy class (BLE). Regardless the application of iBeacon for Apple smartphones and mobile payments, this technology has gained in popularity for indoor positioning by calculating the distance to beacons, for example attached on asset. One of the advantages of utilizing iBeacon is the high range of transmission where this range in different case studies is estimated between 70 and 450 meters. However, the main dissimilarity of iBeacon with aforementioned technologies is that only beacons can transmit signal while the receiver can interact with beacon through an exclusive app. This feature of iBeacon is not considered as drawback, instead, as Apple claimed, this feature makes it more secure when it just lets device to position the iBeacon. In other words, it keeps the receiver safe of being tracked and positioned by another beacon. (Apple Inc., 2016)

For testing the ability of iBeacon for indoor positioning, a research in TNU (Taiwan National University) used iBeacon to locate patients in a hospital. This case study is structured on basis of the inherent feature of iBeacon, called UUID (Universally Unique Identifier) and an RSS localization algorithm and as a result of the study, it was observed that the localization error with 95% confidence was between 3 and 5 meters and that the precision of localization is affected by obstacles in the building and walls and partitions. The precision of localization can be affected by obstacles in the building and walls and partitions and in the clearer area, the precision can meaningfully increase. (Xin-yu, et al., 2015).

Optical technologies

Laser-Scanning

Coined in 1960 and acceded commercially into the market in 1974, it was only by 1988 when laser scanning for surveying has emerged as a commercial solution (Margalit, 2011). Soon, scholars embraced the laser scanning for wide ranges of industries like agriculture, automobile, aviation and finally construction. Figure 9 reveals the pattern of increase of the academic papers, published on the application of laser scanning for two decades since 1985, found on the search engine ProQuest.

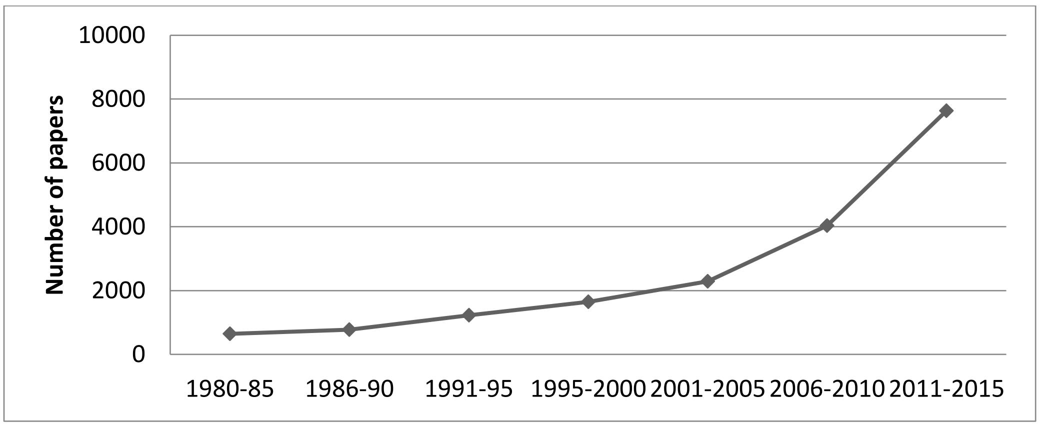
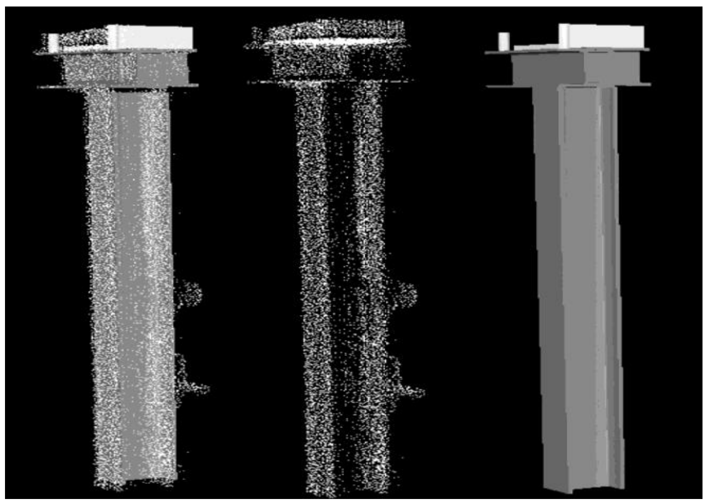


Figure 9 Number of papers on Laser scanning published between 1980 and 2015, Source: (ProQuest, 2017)

The structure of the laser scanning is not very complicated and its function has erected on base of two methods, TOA and PSLP. In the TOA or Time of Arrival, the surrounding is scanned with the laser pulses and 3D figures are made on base of the calculation time between the transmission and return of laser pulses. PSLP or Phase Comparison method is more precise since in this method the laser pulse is assisted with the wave shape signals and dissimilarity in the shape of transmitted and received signal waves contributes to a 3D view of the object or the surface. In two methods, thousands of pulses in a short period of time are fired in order to obtain the exact coordination of each point in norm of (X,Y,Z); the result will be a precise 3D view figure with a variance of around 6mm. Laser scanners need direct line of sight to transmit up to 150,000 pulses in a second and in a range of approximately 150meter (Bohler & Marbs, 2002) (Shanbari, et al., 2016).

Laser scanner for 3D modeling makes use of Point Cloud, which is a technique for gathering millions of coordinates to make a 3D figure. Hardly tied with laser scanning, point cloud technique is a way to make 3D (or 2D) models by putting points beside each other in a coordinate system. Picture 2 illustrates the process of modeling a laser scan of a structural element using point cloud and Autodesk Revit software. This method has the high potential to bridge the shortages in the drawings and surveys, particularly in the terrain modeling. To tackle this shortage more effectively, Gao et al. (2012), suggests the progressive point cloud scanning of spaces in the construction projects along the project lifecycle. This model not only ease the automatization of the as-build documents, but also increase level of accessibility to the documents for measurement and visualization between milestones.



Picture 2: Point cloud 3D Laser-scanning to BIM (Wang, et al., 2015)

3.2.2.3 Internet of things in the industry

Applications of IoT in the industries

The concept of electronic government (E-government) is put forward in 2005 and soon was virally applied by scholars (DESA, 2014). Connected government or E-government is an infrastructure for mutual interactions between citizens and businesses with the government and between governments. IoT links the state's services with client by using internet and cloud-based services and consequently, large amounts of data, in national scale, can be collected, processed and analyzed just in short period of time. The results save considerable amount of time and resources. These facilities increase the capacity and speed of services through which Internet of Things not only increases the security of tasks, but also it influentially prevents counterfeiting. Governments are using IoT for controlling traffic (Smart video and sensor surveillance), security (Auto face identity with nationally connected cameras), net platform services (National demographic statistic and elections) and medical services (National network of monitoring the patients-pilot study) and military cases (Nationally integrated system to control weapons by the satellites and the radars, THAAD-Terminal High Altitude Area Defense, for example.), these being just few examples of the application of the Internet of Things.

Industries are implementing Internet of Things solutions within their supply chain, from manufacturing to delivery, with great results. Healthcare, food, inventory and mining are just few industries where IoT is currently applying. Number of Internet of Things applications in different industries is described below. (Xu, et al., 2014)

As a concept in the health-care system, for example, the patients' vital signals are sent through wireless connection to their doctors on platforms such as smartphones or personal digital assistants (PDA). This data also will be stored in a cloud-based database for further access and analyzing. In hospitals, by using a combination of sensors and RF technologies embedded in devices, emergency situations can be easily detected and the position of patient along with health signals can be sent to nurse stations.

IoT is serving the food industry through increasing the precision of supply chain, speed of delivery and tracking the stock. Today, RFID tags, sensors, GPS and LTE technologies produce a connected platform for monitoring and tracking the food from produces to consumer. RFID technology can help supply chain management through tracking the stocks' information, such as manufacturing and expiration date, supplier, destination, ingredients and inspection history (Xu, et al., 2014). With RFID tags, counterfeit products can be easily recognized and the quality of food, as well as the distribution process, are closely monitored. Besides, among distribution, connected sensors can measure the physical status of the foods and the transport.

Internet of Things exists in the transportation and logistics industries. With RFID tags and wireless sensors, companies operating in these industries are capable to conduct real-time positioning and monitoring of the assets from departure to destination. Today, fleets of airlines are connected to internet and the information of their location, cargo type and status of pallets are precisely recorded in database and is accessible for the owners, the customers and the governments. Another example for using IoT in these industries is recording drivers' vital health signals and their driving behaviors through motion sensors or eye-scanning sensors, and the results can be saved in the driver online profile for further managerial decisions.

IoT in construction

Valero, et al., (2015) consider that the adoption and implementation of Internet of Things in the construction industry lags behind other industries, looking at isolated projects. This stagnation in the construction industry has been attributed to the size of industry, type of activities, expenses and the changing resistance inherent in the industry. (KPMG, 2016).

So far, applications of Internet of Things in the construction industry cover connectivity between smart appliances and smart fixtures for the creation of "smart buildings". (Ghayvat, et al., 2015). Yet, the perspectives that the construction industry offers for adoption and implementation of innovative solutions, allow specialists in this field to consider this industry as a Greenfield for IOT and categorizes its application into tracking labors and safety on the site and locating the assets. (Ray, 2016)

The term "Smart cities" represents a great interest for the construction industry and for the organizations that are active in this industry. This interest has also spread to education entities, such as Aalborg University, where bachelor and master programs are available for students looking to learn how innovation can change the way construction is done. Looking at the terms above, "Smart cities" and "Smart building", we look at elements that have the capacity to communicate between each-other, to produce information on their status and have the capacity to work as an integrated part of a larger system.

Alavi, et al., (2017) offer a taxonomy on the uses of Internet of Things in the construction industry. They argue that Internet of Things has revolutionized the way construction industry designs, plans and builds projects, especially public ones. With applications in all areas of a construction project, from design to engineering and planning, Internet of Things is expected to provide valuable data to improve the processes in the construction industry.

Looking at the way IoT can collaborate with other innovations in this industry, such as Building Information Modelling, IBM (2017) arguments that a collaboration between these two, IoT and BIM is in favor of any project as data captured through the related IoT technologies can be implemented in the 3D BIM model.

3.2.3 Construction industry and Key Performance Indicators

Looking at measuring the performance of their activities, organizations face a great challenge in identifying the most suitable solution for their needs. For the construction industry, a great number of papers and scientific reports present and analyze the complex environment of this sector of the economy in regard to both resistance to change and conservativity, these being considered main factors to influence productivity. It is known, that in this conservative base, there are many economic and quality based KPIs with both quantitative and qualitative criteria that help provide a reflecting image of the performance of the company. Overall, with the scope of observing the usage of resources, Key Performance Indicators create benefits for the construction industry through improvements applied to the end product. Through annual reports such as the United Kingdom's construction industry performance report, where well acknowledged statistics companies like, Glenigan and CITB collaborate, helps to create and maintain a priceless data base for analysis and bring value to both the construction industry and in a general extension to the broader economy. (Davis, et al., 2016)

Within this chapter, a brief examination of the construction industry at the European level will be conducted to observe its behavior in regard to performance and productivity. As the modern economic environment requires well organized, transparent and detailed knowledge of the correlation between different business fields, administration bodies provide annual reports on the construction industry's performance.

After a survey of almost 1500 companies, it was observed that nearly one out of two companies (46%) foresee their annual turnover to rise. In addition, 44% of the companies foresee their turnover to remain stable and finally only 8% awaits a turnover reduction. These indicators present an overall recovery in the UK over the last 12 months. This downturn will create a harder environment in taking investment decisions in values of both personnel or technological updates. In addition, besides these outcomes, the EU referendum for the exit of UK from European Union will extend the need for individual performance frameworks that will sustain a construction industry environment, undistracted to changes like these. (Davis, et al., 2016)

Productivity is a significant aspect of every company's regular base activities and of course a possible business success or fail indicator. Measuring the direct or indirect labor of the company is feasible by just calculating the dollars per unit and the units per hour performed of direct and indirect labor (Lincoln H. Forbes, 2012). Thomas Randolph (2012) argues that the construction industry faces a major difficulty in obtaining profit after a better labor measurement implementation.

As construction industry is considered a very important asset to the economic status of E.U, many attempts occur from the comity to help and improve the performance of the sector by making it even more competitive. The importance of the specific industry is reflected on its big contribution to jobs availability and financial participation on the European economy. The industry provides direct job to 18 million people providing 9% of the total EU's Gross Domestic Product (GDP). (European Commission, 2017)

The European commission introduces many new regulations, aiming on improving construction industry's performance but also aligned it with energy efficiency and the change of the climatic status. A European Commission's report presents the impacts of a E.U regulation in construction products showing that smaller companies face higher cost (1,31 % of their turnover) in aligning their activities than the larger companies (0,6 % of their turnover.) (VVA; DTI; TNO, 2016)

As part of the strategic development of construction industry in Europe EU commission addresses the impacts of economic crisis on the sector, as building and infrastructure related business decreased by 16% from 1-2008 until 11-2011. (European Commission, 2012)

In this strategy of European Union, five important objectives are covered.

- To stimulate and encouraging environment for investors
- To Improve the personnel-capital of the construction sector
- To improve the efficiency of resources, align the performance with environment legislation and increase the opportunities for business development
- To empower the construction market
- To support the EU position on boosting global competition in construction industry. (European Commission, 2012)

Based on the literature found, the alignment of any construction company's activities including the monitoring processes and strategy, with the general framework of the corresponding associations like e.g. E.U is considered mandatory.

4. Analysis

4.1 Selection of key areas

Construction industry is a complex term that includes the basic phases of activities related to land preparation, construction, facility management and repair of any kind of structures. As construction's industry's definition is not something fixed, it varies based on the different perspective and outcome of the specific industry or specific company analyzed.

During the process of analyzing the performance of the construction industry, this chapter will try to identify which fields of the aforementioned industry will provide suitable basis for providing improvement solutions based on an analysis of available reports used in the industry, using the right suggested model of combination of BIM and Internet of Things (IOT).

Through an analysis of available literature, it was observed that performance in the construction industry tends to increase at a different rate, when benchmarked to other industries. Researchers and professional, for example (Christensen, et al., 2015), attribute this trend of the construction industry to its conservatorship characteristic, making the construction industry less performant than other. (Department for Business, Innovation and Skills , 2013) supported by (Designing Buildings Ltd. 2016, 2016)

It was observed that many connections have been created between factors that influence the productivity and performance of the construction industry. Looking for example, at defects, these can have a direct influence on the profits of a construction firm, by allocating funds to remediate them, while simultaneously affecting the perception that clients have on the firm. Defects can, at the same time, affect the health and safety aspects looking at increased risks in this area or can affect the planning, trust of financial bodies and so on. (Ahzahar, et al., 2011)

Having a set of limitations that apply to this report, not all factors that influence performance can be examined and analyzed within this report, and as such, a focus was placed on Defects, Health and Safety and Planning. It was observed in the perused literature, that these three factors greatly influence each-other and it is expected that, through improvements applied in one, the effects will also be observed in the others.

The connection between the new developing global market and the importance of the perfect planning in construction companies, extensively determines the winner in a competitive tender (Park, et al., 2010).

The critical area of health and safety is deeply met and analyzed by many researchers. Some of them like the “the Accident Analysis and Prevention” created a large database by connecting the health and safety issues with workers’ behavior in the construction sites (Guo, et al., 2016). Amongst others, a risk analysis defines the tolerances of the risks related to safety as the key factor that leads to increased safety issues on the construction sites. (Wang, et al., 2016)

4.1.1 Defects in the construction industry

In a complex environment like the construction site, many tasks and different type of technology implementations take place at the same time from different directions. This, combined with the high-quality standards coming from strict national regulations on construction, render the necessity for a valid defect allocation system a mandatory for every construction company.

Defects and any kind of decline in the view, the ergonomic features and the safety of a construction outcome is a very typical flaw in a site. The defects and problematic components are mainly spotted in the areas of building imperfections, deficits and the level of a non-efficient quality. (Ahzahar, et al., 2011)

Ahzahar (2011) states that, when trying to define the term defect, it can be considered as “the nonconformity of a component with a standard of specified characteristic” and can be characterized as a failure of the building. Flaws like these can come from engineering errors on calculations or from work imperfections during the construction phase, varying from non-effective materials, errors and mistakes on the supplier specifications of the product or wrong installation and implementation by the working personnel.

On the other hand, a similar definition of the term defects is given by Nielsen, et al. (2009) after categorizing the different types of defects in physical and process related. A defect with a physical status can be met when the documents related to the project or a building does not present the characteristics expected based on the contract, the legislation of the corresponding geographic area and finally its problematic usage by the end-user. Process-oriented flaws and defects are usually observed in the construction process of a project, and it is limited to the benchmarking of the competencies and time that are not in alignment with the process as it was optimized and described in the design phase to all the supportive documents or engineering files. (Nielsen, et al., 2009)

Another method of taxonomizing defects is based on the effects that these defects have on the project and consequently on the outcome of the project. Based on this, defects can be categorized as leading to Health and Safety issues or leading to financial issues. In the first category are included all flaws that, through variations from the national legislation, can produce health and safety hazards by change in the performance of the end product. Defects that can lead to economic issues are, to some extent, difficult to distinguish from defects leading to Health and Safety issues as the latter can also lead to financial issues, while the former does not necessarily need to lead to Health and Safety issues. Through risk assessments, defects in work and procedures can be anticipated and as such, their results on the project and the stakeholders can be mitigated. (Nielsen, et al., 2009)

Any building site is related and directly dependant from the environment around it. With the term environment, both climate and urban planning should be considered. In areas with extremely high levels of humidity, a more detailed monitoring process in regard to the materials that are implemented and are exposed to the weather conditions is needed. Possible failures may occur based on the wrong implementation or the low quality of the product. Defects in a construction project can also arise from the building's geographic position. Construction sites close to water are more likely to face instability issues and damage to the envelope due to environmental effects on the building materials, e.g. high humidity. (Ahzahar, et al., 2011).

A survey conducted on 12 contractors and consulting firms revealed the most common failures, these being presented in Table 3.

No	Defects/ Failures
1	Blemishes (Scaling, Honeycomb)
2	Corrosion of reinforced steel
3	Damage of exterior surface
4	Dampness
5	Peeling Paint
6	Roof defects
7	Cracking (floor, beams, etc)
8	Spalling or chipping
9	Foundation failure
10	Structural instability

Table 3: List of most common defects, adaption from (Ahzahar, et al., 2011)

For projects situated in urban environment, space allowance for site organisation can sometimes be limited. It can be considered a challenge for site managers to identify and locate defects of the construction due to various constraints, such as height of the defect or proximity to adjacent structures. Additionally, underground structures in urban environments can be considered a hazard as these, without a proper identification and localization, can pose threats to the proper management of a construction site.

4.1.2 Planning

In complex environments, such as a construction site, planning of activities to be undertaken is highly important if the project should finish on time, within budget and with as little defects as possible and as little or none health and safety issues. Planning of a construction project is a challenging task for a construction manager as all activities, requirements and risks need to be foreseen.

Chan, et al. (2010) argues that a good planning can represent a competitive advantage for companies looking at maintaining or even increasing the construction market share.

Planning require construction estimators to consider and include into their calculations, specific data in regard to resource usage, material and labour, on-site safety and healthcare and particularities of the construction site (Sutt, et al., 2013).

The aspect of planning in construction is highly important in both logistics and safety. More specific, in construction sites in crowded urban areas, a plan with a detailed material usage per time slot is needed and provides a significant edge in better cost estimation and best health and safety measures implementations as the health and safety manager would be able to be aware of the available zones in a time dimension based schedule.

Regarding the other typical monitoring planning processes, all the time-related data include specific information on the time slags between the tasks and the working hours needed to finish a specific task. Other factors, like the total amount of the working force and recourses per day, are as well important as the dynamic balance on site should follow the project management monitoring methodologies like the working forces available per task, per day or the machinery usage in all the time phases of construction.

The different type of projects may require more specific planning tools. If the construction site use for example cranes, other special machinery or even site temporary roads, the planning manager can monitor and store the time per task needed, in different weather conditions and compare it with the tasks running in parallel. (Sutt, et al., 2013) From the abovementioned analytic procedure, it is more than obvious, that technological advanced tools, with features providing precise data on volumes of materials reaching and being stored on site, are more recommended on construction sites.

4.1.3 Health and safety.

During the process of analyzing the methodology used by the construction industry to benchmark their performance in regard to health and safety is a combination of old and typical indicators with new and more precise. As typical and very common, indicators for monitoring the health and safety levels in a construction site is the total number of accidents. In many cases, the type of accidents is categorized as fatal accidents, serious injuries that require health care and minor accidents. (Edwards & Love, 2016)

These indicators can be spotted and analyzed in comparison with the total duration of the project or the total amount of the personnel that participated and worked during the total cycle of the construction outcome.

The legislation and law framework around the construction industry and how to perform and secure the highest health and safety levels on site is very strict and creates a common baseline to all construction industries as it is considered a necessity for every construction activity. External inspections are held by authorized corresponding state's employees and they can access and examine the measurements taken by the risk manager on site. (Saurin, 2016).

Legislations between countries may differ in detail on dimensions of the risk areas and forbidden zones but in general they follow the same methodology on identifying the risks and dangers on the design phase, evaluating them and check by authorities and then inspections on site for validating the implementation and compliance on site.

With the improvement in risk analysis and mitigation, companies and construction industry's managers try to reach the causes behind the health and safety problems that may occur. Indicators like workers safety feelings are introduced and analyzed. Terminology like situational awareness, accurate safety and implicit safety are categorized and used in grading the status of the site. (John W. Whiteoaka, 2016).

Some of the academic papers characterize the performance of the industry as poor (Qinghua, et al., 2015) and argue on that based on the dependency of the internal format and organization of the company and not only related to individual factors. (Sherif Mohamed, 2011). Internal factors such the type of leadership applied and strategic values are considered more than important and create a very brad and challenging area in construction processes. (Qinghua, et al., 2015)

4.2 IoT Technology Selection

Up to 70% of the overall construction cost is direct cost related to material, labor and machinery. As a result, having precise information of the performance, location and status of the assets in a construction site contributes to the better management of assets and it decreases the risk of erroneous decision making. In a complex project, where numbers of contractors and sub-contractors work simultaneously, the probability of confliction and risk considerably rise. Consequently, for the main contractor and even the owner, it is essential to feed the managers with the real-time and precise data about assets for scheduling, planning and determining critical areas. Additionally, it aids to improve the project performance indicators by saving time, increasing efficiency, avoiding risks and unwanted maintenance costs. A correct selection of IoT technologies has a direct influence on the tasks duration, saves the recourses of the project and diminishes the expenses of rework and inspection. (Patrascu, 1988)

In the chapters above, a taxonomy has been created with the purpose of presenting to the readers of this report, available technologies that make use of existing innovations in the construction market, such as Internet of Things and Building Information Modeling. As resources for the creation of this report were limited, in the following chapters the focus will be placed on RFID system as this was observed to benefit from an increased popularity amongst organizations, especially in the logistics and transportation industry. The RFID system analysis will look at the use of it for the purpose of localization of man-power on a construction site and further to bring benefits to the selected areas, Health and Safety, Defects and Planning. Challenges and benefits of this system will be analyzed to observe how the system will perform, or is expected to perform, during operational hours and how the system will/can collaborate with BIM technology

Additionally, we will look into a technology that, although not directly connected to Internet of Things, has the potential to bring benefits through connection to Internet. A selected UAV system with LiDAR and Photogrammetry capabilities will be examined based on reported benefits of its use on construction projects and the expected benefits through connecting this technology, via internet, to a BIM model.

4.2.1 RFID

RFID technology is the main and the most popular technology in IoT concept. RFID still is one of the most effective tools for performance atomization and its implantation doesn't impose expensive costs to the project (Costin, et al., 2012).

Widely application of this technology for more than 70 years and number of studies focused on RFID, make it as a mature, trustable and ubiquitous technology. (Zhong, et al., 2017)

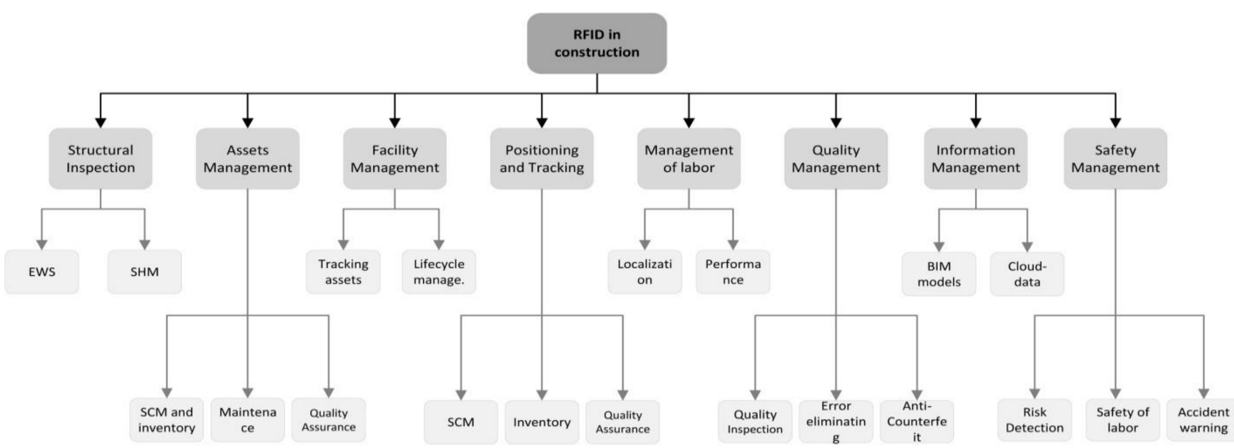


Figure 10- Applications of RFID in the construction industry, Adapted from (Wang, et al., 2017), (Costin, et al., 2012), (Wing, 2006) & (Wang, et al., 2007)

*EWS: early Warning System, SHM: Structure Health Monitoring, SCM: supply Chain management

Figure 10 gives an overall idea of the fields that RFID can play a profitable role in the construction industry.
With the advancements recorded in the RF protocol security, level of confidence in these types of devices has considerably surged. In comparison with the newcomers like iBeacon, number of articles and studies has been focused on RFID and low expenses of the tags and the readers, shows an increasing tendency in industries towards the myriad applications of RFID. Simplicity is another advantage of this radio frequency technology and today, even in toys for children different types of RFID technology are introduced. (Emerald Expositions, 2017)

There are many reasons to convince construction managers to make use of RFID in fields like quality, health and safety and planning. It is known that the number of work related accidents in the construction industry is still high and the use of RFID technology for localizing personnel can bring an improvement to this aspect and further decrease the number of WRAs. In this thesis, RFID is being analyzed as a solution for identification and localization of personnel for adding improvements to the above-mentioned areas of interest, with emphasis on the Health and Safety one where it is expected that RFID will add more value. (Valero, et al., 2015)

4.2.1.1 Localization Methods

Localization is a context awareness concept which helps mangers to monitors elements inside and outside of buildings amongst the building lifecycle. The need for asset and personnel localization in the construction can be split into the indoor and the outdoor tracking and localization (Hightower, et al., 2000).

However, few of them worked on the real-time localization. Real-time localization of workers inside the construction sites with acceptable precision will be looked into. Although RFID is not the most accurate method, utilizing hybrid methods, for example GPS-RFID, can increase the precision of positioning by 1 meter (Shahi, et al., 2012).

There are the methods for using RFID for localization purposes. First when the reader is stationary and the tags are mobile (for example when workers are tracked) and the second one is when the tag is fixed and the reader is mobile (fixed equipment is tagged) in order to find the real-time location of reader. (Costin, et al., 2012)

In comparison to outdoor localization, indoor one is more complex due to obstacles and changes in the signal. Structural elements, furniture and architecture of building can influence the precision of radio frequency estimation. Metal for example reflects or absorb radio waves. For indoor localization, the assets are tagged and readers are fixed and used as a benchmark (Yamano, et al., 2004).

Indoor localization can be categorized into four distinct methods of proximity, multilateration, angular, and scene analyzing. (Motamedi, et al., 2013)

In the first method, proximity, the location of target in vicinity of receivers, can be defined by creating a network of comminuting tags and readers. The location of target is defined on base of detecting a tag in the readers responding area. Similarly, the target position can be detected by measuring the nearness to other tags or readers with pre-defined coordinates. The TOA or RSS methods are used to measure nearness to the known points in the network. This method is also called neighborhood localization. (Zhou & Shi, 2009)

Through multilateration, the target's location is detected by at least three interrogators which their positions have already known. This method includes several techniques for measuring the distance, such as TOA (Time Of Arrival) by which the target's location is calculated on base of arrival time of tag' signals. Similarly, TDOA (Time Difference Of Arrival) uses relative time measurement, where the transmission time is unknown and only sources and receivers' time of arrival are considered. In TDOA, unlike TOA which uses absolute transmission time, only differences of senders' arrival times are measured. In RTOF (Round Time Of Flight), the time of signal transmission to the target and back is measured in order to detect the target. (Zhou & Shi, 2009)

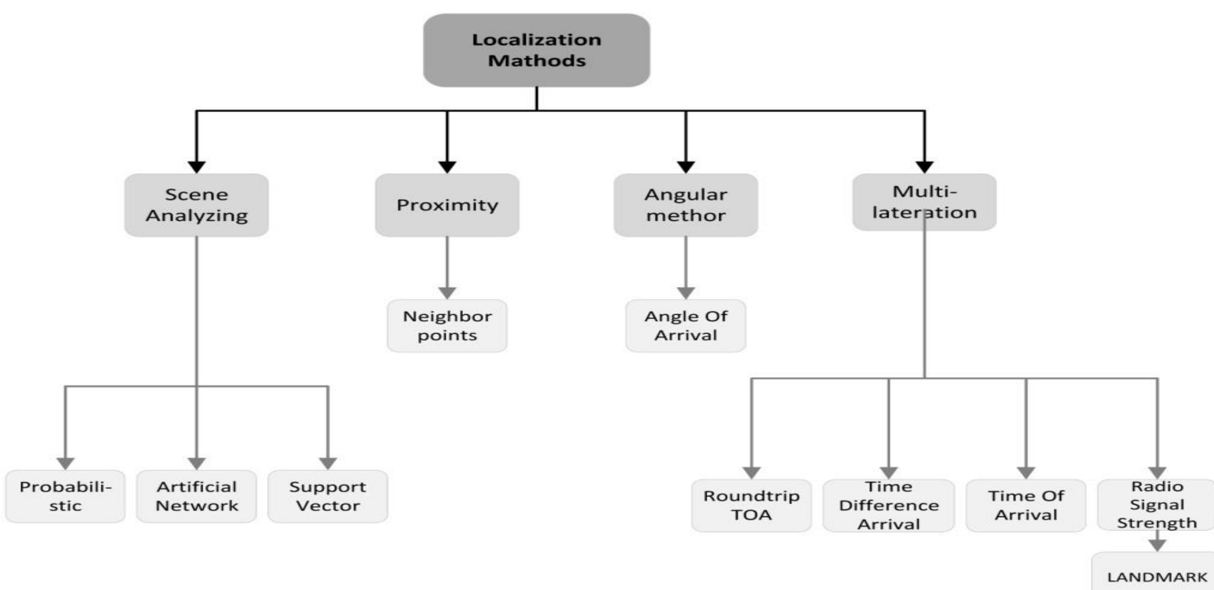


Figure 11 – Localization Methods – Source: (Zhao & Shi, 2009) , (Farid, et al., 2013)

Third localization method is Angular estimation that uses angle of arrival (AOA). The location is calculated by the angle of arrival signals received by minimum two readers. The last method is Scene Analyzing that is erected on base of radio signal mapping. The strength of signals in the area helps the system to prepare a map of signal behavior. In this method, a database of signal behavior of the zone is prepared and the location of target is calculated by comparing the similarity of the target RSS pattern and the database radio map. (Zhou & Shi, 2009)

For localization of assets, the primary information is stored in the facility management software. By combining the location of assets and 3D models the personnel is able to easily locate the assets. Fixed assets can be defined as an object in 3D models and BIM commercial software. Assisted by a central database, the supervisors or inspectors, equipped with the reader, can locate them and access to this data. As soon as the personnel enter in the signal range of assets, tags' information is read and the supplementary data is retrieved from database. (Motamedi, et al., 2013).

Method	**Type**	**Accuracy**	**Coverage**	**Only LOS***	**Cost**	**Preset requirement**
Proximity	Time-based	Medium	Good	No	Low	
Angular	Angle-based	Medium	Good	Yes	High	Predefining coordinates
Scene Analyzing	Signal Strength	High	Good	No	Medium	High calibration
TOA / TDOA	Time-based	High	Good	Yes	High	Time synchronization
LANDMARK	Signal Strength	High	Good	No	Medium	Calibration needed

*LOS is need for line of sight for the detection and localization

Table 4 Comparison of localization methods for indoor spaces – Source: (Farid, et al., 2013), (Mrindoko & Minga, 2016)

For localization of the mobile assets, a case study implemented in Concordia University, suggested a combination of the reference points and RSSI techniques. In this method, available fixed assets are considered as a reference points and the signal strength pattern received of both stationary and mobile tags are compared by the reader. The reader calculates the proximity of the target by comparing the level of similarity (strength) of patterns. Figure 12 illustrates localization by comparing the signal similarity. The left figure shows that finding the best similar signals wouldn't necessarily give the most precise coordinates. However, grouping the neighbor tags which have almost the similar RSS will contribute to better result. In the right figure, the accuracy, the difference of the estimated location of target tag and real location is considerably higher. (Motamedi, et al., 2013).

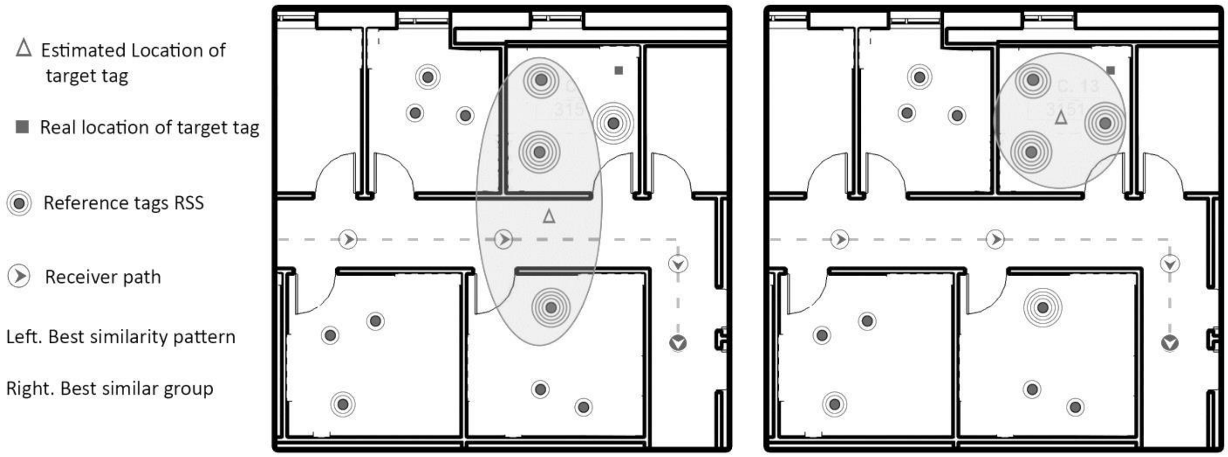


Figure 12: Localization by RSS and similarity of signals Adapted by: (Motamedi, et al., 2013)

In another case study by Costin and Teizer (2015), the integration of RSSI and passive tags are utilized to locate a mobile object. In this method, oscillation of signal strength is measured to calculate the distance between tags and reader. Estimation of signal strength is done by Friis equation. This equation is coined in 1945 for measuring the received power of one antenna which transmitted in a known distance. The mobile object with its four antennas is considered as a reader and fixed objects were attached by passive tags and multilateration method were used to detect the location of objects with 3-meter error and 95% confident.

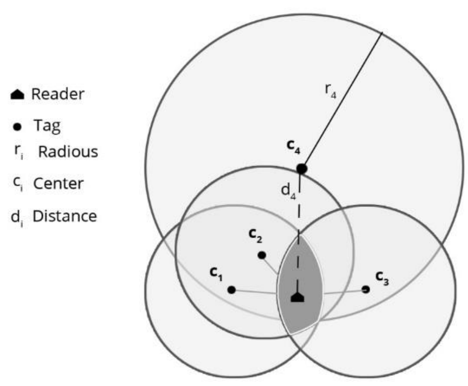


Figure 13 Multilateration with four different RSS. Source: (Costin & Teizer, 2015)

In the schematic view of multilateration, d_i is the distance between reader and each tag. In this method center of each circle is location of tags and tags coordination is already recorded in the calculator. Similarly, radius of each circle is RSSI and is calculated by software from one of the available RSS formula. Here, d is tag read radius. In this method by knowing the output power and performance characteristics of antennas and the location of tags, the localization will be done automatically.

In addition to those studies, recently hybrid methods of localization by using other technologies have gained in popularity. A great number of WLAN based solutions have been offered which heavily depends on internet or local access networks. Taneja, et al., (2011) suggested a cheaper solution including the integration of WLAN and RFID tags. The combination of RFID and WLAN is considered because these technologies don't need direct line of sight and achieved accuracy was in acceptable range, around 3 meters.

4.2.1.2 Examined localization concept

With great results on the localization of assets in various industries thorough the use of RFID solution, the following sub-chapter will look into localizing mobile assets, especially man-power, on a construction site while looking at performance, active hours and location, and awareness with the purpose of increasing the health and safety rating for construction projects through operating on real-time data.

System R.TIS is a concept designed for use in conjunction with fixed assets; however, this solution can be adapted for the use on mobile elements, such as man-power. R.TIS is erected on base of RFID and communication protocols, like WLAN, for zone-based localization. This method is a combination of RFID technology, cloud-based server and Revit connected with RFID through an API as seen in Figure 14.

The R.TIS information is transmitted to the database and an external middleware uses the 3D information obtained from BIM models to visualize them for various purposes. Database data includes real-time data such as time, signal characteristics as well as pre-stored data like workers information, contractors, skills and medical skills and supervisor comments.

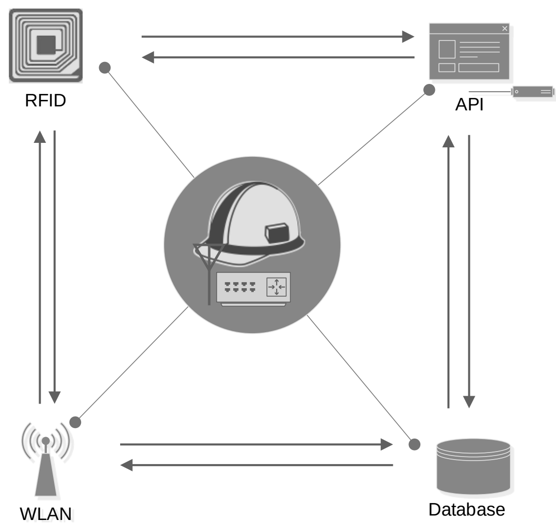


Figure 14: RFID system components for zone-based localization (Own creation)

For establishing R.TIS, firstly the construction site according to number of workers, tasks and construction fields are divided into zones and each zone gets a zone ID. The 3D maps of construction site are provided by BIM software, here Revit, and it is visualized by a middleware in different layers. Dividing the zones into smaller area means each grid of zones can be controlled and supervised easier. Since the worker should be detected in the zones separately, the smaller zones are, the more precision obtains. Entrance to each zone should be limited into gates equipped with RFID readers. The readers can be installed on top of the gates. For avoiding congestions in crowded zones, number of gates can be increased. The helmet or safety vest of each worker is equipped with a passive RFID tag. For increasing the chance of reading the tags by readers, we suggest installing tags on the helmets and gates be guarded by a crossing boom and it opens only when a tag is read.

Different zones will have particular security status to access. These constraints should be allocated to the zones in advance according to the schedule and type of tasks should be done at that day. This process can be done automatically by an automated scheduling system where the status of each zone is automatically retrieved of schedule. If a risky task is performing in a zone, the zone’s status changes from “Normal Zone” to “Risky Zone” and consequently, for that period of time only authorized workers or sub-contractors enter the site. For instance, if an unauthorized worker wants to enter into a zone, the gate will not open and if that worker, however, enters the site; the system sends a warning to the supervisor (and worker) and consequently, changes the color of zone in the 3D model. An LED display and beepers can be installed by gates to automatically show the zone’s status and inform unauthorized workers. The presence information of workers, gathered by RFID, can also be used for quality and performance measurements. This information can be stored to a database for further uses by supervisors.

RFID tags, attached of helmets or safety vests can improve safety issues in the construction sites. Equipping the machines and workers with RFID diminish number of fatalities stem from accident between construction machines and workers. In a concept “RFID of everything”, a neural network of machines, workers and cloud-based server are interacting together to decrease the risk of any accident. This system even has potential to reduce the accident between machines. (Zalud, 2016) (Li, et al., 2011)

Figure 15: Concept of RFID of everything for safety in the construction site, Adaptation from: (Caterpillar Inc., 2016)

According to type of machine, task and maneuverability of machine a danger range is defined. These danger ranges for different machines vary; for e.g., the range for an excavator is larger than the one for a roller. Subsequently, when a worker enters into the working/danger zone of a machine, his/hers RFID tag is detected by the machine’s receiver and the reader will inform the driver, worker and send a string of data to the cloud for the supervisor and other beneficiaries. These types of events, which don’t result in injuries, are called “near miss” and they are considered as an important key performance to measure ratio of the safety to the project lifecycle. In a critical situation, when the machine and worker put in a critical distance of each other, the machine can be programmed to stop working automatically. In the project scale, where hundreds of worker and machines are simultaneously working, all information and risky situations should be analyzed by complicated algorithm in a fraction of second and decision is taken and inform all the beneficiaries. This concept is accessible only when the automatic schedule, RFID network and risk algorithm and API are connected in a cloud-based network and interact instantaneously.

Caterpillar (Cat), construction machines manufacturer, has recently worked on a RFID detection project in which Cat has attached RFID tags on workers and the receiver on one of its machines in order to mitigate the risk of accident by machines. A real data of this detection system tested on a construction project during 30-day trial test shows that the system detected more than 470 near-misses. Looking at the numbers exported from the project, it can be observed a change in the behavior of workers due to notifications received from the system. This change is represented by the drop in recorded warnings, as observed in the figure below.

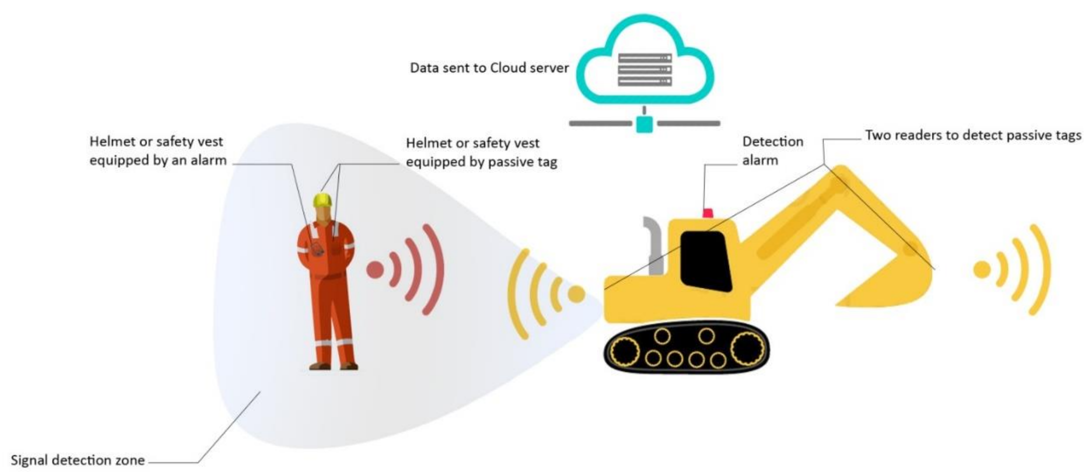


Figure 16 Proximity alarm for preventing accident. Adaptation from Caterpillar (2016)

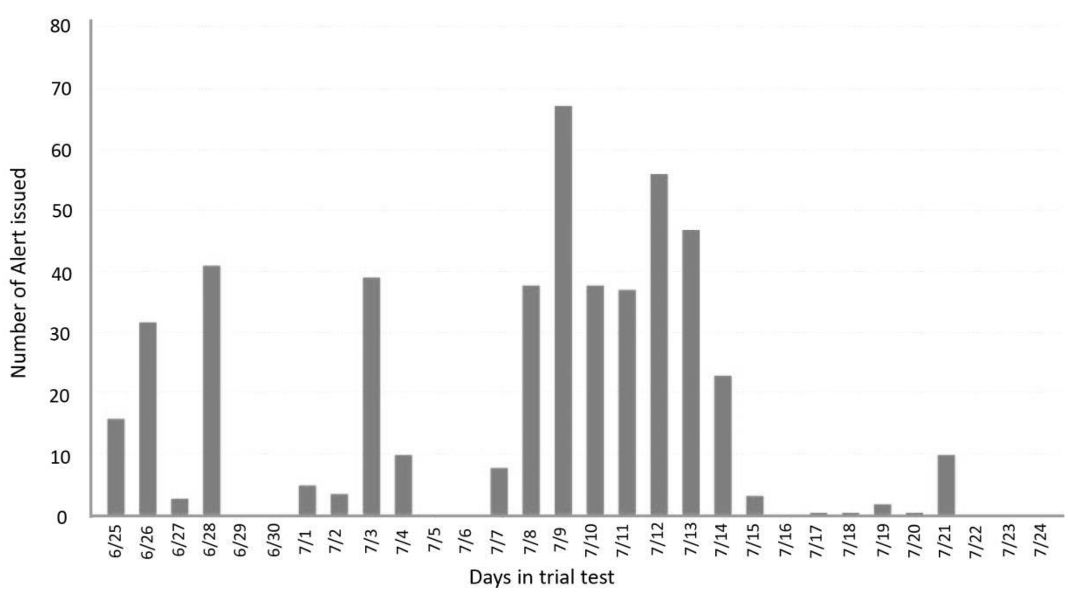


Figure 17: Number of Alert issued by CAT Detect (Caterpillar Inc., 2016)

4.2.1.3 Filtration of data

The information gathered by RFID tags is prone to error because of repetitive enter and exit of workers. Data filtration is one of the vital processes should be done automatically before the data is stored in the database. In each read, tag information such as frequency, tag unique ID, IP, interrogator's ID, time of read and the received signal strength are stored either in the tag or the cloud. Filtering the surplus and recitative data (SARD) reduces the size of storing file and eliminates invalid or incomplete data before further process. Wang, et al., (2014) and Costin et al., (2012)

Filtration should encompass two steps of "deleting invalid data" and "filtering the SARD". The algorithm for both of these steps should be designed in a way to perform the filtering simultaneously.

The invalid data is the data that recorded from out of range tags or incomplete data. The out of range data can be eliminated by the tag ID and IP of each tag. Commercial RFID reader software has the filtration feature to perform it automatically. For example, this type of software has a time delay algorithm for preventing the read of tag twice or seconds later.

Filtering the SARD requires an algorithm which defined by the characteristics of area, type of tasks and the measuring performance. However, the solution relies on reading only the first and the last reads of a tag and other reads considered as SARD, unless the duration of other reads set in the acceptable range. The reads in between are valid when, for example a worker, stays in a zone for couple of hours and then moved to another authorized zone for other two hours and finally comes back to the previous zone and keeps working for the rest of working hours. Again, the IT manager can set the acceptable period of time for the reader within which the worker lingers in a zone. However, since the workers might work in more than one zone, we suggest that algorithm eliminates data that registered in a period of less than one hour and keep the other. However, supervisor can modify the data manually whenever it needed.

4.2.1.4 Looking at the use of RFID localization method for the three analyzed areas

Defects

Defects are a big challenge for all projects, since these represent resources consumed through re-works, delays, wastage and human resources. Even though RFID systems are mostly used for localization and detection of elements, it has potential to increase the quality and detection of the defects indirectly.

Defect on construction sites appear as a result of various factors. Some defects are due to poor workmanship or other due to inappropriate selection of construction materials. There are also some defects that appear due to inattention of workers or even, in some case, due to ill faith of the workers. Through a proper identification of the location of man-power on the construction site, conflicts between stakeholders can be avoided. Looking at a scenario where workers from one trade have damaged works finished by another trade but not yet handed-over would result in conflicts over liability. In some cases, finished works have been damaged but the liability cannot be attributed to a certain trade or worker as the one that has caused the damaged could not be identified. A log with the location of each worker on site will prove useful in solving clashes between project stakeholders, reduce time spent on conflict resolution and increase productivity.

Type of information	Benefits	RFID role
Presence hour	Assure presence of workers	RFID tag read for enter/exit
Time of worked	Preparing digital worksheet	RFID tag read for enter/exit
Zone of work	Preventing unauthorized workers	Reader in each zone register the tags
Type of works	Tasks in each zone attributed to the worker	Reading tags in the smaller grid zone
Quality	Quality of done work	Reading tags in the smaller grid zone
	Managing number of workers	Visualizing the zones

Table 5: Benefits of RFID tagged workers

Health and safety

Danger inherent in the construction industry and high rate of accidents contribute to many innovative solutions taking advantage of RFID technology. Using smart helmets, early warning system, and automatization of tasks and warning, are numbers of these attempts. Localizations of workers, on itself, can reduce the risks and when it gets supported by a tool for automatic identification of dangerous area the result can be stunning (Kim, et al., 2016).

As already mentioned, the platform for controlling the RFID, has different layers that suits different fields. For safety, the supervisor, scheduler or automatic system can announce a zone as the risky zone because of type of tasks is carrying out there; the platform automatically restricts the entrance into this zone and set all the warning systems into red color. Similarly, a safety plugin installed in Revit changes the color of high-risk areas and visualizes the tag IDs are in this area and send a warning to them. An example of this process is illustrated in Figure 18.

Falling from the heights is considered as one of the main reasons of casualty at construction projects and any attempt in reducing this risk would consider as a great stride (U.S. Bureau of

Labor, 2012). Obstacles and materials that workers carry restrict their line of sight; consequently, it is very vital to inform the workers about the danger of falling. Installing an early warning system on base of RFID technology has great potential to reduce the number of work related accidents due to fall from heights. The RFID readers can be set at high-risk areas and inform the worker when he/she approaches the areas.

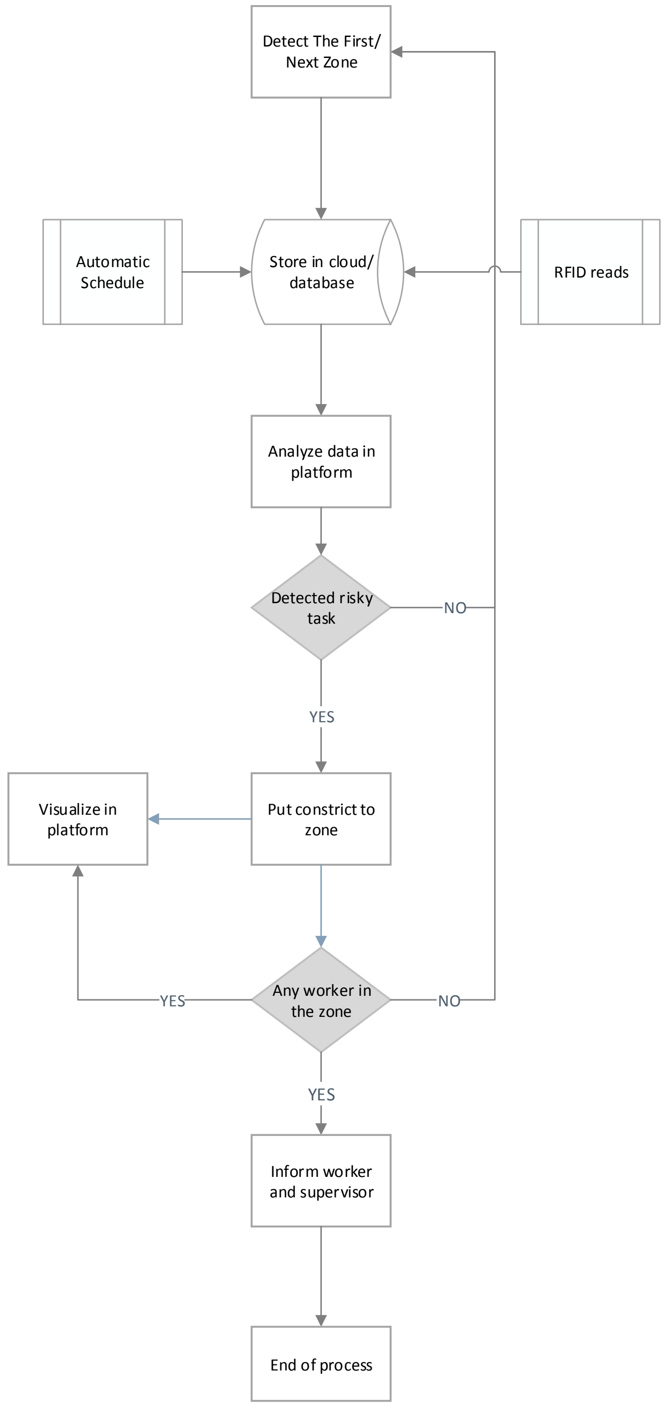


Figure 18: A typical flowchart for zoning the site by gathered data, own creation

Besides the information that the tag provides in terms of localization, access and awareness, codes associated with each tag can be used in conjunction with information database on the workers presents on the construction site. In case of an event, important information on the worker, such as medical history, blood type and allergies, can be easily retrieved and provided to emergency personnel.

Planning

As mentioned in the chapters above, there is a direct connection between the selected three areas of interest. Defects and Health and Safety issues have a great influence on the planning of any construction project as these can add to the time frame of a project leading to increased costs.

Planning wise, the implementation of a RFID system has a great potential for identification of manpower and assets throughout the construction site. Information received from the RFID tags allows project managers to observe the behavior of workers on site, congestion areas and wasted hours.

A study conducted by Costin, et al., (2015) on the use of RFID for monitoring manpower offer great results on this topic. In the figure below, it can be observed how the number of workers for different trades increase and decrease over the studied period for the analyzed location.

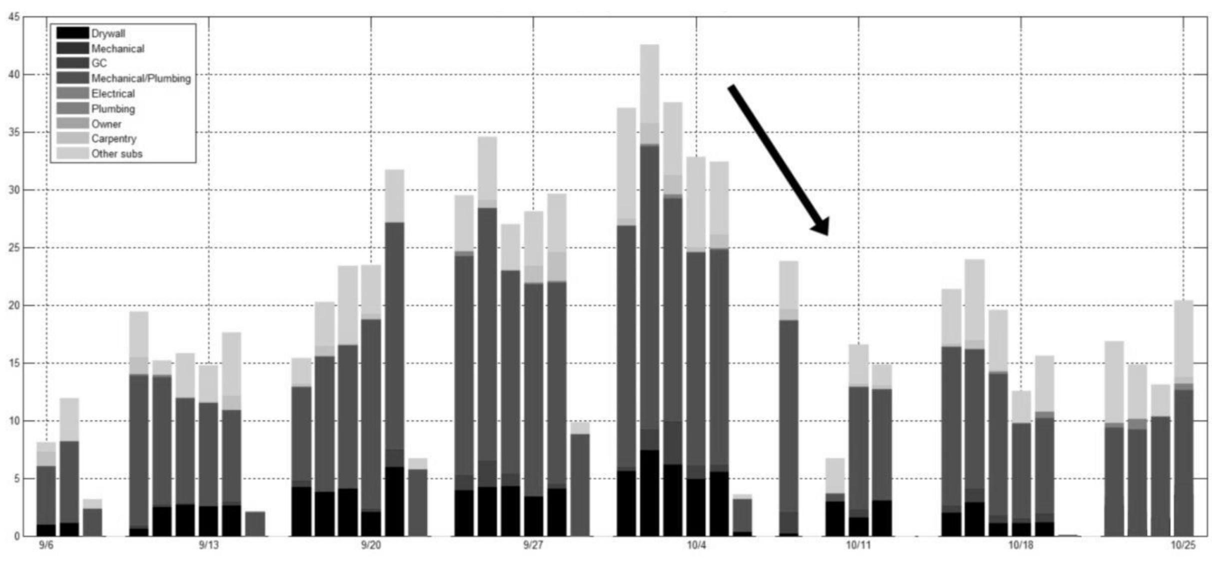


Figure 19: Reducing the number of workers and ending some tasks in the last week. Source: (Costin, et al., 2015)

With implementation of a RFID systems, organizations can achieve reductions of labor costs of a mean 40%, this figure will depend, of course, on the way the system is implemented and used. (AMG, 2014)

Alternatively, the implementation of RFID for monitoring personnel looks at a substantial reduction in Health and Safety issues through a proper management of personnel, limitation of access and notification in situations of great risks. (AMG, 2014) and (Caterpillar Inc., 2016)

Data gathering and storage allows project managers to create knowledge from each project where the system has been implemented. Through the created knowledge, managers can diffuse the learnings and mistakes from each project, ensuring that unpleasant situation do not re-occur and that productivity and quality are improved while wastage is reduced.

4.2.1.5 IoT control and monitoring platform (ICMP) for RFID

Companies using the Internet of Things related technologies are highly dependent on manufacturer's software and APIs which are designed and specialized for that specific solution. This matter gets higher prominence when various technologies and products from different manufactures are simultaneously utilized in a project to gather real-time data for processing and analyzing. Philosophy behind the IoT platform comes from the perception that these technologies should be thoroughly integrated and controlled by a flexible platform compatible with BIM models, installed IoT system and smart sharing devices. ICMP can be defined as a jumping-off point for linking the IoT allied components to the end devices through device and data management. (Singh, 2016)

Signth (2016) describes ICMP as a cloud-based connector linking the data network and the sensors by using specialized applications with the purpose of managing the data gathered by network of sensors. The importance of IoT platform has prompted big enterprises to have their own platform and, as predicted, that the total value of IoT platform will go beyond of one billion dollars in 2019.

While initiatives, like Amazon and Microsoft, have already deployed their own IoT platform, the conducted literature review revealed that such a system, specialized for construction industry needs, doesn't commercially exist.

Deploying an IoT platform, as a connector between objects, systems and people, requires some intrinsic features like database, network connection, processing and analytics applications and wide range of interoperability for upcoming needs (Scully, 2016). Adapted from Scully's platform structure, Table 6 elaborates some of these features in a new array for establishing an IoT platform, as a concept, for RFID methods offered in this study.

<table>
<tr><td rowspan="9">Cloud/Database
A cloud-based storage and applications for shared contents</td><td colspan="2">Connectivity and interoperability
Ability to incorporate different data formats compatible with platform UI and backend apps.</td><td rowspan="9">Additional Interfaces
Integrated with other IoT devices and APIs</td></tr>
<tr><td colspan="2">Rule engine
Complex algorithm for checking the rules</td></tr>
<tr><td colspan="2">Device administration
Monitoring status of connected devices, connections and applications on the clouds</td></tr>
<tr><td colspan="2">Processing
Gathering raw data from different IoT technologies, sorting and processing data</td></tr>
<tr><td colspan="2">Analyzing
Complex data analyzing, estimation and prediction by both mobile and cloud-based applications</td></tr>
<tr><td>Risk Management
Issue warnings and take decision on base of rules and estimation</td><td>Learning Machine
Smart learning from actions and processed data for further decisions</td></tr>
<tr><td colspan="2">Data Visualization
GUI for shareholders of trinary critical areas, compatible with PCs and mobile operating systems</td></tr>
<tr><td colspan="2">Security
Whole the platform should be secured by security protocols readable by smart devices</td></tr>
</table>

Table 6: Features required for an IoT platform, Adapted from (Scully, 2016)

Gathered data from different RFID tags are sent to the ICMP and according to the type of tag, these data are sorted and transmitted to the appropriate application to be processed.

Looking at the work process for the RFID system, we can observe by following Figure 20 that data are produced by the Receiver after a tag has been read. The information is further stored on a cloud system which is defined by the organization and is not being examined in this chapter.

The IoT control and monitoring platform will pull Tag data and merge them with construction plans obtained from the BIM 3D model. The operative responsible for processing data, this might be a BIM Technician or BIM manager, will analyze data and ensure data will be available for accessing by the relevant departments.

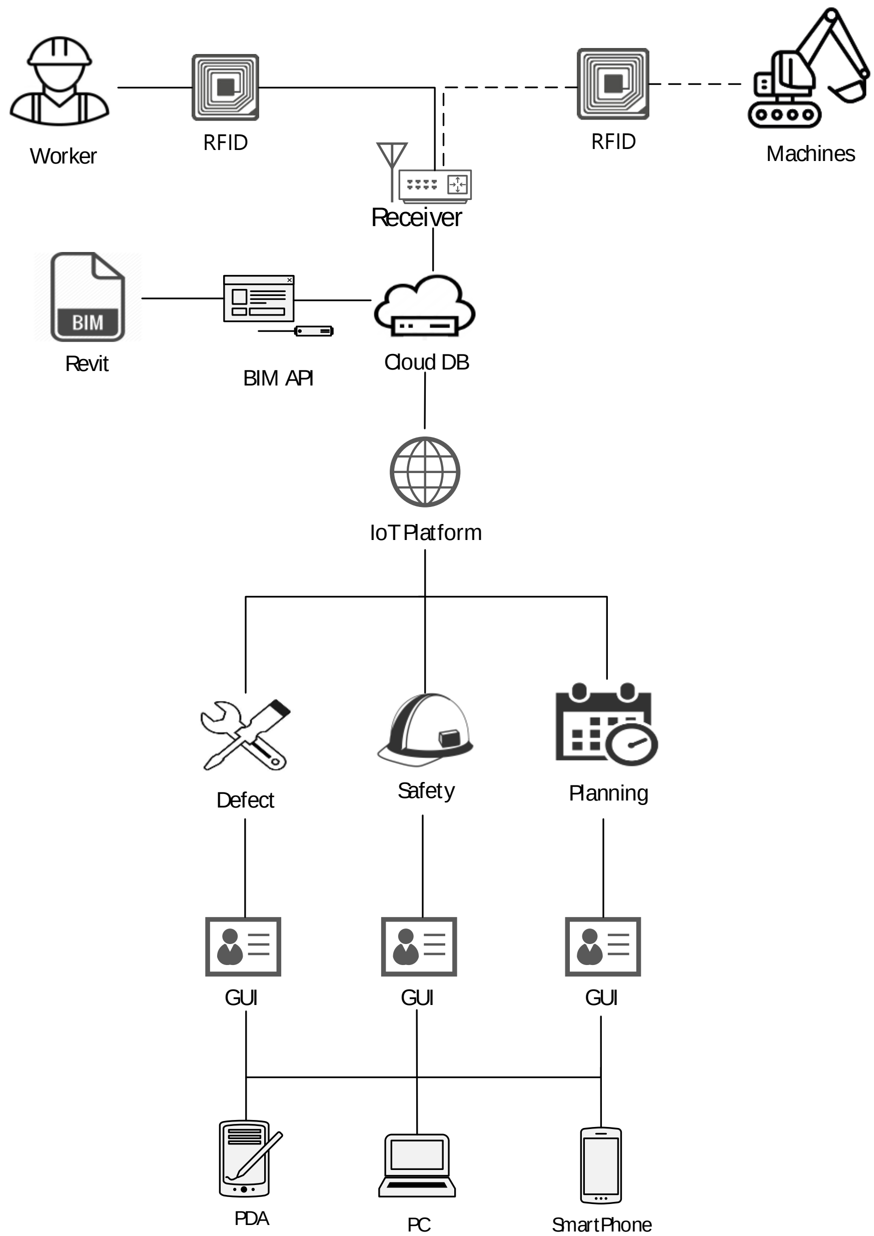
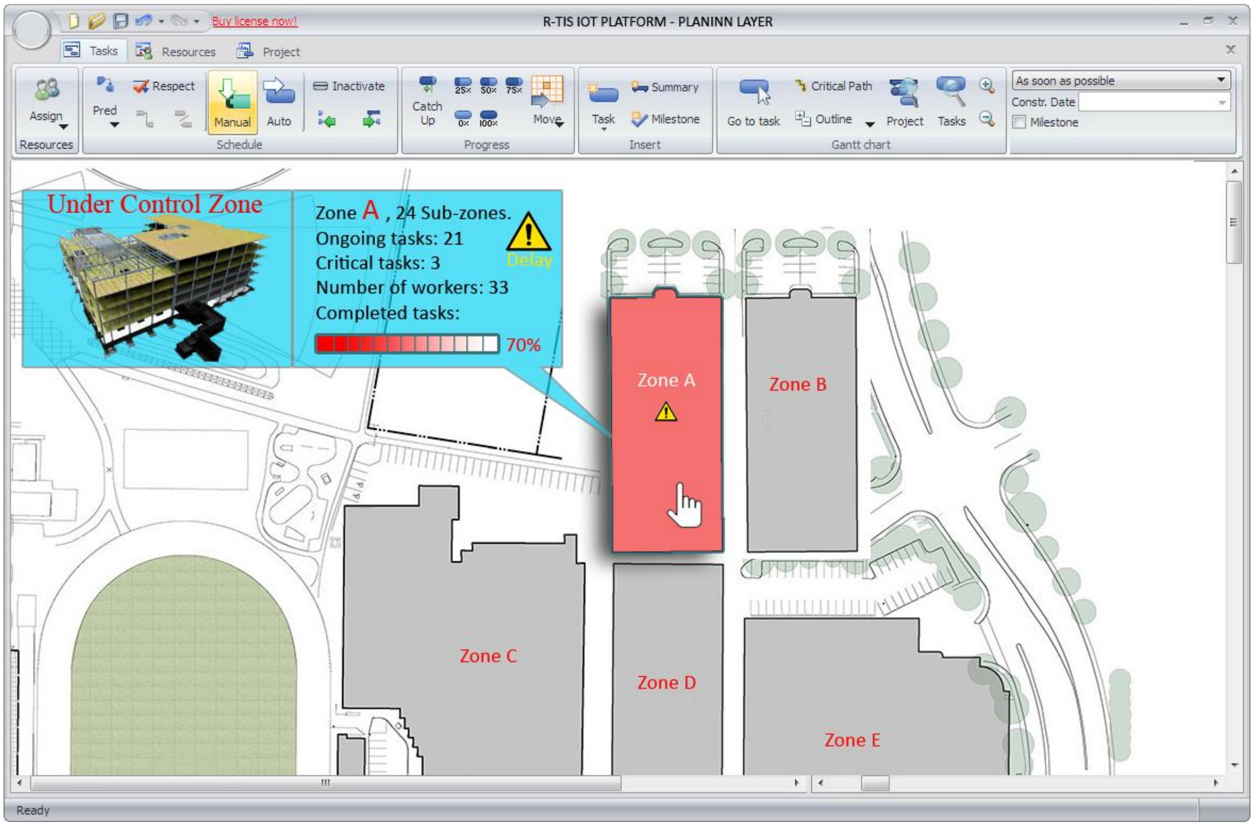
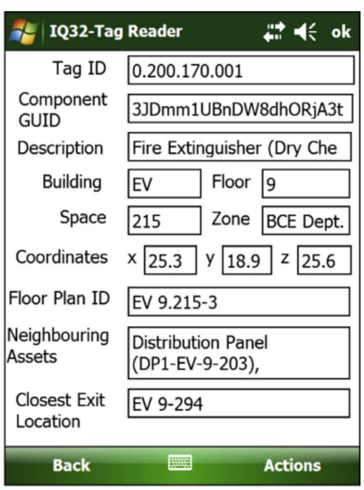


Figure 20: Schematic view of RFID process in three fields

ICMP platform allows the operative responsible for its running to observe the changes in the site through the read data from the tags. As mentioned above, some of the aspects that can be observed through the platform are the location and number of the manpower on the construction site, congestion areas, limitation of access to personnel and other. In Picture 3, a construction site is displayed in the UI of the IoT platform. Selection of an area of the site allows the operative to see the number of tasks and number of workers within the selected area. In the event of an unauthorized access, information on the wearer of the read tag can be viewed and appropriate actions can be taken before incidents can occur.



Picture 3: A sample of user interface in the planning layer



Tag ID: **2001**	Full Name: **John Art.**	Job: **Electrician**	Contractor: **J.K TT**	Employee No.:**J2201**		
Entry point	Entry Time	Exit Point	Exit Time	Zone	Sub-zone	Constraint
Main Gate A1	08-06-2017 - 08:01:25	Room4- A1	08-06-2017 - 09:30:22	A	Gate A1	
Room4- A1	08-06-2017 - 09:38:22	Room11-A2	08-06-2017 - 11:30:04	A	1	
Room11-A2	08-06-2017 - 11:30:22	Room14-A6	08-06-2017 - 11:35:02	A	2	
Room14-A6	08-06-2017 - 11:35:02	Room1-N11	08-06-2017 - 11:37:39	A	6	**WELDING**
Room1-N11	08-06-2017 - 11:57:35	Room 1-A5	08-06-2017 - 12:17:10	N	11	**Unauthorized**
Room 1-A5	08-06-2017 - 12:17:10	Lift	08-06-2017 - 12:18:35	A	5	
Lift	08-06-2017 - 12:18:35	A20	08-06-2017 - 17:02:01	A	20	
A20	08-06-2017 - 17:02:01	Main Gate A1	08-06-2017 - 17:10:01	A	21	

Picture 4: Schematic view of a zone violation, Adapted from (Costin, et al., 2015)

Picture 5: A plug-in for sorting the tag's data (Motamedi, et al., 2013)

4.2.2 Drone laser scanning and photogrammetry

Utilizing the UAVs (Unmanned Aerial Vehicle) dates back to 1920s with concepts similar to those today being found as early as 1960s. However, it is around a decade ago that using UAV has gained in popularity in the civil industries such as agriculture, post and delivery, oil and gas explorations, surveying, inspection and security surveillance. Table 7 reveals the milestones in the UAV evolution. (Keane & Carr, 2013)

Year	Company	Type of Drones
1922	US Air Force	First radio controlled UAV by British RAE
1944	German air Force	Combat, WWII
1955	US Navy	Combat and Intelligence
1964	US Air Force	Combat, Used in Vietnam War
1973	Israel Air Force	Combat, Carried anti-aircraft missile
1991	US DoD	Combat, Used in Gulf War
~2010	N/A	First UAV for Surveying

Table 7. Drone evolution history, Source: (Keane & Carr, 2013)

Advancement of the GPS and gyroscopic portable devices, telecommunication systems and transferring the UAV technology from military section to civil industries contributed to a great surge in utilization of UAVs. Usage of UAVs in the construction industry lags behind other industries like agriculture, energy and even post and delivery. Reasons like national restricting rules, technical expertise in controlling the drones and difficulties in the processing data have prompted site managers to overlook the benefits of the drones' applications in the projects. (Siebert & Teizer, 2014).

The reviewed literature allowed the observation of a variety of forms of UAVs. These can be either drones, planes, copters, quad-copters and other. For the conduction of this report, there has not been prepared a thorough investigation on the types and, challenges and benefits of these types, and as such, within this report, the terms UAV, drone, copter, quad-copter and the like are considered to refer to the same element – unmanned aerial vehicle.

On the use of UAVs in construction projects for purposes like site inspection and health and safety and measurement, case studies show that with the increase of needs and complexity of tasks of the construction projects, UAV hardware and software companies have been inspired to redefine their solutions for construction projects by adding new abilities to their products. (Brasfield & Gorrie, 2017).

4.2.2.1 Laser scanning in construction

A reduction of costs of the laser scanners and increase in the number of sub-contractors who implement 3D scanning services, tendency to use the laser services has also increased. Proliferation of diversity of the professional scanners, accessories and the proficient labors in both software and hardware sections are changing the outlook of this technology in the construction industry and it is expected that the market of 3D modeling by laser scanners in fallowing years will be blooming. Number of articles that directly subjected the 3D laser scanning has increased, especially after 2010 and it shows the science and the industry tendency towards cloud-based 3D modeling. The competence in offering the functional solutions for integration of BIM and laser scanners between giant software companies, contributes to the next level of mature software. Faro's PointSense and PointCab 3D Pro are two instances of these types of software which both are compatible with BIM tools like Revit. (Yoders, 2014)

Laser scanning faces many barriers to be widely implemented in the construction industry. A professional package including a terrestrial 3D scanner, software and training expenses will cost around $60000. However, an article in Redshift for Autodesk (2014) argues that this investment in comparison with its benefits will be negligible and it pays off all the casts, by saving time, cost and labors, probably after first or second project. In addition to the implementation costs, there is a resistance from the managers who are remaining on the traditional modeling methods, while technology and new needs are pushing this technology inside the industry, the industry still is pulling it away. To sum up, it seems that the main obstacle of widely implementation of laser scanners is not only the cost, rather it is lack of organizational knowledge and expertise in establishing and implementing the technology. As laser-scanning equipment is getting more accurate, accessible and cheaper, the 3D scanning and point-clouds modeling has significantly become easier and more functional in the projects. (Yoders, 2014)

Using UAVs

The use of UAVs for 3D laser scanning purposes has entered the civil market quite recently. As already mentioned, as-build mapping is one of the main features of 3D laser scanning in the construction projects for modeling the structures, construction sites and earthworks. Laser scanners can create accurate 3D models of available structures in the site that used for BIM modeling, progress comparison, estimation and inspection. Surveying with the use of a LiDAR mounted on a UAV as a fast and precise solution of measurement is being employed at an increased pace due to a consistent interest from clients. Since the laser pulses can penetrate over non-rigid objects, this is a reliable solution for mapping of non-clear surfaces, for example when it is covered with leaves, or even in bad weather conditions such as fog, snow and rain. (Corrigan, 2017)

UAV photogrammetry opens new horizons for modernizing the aerial photogrammetry in a more precise and economical way (Eisenbeiß, 2009). Traditional photogrammetry, as it literally means "light drawing measurement", is the technique of measuring surfaces by putting pictures together.

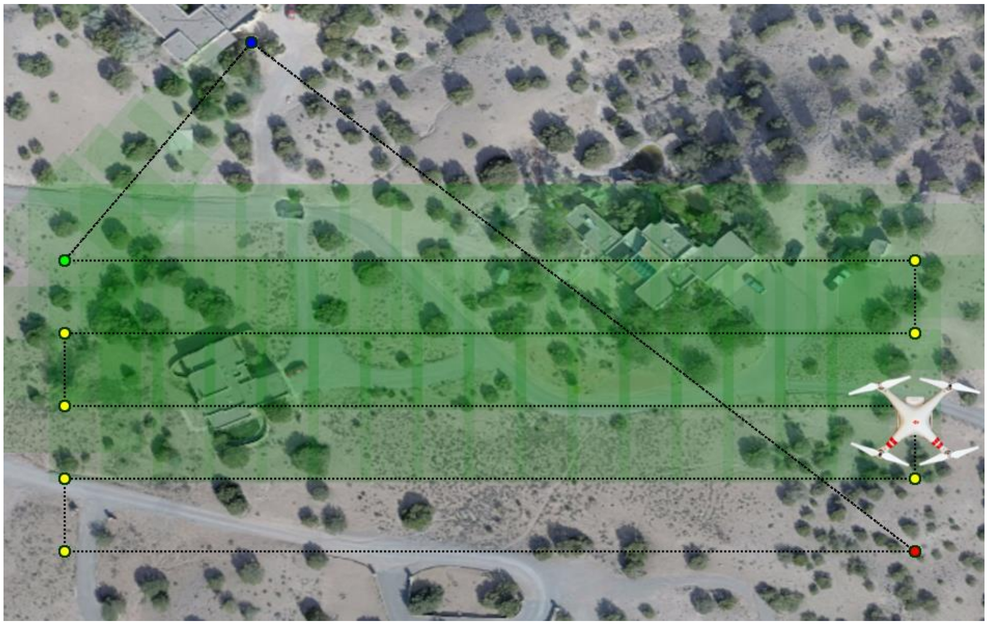
In other words, it is obtaining precise measurement of environment through several disciplines like optics and geometry techniques. Modern photogrammetry, however, goes further than bare photography and it is integrated with other technologies, such as 3D point cloud mapping, lasers and high-resolution cameras, to yield more accurate coordinates for mapping and inspection. With a sophisticated algorithm like stereoscopy, modern photogrammetry has a potential to records 3D coordinates of points by taking multi positional photos. Pix4D for example, a set of commercial photogrammetry software, uses the similar technique, to make 3D coordinates of taken photos. As a result, it is an estimating method, used for obtaining the 3D coordinates with multi positions photography. In this method, each photo generated of integration two or three photos taken from different positions. (Photogrammetry, 2017)

In the aerial photogrammetry, the camera is mounted in a UAV and it is manually or automatically controlled over the project. The affordability and benefits that drones bring to the industries caused the interest for utilizing drones for photogrammetry to increase since 2010, the year that they have started serving the projects mostly for mapping. Table 8 reviews some of articles published on photogrammetry in the construction industry.

Year	**Topic**	**Reference**
2009	Features of UAV photogrammetry	(Remondino, et al., 2011)
2011	3D mapping with low cast drone	(Neitzel & Klonowski, 2011)
2014	Photogrammetry and computer modeling	(Barazzetti, et al., 2014)
2008	UAV mapping for low altitude photogrammetry	(Zongjian, 2011)
2014	Earthwork 3D mapping by UAV	(Siebert & Teizer, 2014)
2015	UAV for topography	(Gonçalves & Henriques, 2014)
2007	Combining photogrammetry and laser scanning	(Lambers, et al., 2007)

Table 8: Papers published on UAV photogrammetry and point cloud

UAV mapping is creating 2D and 3D maps by scanning with a drone that has a photo camera or a laser scanner mounted to it. Picture 6 illustrates drone mapping with parallel grids scanning. This method of photogrammetry is called Nadir and the lens of camera in this method is set straight down and taken pictures overlap each other so that they are merged by software. (Photogrammetry, 2017)



Picture 6: Drone mapping parallel method, start from green point and ends in red point, Source (DronesMadeEasy, 2017)

Undoubtedly, the integration of the modern photogrammetry methods, such as the drone photogrammetry, the laser scanning and BIM commercial software will facilitate the surveying, inspection, maintenance, safety and surveillance processes. UAV imaging, in both safety and maintenance, has recently attracted a lot of attentions of many industries and scholars. Energy department of Aalborg University, for example, is working on a laser-scanning drone to inspect the blades roughness with high-resolution camera. (Madsen & Nikolov , 2017)
The selection of each of these technologies depends on type of work and good perception of their benefits and limitations.

Figure 21 demonstrates the limitation of UAV's operation for laser scanning and photogrammetry. Although the laser's accuracy is much higher that its rival, but its coverage area is limited to 4000m^2. The accuracy in scale of millimeter makes the laser scanner the good choice for high precision works like BIM modeling.

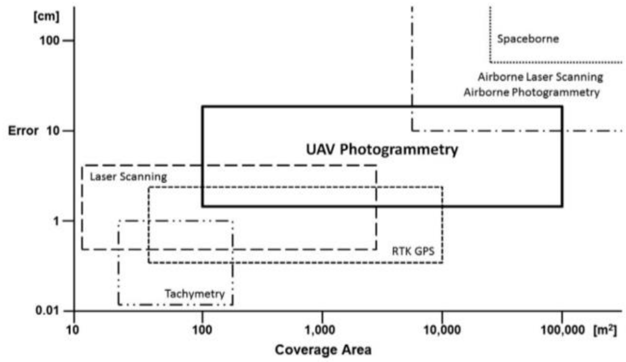


Figure 21: Laser scanning and photogrammetry limitation, Source: (Eisenbeiß, 2009)

4.2.2.2 Examined technical solution

In terms of structure and type of flight, Siebert and Teizer (2014) have categorized the UAVs into four categories, Helicopters, Airships, Fixed wings and Multicopters., due to features like high flexibility, very low costs, high setup time and simplicity of implementation, are the better choice for limited surveying purposes. In terms of range, U.S. Department of Defense (DoD) has enumerated five distinct groups from 1200 ft and less than 100 Knots to 18000ft and very high speed. Table 9 deliberates the DoD's categorization for five groups of UAVs. (DoD, 2010)

Category	Size	Maximum Takeoff Weight (Kg)	Normal Operating Altitude (ft)	Airspeed (Km/h)
Group 1	Small	0-10	<1,200	<185
Group 2	Medium	11-28	<3,500	<460
Group 3	Large	<660	<18,000	<460
Group 4	Larger	>660	<18,000	Higher speed
Group 5	Largest	>660	>18,000	Higher speed

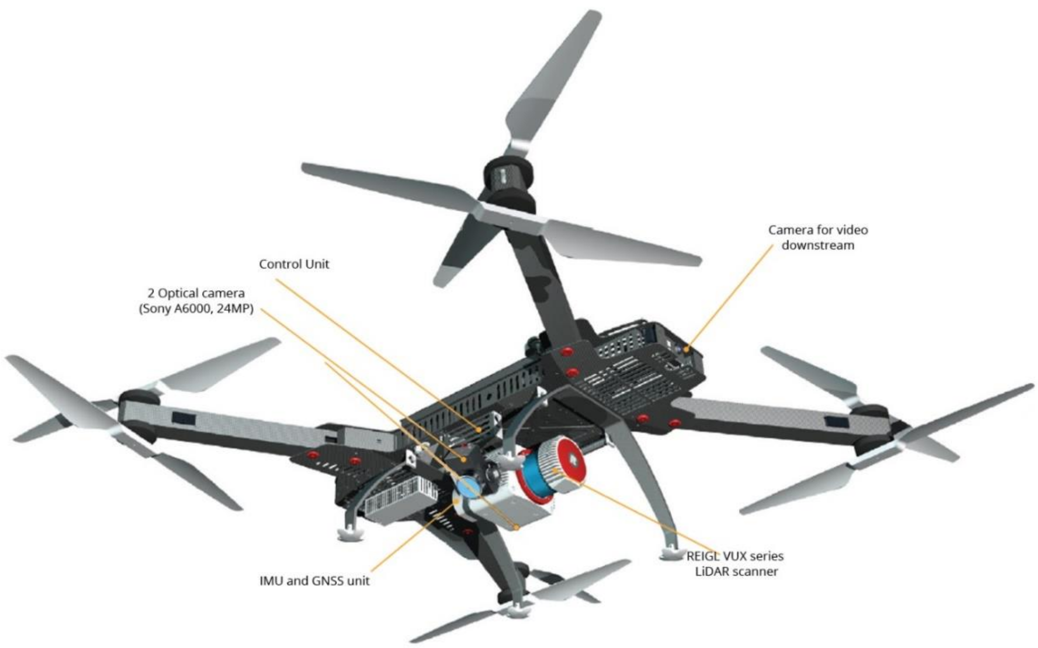
Table 9 – Type of UAV in terms of range and speed, Source: (DoD, 2010)

Consequently, for the monitoring, inspecting and 3D modeling of a construction site, this paper suggested the drones would be a medium size Quadcopter which is placed in the Group 2.

Between available commercial companies, Reigl, an Austrian company active in UAV-based laser scanning, is offering several packages for airborne LiDAR services for the construction projects and the company has also collaborated by providing costs for their equipment.

It is acknowledged that existence of many vendors on the market that provide similar services and for the purpose of this report, we will look at what the company Riegl is offering in terms of UAV devices with abilities of laser scanning and photogrammetry.

Reigl has been an active company on the construction market for over 30 years now and it is offering ready-to-use services for its clients consisting in UAV devices with the required control base and scanning hardware. In their provided packages, the required software for using the UAV and processing the gathered data is included. It is expected that, by using a package consisting of hardware and software produced by the same vendor, the interoperability is higher resulting in higher productivity. Following the description provided by Riegl, their UAV weights around 11kgs and a packed size of 620x980mm. The equipment is a Reigl drone, RiCOPTER, and it is equipped with IMU (Inertial Measurement Unit) and GNSS (Global Network Satellite System). Cameras mounted onto the unit allow for video streaming, photogrammetry and the LiDAR unit allows for 3D laser scans. (Riegl, 2017)



Picture 7: RIEGL RiCOPTER and VUX-SYS, Source: (Riegl, 2017)

VUX features		**RiCOPTER features**	
Max range	550m	**Max. altitude**	10,000 ft
Min range	3m	**Speed**	60 Km/h
Angle coverage	230°	**Flight duration**	30 min
Error range	10 mm	**Engine**	Quadcopter (TBA)
Lase safety class	Class 1	**Control unit**	Ground station PC
IMU and GNSS accuracy	Less than 0.03°	**Power source**	Battery (TBA)
Position accuracy	0.05 up to 0.3 m	**Dimensions**	640mm*980mm*470mm
Weight	2.5 Kg	**Weight min/max**	11 Kg / 25 Kg

Table 10: RiCOPTER product specifications, adaptation from Riegl (2017)

4.2.2.4 Looking at the use of UAVs for the three analyzed areas

Defects

The use of drones for inspection sessions allows a simplified inspection process of areas at considerable heights or hard to access areas, while at the same time improving time allocation and reducing risks associated with these tasks. Making use of the photogrammetry capabilities of the system allows for a better site monitoring while the laser scanning device will aid in the preparation of the as-built documents and BIM drafting.

Rework accounts for 12% construction costs and any improvement in this field represents a great saving of funds and time (Love, 2002).

Drones can provide inspectors and HSE supervisors with real time data while increasing the speed, efficiency and precision of inspection. Detected defects can be quickly communicated to the sub-contractor for remediation. A drone can inspect for defects in the spaces that are not easy to be checked by personnel, for instance sidewall of high concrete reservoirs, bulwark of dams, high elevations of chimneys and inside of non-secure tunnels or trenches. Drones can also inspect the structural health, for example, they can inspect structural defect with very high-resolution cameras from several angles. These features not only reduce labors' working hours but also in can reduce the risk by deduction of effort intensive tasks.

Want, et al. (2015) argue that real-time quality inspection and early defect detection are the most important competitive advantages of drone in minimizing the delay and cost overrun. Programming the drone for periodic site photography and documenting the processed photogrammetric images contributes to effective monitoring of the site development and it helps managers to compare the project progression in different milestones.

Alternatively, calculating the volumes of earthworks by 3D surface mapping and terrain modeling can be carried out by drones more quickly and accurately than traditional methods. Combination of drones and commercial analyzing software, as DeployDrone, a mapping software producer, claims have great potential to increase the speed of point clouds modeling in BIM. In a case study conducted on Brasfield and Gorrie VDM by Lamb (2017), in a 240 Km^2 project, drone mapping decreased the modeling duration, especially amongst data gathering, by around five times. Drones also reduce number of labors and machines allocated to a task and this saving of resources entails improvement of project KPIs, such as ROI. In this case study, the main contractor, Brasfield and Gorrie, stated the following:

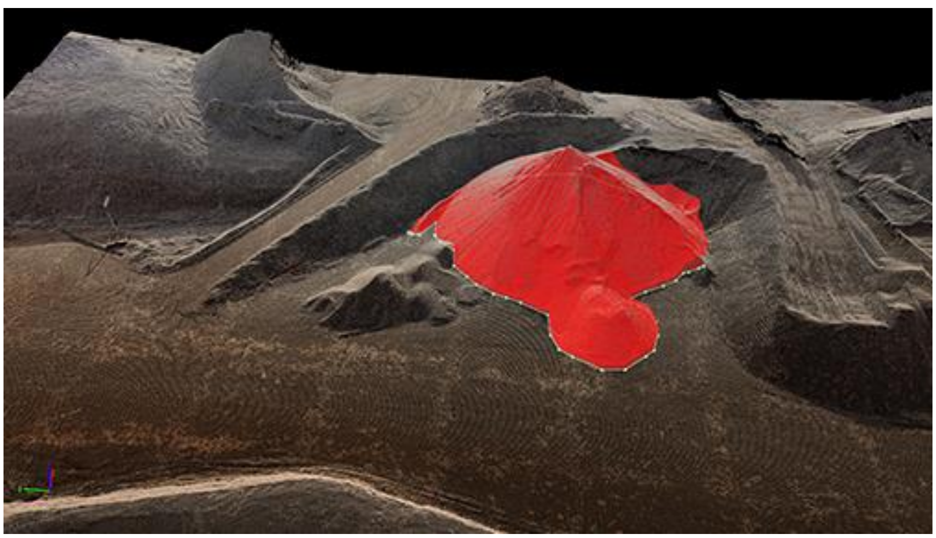
"Obtaining a point cloud of the entire site in a few hours using a drone is a huge benefit to the schedule and the budget… With a relatively small investment in time and money we were able to verify field conditions and complete an analysis that would have otherwise taken much longer and been much more expensive. We received a very high ROI in this instance." (Lamb, 2017)

Table 11 elaborates the difference between manual and drone mapping done by Brasfield and Gorrie Inc. for in a hospital construction site in Florida.

Mapping process	Traditional (Manual)	Manual time	Drone-based	Drone time
Preset	Accept survey	1-2 Days	Mobilize to site	1 Day
Data collection	Data gathering and post-processing	1-2 Weeks	Fly drones and data gathering	1-2 Days
Delivery	Delivery of CAD file and Contour map	1-2 Weeks	Delivery CAD file, Point Cloud	1-2 Days
Total time		**2-3 Weeks**		**3-4 Days**

Table 11: Comparison between manual and drone-based mapping, Source: (Brasfield & Gorrie, 2017)

The main applications of drones in earthworks are the measuring and volume calculation. Picture below shows the automatic volume calculation done by Pix4D software. The software analyzes the images taken by drone to make a 3D figure and consequently, the actual volumes with the design volumes are compared and the difference can be sent to the site manager to be confirmed.



Picture 8: Measuring the volume of earthworks by Pix4D software, Source: (PIX4D, 2017)

Health and safety

In terms of health and safety, the main focus is directed on the drone's potential to identify the risk area and inherent hazards. For reducing the risk, one of the influential measures is facilitating and automating the risk identification process.

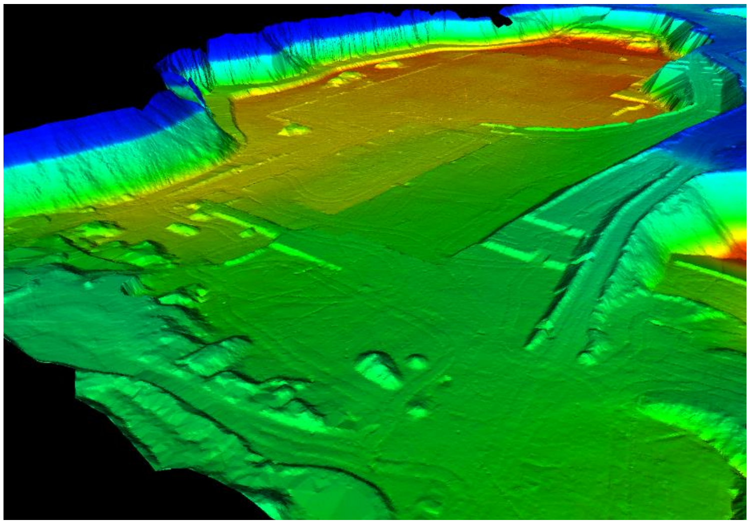
Recently, number of researches has been done on automating the risks in BIM. Zhang et al., (2013) has proposed an automated platform in order to check the fall hazards in BIM models by evaluating the model properties with a database of safety rules and instructions. The result of these attempts, which are focused on indoor spaces, defines the risks and offers precautionary measures, for e.g. installing guard rails or scaffolding.

Focusing on outdoor surfaces, the drone can create both 2D and 3D photos of the site in order to detect the potential risks in the site. For instance, if the excavator is supposed to excavate a trench with the area of $50m^2$ and depth of 4 meter, violations of the dimensions can increase the risk of fall, especially when safety instrument has been considered for the design dimensions. The analyzing software can calculate these dimensions without any needs of manual measuring.

Moreover, the images captured by drone can also be processed to give overall view of the site for inspection purposes. The operators can zoom-in the high-resolution 3D maps for detailed inspection, such as the structural elements, leakage, and other. The overall view can be helpful for asset management, for example, the array, numbers and status of assets can be easily observed and monitored. Similarly, drones can downstream the real-time video for surveillance purposes, especially for the tasks located in the hard-reachable spaces. In a case study, Hover Visions, an American company specializing in aerial video and photography, worked on a very high-resolution aerial photography for increasing the resolution of mapping in order to monitor risk of leakage during construction of concrete reservoirs. Picture 9, illustrates the construction site status including assets array and current tasks.

Picture 9: Overall view of a construction site, photogrammetry by drone. Source: (Austin Surveys, 2017)

3D laser point-clouds create precise 3D coordinates of the construction site for measuring the elevation of terrains, earthworks, structures. This method can help to find critical areas in the site, by visualizing the elevations with different colors (Austin Surveys, 2017). Picture 10 illustrates the drone laser scanning of a site after earthworks for calculating the volume by elevation difference method.



Picture 10: Measuring the elevations of a topography by drone laser scanning, Source: (Austin Surveys, 2017)

Planning

Estimation of construction projects is done based on a set of data that are available at the start of the project. The project plan and the project schedule are set based on these data. Project managers in charge of conducting the estimation process of a project are working on secondary data or even on incomplete data.

Higgins (2004) argues that the costs of project rework can reach 1%, for greenfield type projects, and between 5% and 10% for brownfield projects. Higgins further states that these costs can be mitigated through the use of UAV scanning processes.

Looking at the study conducted by Vincent and Ecker (2010), an increase in productivity can be observed through the use of UAV surveying. Compared to traditional methods of surveying, the UAV has brought an approximate 300% productivity increase for this process for the studied project.

UAVs can be equipped with various scanning devices, in this report being examined only LiDAR and Photo Cameras, that allow the capture of existing site situation for various activities such as site planning, site surveying, 3D modelling, site inspection and H&S coordination and other.

3D modelling enhancement through the use of LiDAR and Photogrammetry has been assessed by Autodesk, for the refurbishment of their Toronto regional office. In a case study released by the company, it was advocated that the use of LiDAR scanning allowed 3D modelers to incorporate as-build elements from the site with focus on modeling of on-site made bricks that have been used for the construction of various elements in the building. The scan has save the organization a considerate number of hours that would have been allocated for site measurements. (Attar, et al., 2010)

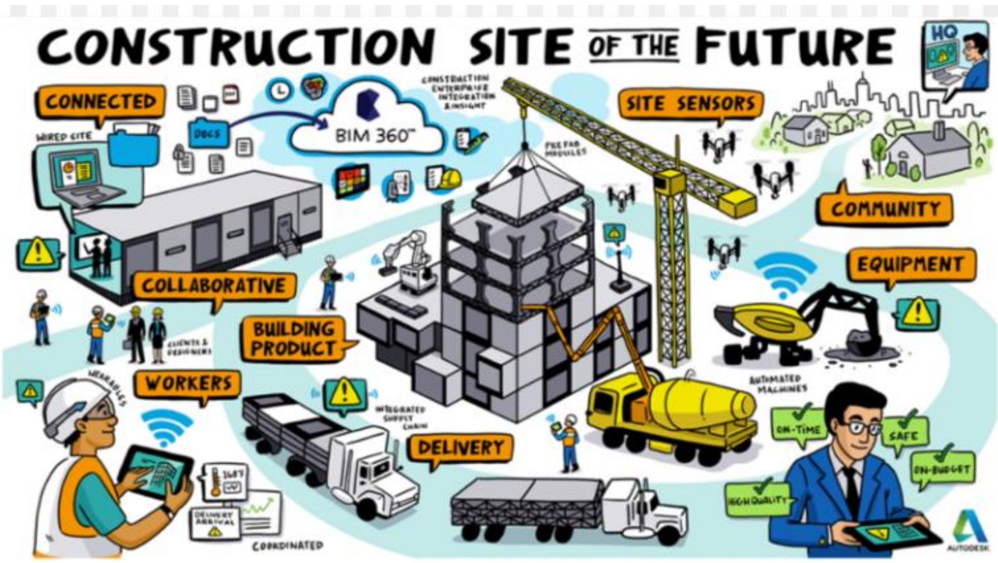
Use of UAVs for site assessment allows the site management to inspect and detect defects in certain areas where the inspect would require special procedures. Gabrin and Budny (2017) claim that use of UAV for the assessment of civil structures, such as tall bridges, towers and other, allows for a better evaluation of the works and the condition of the construction with a considerable reduction in preparatory and safety works.

By reducing errors and rework time, this technology can impact greatly the project schedule. When discussing LiDAR surveying, Higgins (2004) claims that 'avoiding the costs of schedule overruns – lost capacity in process and power plants, added days of traffic lane closures in transportation projects, lost production on offshore platforms, lateness to market and lost opportunity in consumer products – can have even greater economic impact than reducing direct project costs'.

4.3 Connection Internet of Things and Building Information Modelling

Internet of Things is the new trend in the world of Informational Technology, IT. The first usage of the term appeared in the end of the '90s when Kevin Ashton used it to sketch an internet connected network of everyday objects. Ashton later coined the term as when he described the benefits that RFID tags bring to organizations by gathering data from the supply chain on the handled products. (Rose, et al., 2015)

Cisco, a company specialized in providing networking solutions, has estimated that the internet traffic produced by non-PC hardware will increase from around 40% in 2014 to around 70% in 2019 while the number M2M will increase to 43% in 2019 from a 24% in 2014. The company estimates that in 2020, the number of internet connected hardware will be 3 times higher than the global population number. (Cisco, 2015)



Picture 11: Depiction of "Construction site of the future" (The BIM Hub, 2016)

So far, the global IT community has not managed to offer a standard definition for Internet of Things. IoT has been defined in different way by scholars, researchers, professionals and innovators. It was observed that, among all different versions of its definitions, all revolve on the concept that IoT is working with data produced by things. One can say that with IoT, elements that belong to the "things", either physical or virtual, are transformed into producers and consumers of information. (Isikdag, 2015)

Looking at the construction industry, Internet of Things has been employed in many elements within this industry. Ranging from smart thermostats to smart sensors measuring different variable or even to tracking devices for the supply chain, available literature stipulates that IoT, although at an incipient phase, it has produced promising data with space for more.

Analyzing the possibility of connecting two major innovative solutions in the construction industry, meaning Building Information Modelling and Internet of Things, one must look at the basic elements that define the two.

Internet of Things is the mean through which two devices or two instances become connected over the internet with the scope of producing and receiving data. Building Information Modelling is a work process through which all data that is produced during all the phases of a construction project, from inception to commissioning are gathered to one place and managed accordingly.

Looking at the above, one can easily observe that the two is compatible in terms that one produces the data that the other is designed to manage.

In this report, the usage of a UAV Laser Scanning and RFID tags solutions for the use on construction sites with the purpose of improving selected aspects, is investigated.

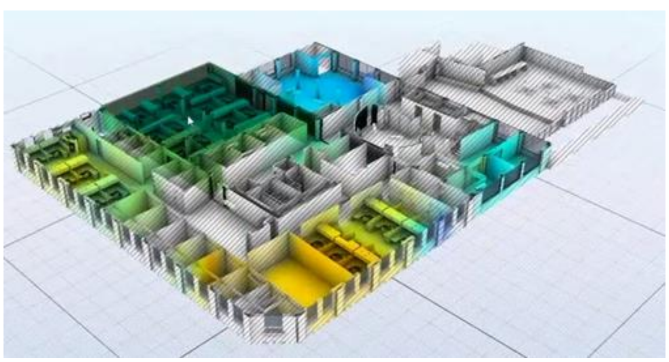
In order to facilitate the connection of "things", the supply of a connection bridge is required, meaning first step into connecting IoT and BIM is ensuring the supply of internet for the construction site. Internet connection will allow the transfer of data from one "thing" to another.

4.3.1 Connecting the two innovations

Project Dasher

Looking to understand the connections and benefits that can appear from linking Building Information Modelling to Internet of Things, The Environment and Ergonomics team at Autodesk Research has established a research project call "Dasher". The aim is to observe how the two innovations can work together and how data collected from various smart sensors can be implemented into a 3D BIM model for a better management of data and further for enhancing the facility management process for a building in case. (Autodesk, 2015)

Following a complete laser scan, an accurate 3D representation of the existing building has been produced in a point cloud file, which was further used for the creation of the digital 3D model of the project. This allowed the designers and engineers to capture realistic construction elements of the heritage building 210 King Street, Toronto. Data collected through a multitude of internet connected sensors placed in the building was introduced in the 3D model to create an accurate representation of the changes that occur in the building during normal usage hours, giving the facility managers the possibility to better address the issues arising and improve user satisfaction. (Attar, et al., 2010)



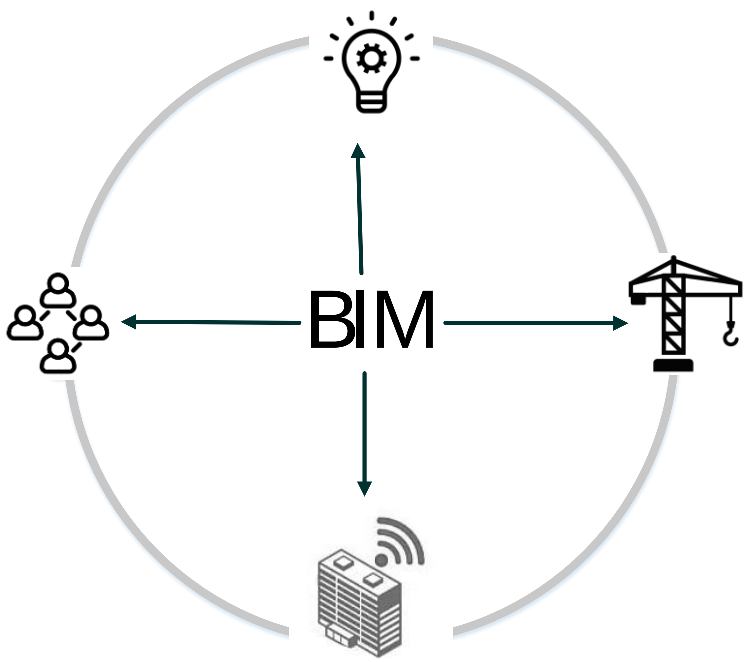
Picture 12: Project Dasher (Autodesk, 2015)

Connected BIM

The software vendor Autodesk, has released a preview in 2016 on the vision that the company has for the future of BIM and the future of the construction industry.

The construction industry has benefited greatly from the advancement of Information Technology and in an era where communication and connectivity is the core of any business process, Autodesk envisions BIM as an element that connects all aspects of the construction project. This means that Information will be in the center of all procedures of the construction process. (Autodesk, 2016)

Autodesk (2016) argues that by connection all elements in the construction project and in the supply chain, improvements can be achieved in health and safety, resource usage, quality and client satisfaction while increasing the life expectancy of the building. Cloud servers are envisioned to be the core of the transfer of information from one element to another, from one team to another and from one system to another.



Picture 13: BIM Connected, Adaptation from (Autodesk, 2016)

4.3.2. Drone laser scanning system and photogrammetry

Unmanned aerial vehicles, or simply drones, have started to be used in the construction industry more and more. The applications for such hardware vary depending on the necessities and can range from promotional activities to site surveillance or site surveying. In this chapter, we will discuss the use of UAVs for the purpose of site surveying and site surveillance through the use of laser scanning.

Laser scanners and UAV are two different types of hardware that when combined can be used for various tasks on a construction site. The laser scanner allows the user to record a multitude of points and their associated X, Y and Z coordinates while the UAV device allows the user to move the laser scanner from one location to another.

The limitations that apply to this report do not allow the authors to analyze the multitude of hardware solutions for UAV and laser scanners and their associated software. As such, in this chapter the discussion will take place from the point of data transfer from the UAV LiDAR to the BIM model and the method through which this can be achieved and further analyzed by looking only at software from Autodesk.

Looking at the analyzed technology from Riegl, producer and distributor of UAV hardware and software, the RiCOPTER drone examined in the chapters above benefits from a communication chipset. This allows the unit to transfer data from its scans through a 4G/LTE connection between the drone and the command unit. Depending on the requirements of the tasks that are undertaken, the choice of the data transmission method lays with the operator. The laser scanning unit that is mounted onto the RiCOPTER allows the user to transmit real-time data through the communication chipset to the server or cloud. Alternatively, where time is not a constraint, data can also be stored on the internal SSD drive incorporated into the unit for a later transfer to the server or cloud by the operator.

There is a large variety of file formats and extensions used by laser scanning vendors with their products. Most of these products will produce data in a proprietary file format and file extensions, while additionally allowing the data to be saved in a generic file format and extension. Data collection from laser scanning processes comes under the form of raw point collection which are further used for the creation of point clouds. Point cloud files aid the processes in the construction project by supplying real-world data for analysis and comparison with the 3D BIM model (Autodesk, 2015).

Information obtained from Riegl showed that the VUX-1UAV scanner incorporated in the examined system stores collected data as a “georeferenced, filtered, colorized point cloud” saved as a .RDBX file extension. (Riegl, 2017)

Looking at interoperability between the selected system and other available technologies, Raw point collection files can also be saved after the collection in generic file formats such as text, encoded either as ASCII or LAS. This means that, with the use of generic file formats, collected data can be transferred from one software to another, or from one system to another, without the dependency of specific hardware/software, thus allowing for a better interoperability. (Atlas, 2009)

The American Standard Code for Information Interchange, or ASCII, allows the storing and transfer of numerical data, under the form of text files, from system to another. Although allowing for a good interoperability, the downside of using ASCII is that, when working with great amounts of data, the file size can be considerably high. LAS file format is a generic and public file format that allows the transfer of LiDAR data between vendors and users. When compared to the ASCII file format, the LAS performs better as the use of a binary file format allows the preservation of data specific to the LiDAR without having to increase the size of the file. Additionally, most software solutions allow for direct import of LAS files into the program while with the ASCII file format, an additional process of reading and interpretation of ASCII data is no longer required. (PCI Geomatics, 2016)

Information provided from Riegl states that their file extension, .RDBX, can easily be converted into a .LAS file to further be used in analysis and data processing software.

Using Autodesk software

As mentioned above, in order to be used in BIM software, collected data through the laser scanning process need to be converted into a point cloud.

The company Autodesk has specialized itself in producing bespoke software for every part of the construction industry, from architecture to engineering, visualization and facility management.

Autodesk ReCap software is capable of transforming gathered data from a laser scan into a point cloud. The obtained information is further registered, analyzed and edited in order to create an accurate 3D image from the obtained points. Further, data that has been processed, cleaned and analyzed can be used in conjunction with other 3D software from the same vendor or from other vendors.

In a case study on the benefits of using ReCap software from Autodesk, it was observed that using point cloud imagery has allowed the project management to increase site safety and improve site comprehension through a better visualization of the work environment. (Nocera, 2016)

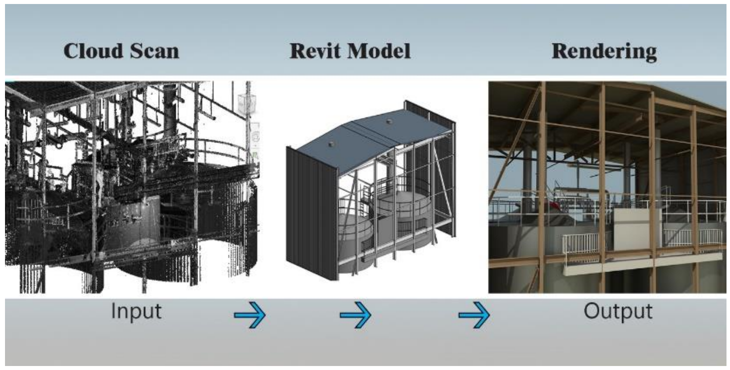
Picture 14: Brownfield site works with ReCap 360 (Nocera, 2016)

Autodesk ReCap is highly compatible with 3D processing software produced by the same vendor, thus when working with software such as Revit, AutoCAD Civil 3D, Navisworks, ReCap can become a valuable asset for the organization.

Riegl (2017) states that Autodesk ReCap can convert scanned data that has been saved as a .RDBX file extension into a .LAS file extension to further be used in Autodesk Revit.

Autodesk Revit, a software capable of handling Building Information Modelling allows for the import of raw point data from a laser scan directly in the 3D model. Since the data collected from scans is saved as a proprietary file format, this has to first be processed through ReCap and converted into a readable .LAS file format prior to its analysis in Autodesk Revit software. Import of the point cloud files into the Revit software is done as a linked element in the 3D model of the construction project. This allows the user to observe the scanned elements and easily analyze, compare and take actions based on real life data (Autodesk, 2015).

One mention has to be made as, when linking an external file to the central 3D BIM model, this linked file becomes part of the BIM model, yet it cannot be altered. The linked element will allow the user to use it as reference element when designing and analyzing the central 3D BIM model and any change that is required on the linked file can be made through the required software. In the case of a point cloud, the points cannot be altered through software as these are scanned according to existing site conditions.



Picture 15: From Point Scan to Revit (Bimservicesindia.com, 2014)

4.3.3 RFID

The transfer of captured data from RFID tags to a BIM processing software, such as Revit, is considered by specialists in the field as a great challenge as the data used in both systems is structured by different rules. Visualisation of real-time data captured from RFID tags in Revit is considered as being challenging and for this purpose, alternative solutions such as add-ins or proprietary software solutions are recommended. (Costin & Teizer, 2015) and (Pedersen, et al., 2008)

For suggesting a link between construction elements to the BIM, Pedersen, et al. (2008) proposed to create a link between BIM and physical objects in the construction process by using available ontologies. In the study conducted by Pedersen et al, an external software is designed to utilize the Revit files for visualizing the data in a new user interface. Since the size of data captured through IoT related technologies is of considerable size and may include redundant information of tracked assets, in many occasions visualizing all of the data is not necessary. The acquired data needs to be filtered in different layers and visualized when decision-maker or supervisor require this.

Looking at the above, Figure 20 in chapter 4.2.1 explains the layout of the system where information captured from man-power or assets is transferred from the tag to the IoT platform.

The ICMP platform is runs on information produced by tags, information which is captured by the received and further stored on the cloud server. In order to make visualization facile and further the interpretation of data accurate, construction plans and site plans are obtained from the BIM model and fed into the ICMP platform.

The transfer of information from the ICMP is done through a set of API protocols setup in order to have data transferred automatically when changes occur. Looking at an example, when site plans are altered in the BIM model, update of information in ICMP is done automatically through API, this reduces the risk of activity overlooking.

Data from tags are merged with data from the BIM model resulting in an aggregated model where information, such as activities conducted and manpower, can be observed by the operative.

Picture 3 chapter 4.2.1 offers an understanding on the use of the platform and the available information within this platform.

4.4 Product usage and scenarios

Through the Contextual Design process, a designer is allowed to gather information, analyze and interpret, create templates and last to test them based on data collected from the end-user. Contextual Design focuses on understanding of the end-user and its methods and procedures of conducting work in order to create the right product for the right user. This is done through in-depth discussions with the user to observe its work procedures and routines as these can sometimes be hidden from the view of the user through repetitive work. (Holtzblatt & Beyer, 1997)

Contextual Design was developed by H.R. Beyer and K. Holtzblatt and it has been developed for use in drawing up user interface products such as information technology systems and hardware. With uses varying from hardware and software solutions for IT to designing web based applications and web-sites and even to enhance courses at university levels, Contextual Design is considered to be a valuable philosophy for design based on the needs of the user. The core of Contextual Design is that "The system must support and extend users' work practice" meaning that in the situation that the product performs well, then it will be accepted and deemed valuable, while if the performance is low then the product it will create nuisance to the user which will lead to avoidance. (Holtzblatt & Beyer, 2017)

A design can be defined as a physical depiction of one's concepts or ideas. This can be written down, drawn or modelled in an IT system, and serves the designer to present his concept to the audience. In order to offer the reader of this report an understanding of the way the two technologies will be applied and will contribute to a better management of the construction site; a scenario will be presented in the following lines.

The scenario will make use of work models from the contextual design philosophy to better express the relations between the workers on site and the technology that is being tested.

Flow model charts found in Contextual Design allow the reader to observe the communication patterns that are present within a situation and responsibilities of the participants while, through sequential model chart the entire process can be observed from the inception to termination.

It should be noted that the following explained procedures are based on reviewed literatures and experience of the authors and are also conceptual. These procedures have not been tested on an actual construction site, thus providing room for further research on this topic.

There is no typical layout of the management team that will be assigned to a construction project as this is tied to the complexity of the site. It is often noticed that, as a minimum, the management team of the main contractor (MC) consists of a site foreman and a site manager.

For this scenario, there will be no BIM tasks attributed to the site management team. Following the above-mentioned changes that BIM implementation brings to the layout of an organization by opening new positions for key personnel in relation to Building Information Modelling, it will be considered that the MC has a separate department for these operations. A BIM Technician will be considered to undertake the below explained operations.

4.4.1 Drone Laser Scanning

The procedures undertaken by personnel is usually complex and full of detail, even though written down, these procedures do not seem to be like that. Designers that think systems and technologies have the important ability to observe structures and patterns in others' work and with the use of work models, the observed particularities of work are presented to others for analysis. (Holtzblatt & Beyer, 1997)

The first step in creating the work scenario is understanding the way communication between workers is performed and how they relate when participating in tasks. This will allow the readers to understand the parts the workers play and their responsibilities and communication patterns. These aspects can be observed easily through a flow model chart. (Holtzblatt & Beyer, 1997)

Looking at the situation of using a UAV for the purpose of laser scanning and photogrammetry there is a great amount of relations and constraints that apply to this process.

As mentioned above, the operation will be performed by the BIM technician as he will be able to understand the requirements of the tasks and the requirements regarding the data that has to be produced.

The BIM technician will be in charge of operating the UAV device and perform the scan of the required area/ object. Looking at Picture 16 in Annex 1 we can observe the tasks and responsibilities that the technician has in relation to the process.

When present on site, the technician must report to the site manager with whom he has to be in permanent contact. He will be informed of any changes in the site layout and any dangerous areas in regard to Health and Safety. The site manager has also to ensure that all subcontractors present on site are aware that a scan of the site is being conducted so as to mitigate any risks of collision between units and personnel and between units and units, as well as, to avoid any accidents by workers paying too much attention to the UAV and less to their environment/ work.

The areas to be scanned should be communicated in due time to the site manager to ensure that these are well accessible, personnel and equipment free (upon possibility).

From a sequential view, through a sequence chart, we can observe the process of scanning the site using UAV with a LiDAR as being straightforward.

The BIM Technician arrives at the site location with the intent of producing a scan of the required area using a UAV, so at the data that is produced during the scan can be used in the BIM model. The scans are expected to be scheduled in the project master schedule and to be performed at certain time intervals in the project, for e.g. weekly scan on Monday.

No.	Sequence
1	Set-up site meeting and send notification to interested parties
2	Arrival at site location
3	Inform Site Manager of presence on site
4	Attend site safety instruction meeting
5	Verify and equip health and safety equipment
6	Transport the UAV equipment at scan location
7	Install equipment on ground and ensure the position is horizontal
9	Startup system, verify parameters and check for error messages
10	Check power supply of UAV device
11	Check integrity of device and attached scanning units
12	Perform test flight at low altitude
13	Return UAV at base unit
14	Select area to be scanned by introducing data in the flight operating software

15	Select altitude of scan by introducing data in the flight operating software
16	Perform scan of the selected area
17	Verify transmittance of data from UAV device to base unit
18	Verify integrity of data transmitted
19	Upon completion, return UAV at base unit
20	Upload received data to cloud server
21	Verify transmittance of data
22	Start the process of packing UAV device
23	Verify all power supplies are switched off
24	Verify all security straps are fixed
25	Verify all locks are locked
26	Notify Site Manager upon completion of scan
27	Notify site security of leaving the site.

Table 12: Sequence chart (Own creation)

Steps 6 to 13 in the sequence chart show the steps that the technician takes to perform the setup of the equipment. The setup can commence only after the site manager has been informed of the presence of the BIM Technician on site and a briefing on Health and Safety has been performed.

The process of scanning will start by selecting the appropriate altitude of surveying and the area to be covered. Depending on the element or area to be scanned, the height of the survey will affect the quality of the scan. Scanning at a high altitude will reduce the quality but increase the coverage, while scanning at a low altitude will increase the quality but will require a longer scan. To produce accurate scans, the UAV path has to allow for overlapping between paths. In this scenario, it will be considered that the scan will be performed for a rectangular shaped area as per the example in Picture 6 in Chapter 4.2.2. Depending on the requirements of the scan, a UAV can perform circular scans where the focus is on elements and structures, rather than on areas. Reviewed case studies on the use of UAVs for scanning pointed out that better results come from scans with a minimum of 50% overlap.

As described in Chapter 4.2, the transfer of data is performed through the use of a communication chipset mounted in the UAV that will allow a direct connection to the cloud server for data saving and storage. The communication is being done through 4G mobile data connection.

Once the process of scanning has been completed, the drone will be driven back to the docking station for recharging (in case of multiple scans) and/or packing. The BIM Technician will finish the process by informing the site manager of the completion of the scan.

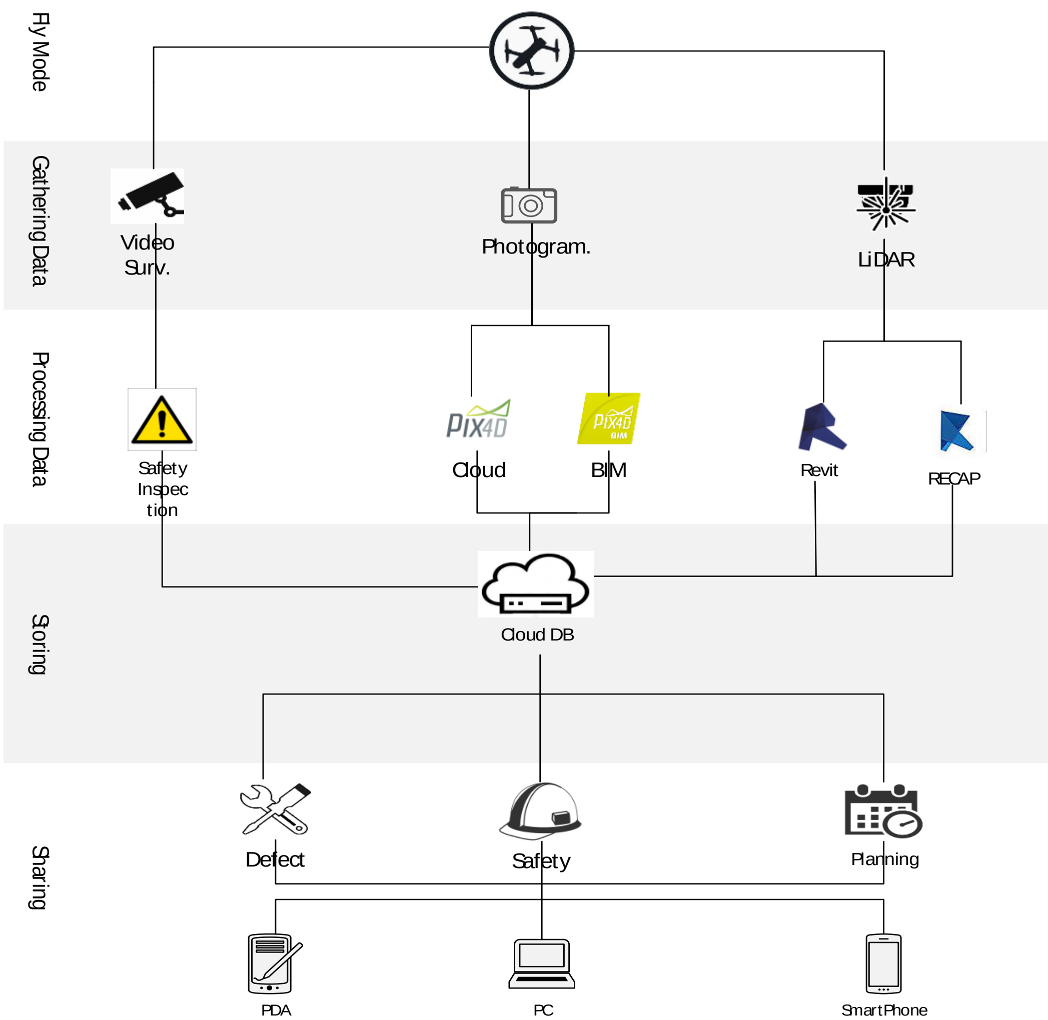


Figure 22: Drone's operation layers, own creation

Looking at the figure above, a schematic overview of the process for operating the UAV device for the conduction of scans is observed.

4.4.2 RFID Tags

Using the RFID tags on the construction site is a less complicated process than using the UAV for scanning a certain area. These tags will be mounted on the health and safety equipment of the workers present on the construction site.

In order for the system to function and data to be produced and recorded, the site manager, or health and safety coordinator, must ensure that safety equipment is being used by workers taking part in site activities. This responsibility is part of the Health and Safety procedures pack for site works and, at the same time, allows for the use of the tags.

As mentioned above in the description of the system, the information from the RFID tag will be captured by the receiver when a tag will come in its range. Through reading the information stored in the tag, the system will assess the wearer of the tag, its purpose for being present in the respective area and further the level of clearance.

In cases when unauthorized access is recorded, workers might be denied entrance or his present is announced to the operative of the system, either site manager or BIM operator/technician.

Information of present workers, on the work areas is available for analyzing and processing through the ICMP platform. This platform offers the read information to be viewed on an overlap with the existing site plans, extracted from the BIM model through a set of API commands.

5. Cost/Benefit Analysis for investment decision-making

In common terms, the cost benefit analysis is intended for assessing the net societal benefit of large projects that have an impact on the broader public, thus being considered a public policy assessment tool (Boardman, et al., 2006). This assessment has to be framed within a context, and in this case, the context is the civil construction industry project surveying. In these lines of thought, the mentioned drone technology is only a small component of the civil construction industry project surveying system, making the endeavor of this analysis a rather modest one, with the provision of the relative costs and benefits.

Like any other new technology, the adoption of both Drone Laser Scanning and Photogrammetry and RFID requires a thorough evaluation of the potential benefits they offer, benchmarked against the costs implied by fostering these technologies within the internal business model. This process is seen as vital in the decision making, as the end outcome of investing in such technologies might incur the business losses of any nature or it might end up profiting the project, thus benefiting all the shareholders.

Within the scope of the project, there is no relevance in discussing further the advantages and disadvantages of conducting such a cost benefit analysis; the following investigation can be perceived as a simplified analysis to aid complex decision making.

In order to achieve a leaner structure of the analysis, there will be a split between investigating the Drone Laser Scanning and Photogrammetry and the RFID.

5.1 Drone Laser Scanning and Photogrammetry

All throughout the project, it is promoted the idea that the Drone Laser Scanning and Photogrammetry technology has enhanced benefits to the manual methods of project surveying. The magnitude of these potential benefits has to be aligned with a convincing economic justification of employing the technology.

With considerations to the technology itself, the main product, as a result of its use, is the information on the building's condition, for example, if a wall is damaged or inclined. In particular, it is the value of this information provided that determines the relative benefits of the technology. For comparing the costs with the benefits and assess their differential factor, it is necessary to reduce the costs and the benefits to a common unit of measurement, usually assigning a dollar value to each item which will contribute to the potential costs and benefits (Boardman, et al., 2006).

The technicalities of the construction industry dictate the way a new technology can and will be implemented. The complexities of the network of partners and subcontractors makes it difficult for adopting only one method to remain open in the face of investment opportunities. Consequently, we envision that such is the case with the drone technology as well and thus, create two scenarios for the cost benefit analysis: one scenario will be prone to having '*in house' capabilities* for owning the technology, and the other will take the *option of outsourcing*.

5.1.1 In house Costs LiDAR and photogrammetry

For the in-house scenario, the estimated costs will include the initial investment costs, both for hardware and software, training costs for operators who will handle the data and the sustained cost for the operation of the technology.

In general, it is thought that the aerial LiDAR (aka drone laser scanning) is a very expensive option to build in house, making is suitable only for large agencies which are subject to extensive surveying and challenging conditions. Remaining in the same spectrum of discussion, the comparison is made between the in-house scenario and the outsourcing scenario; however, there is still a need for considering the aerial LiDAR costs compared with a traditional surveying in order to justify the relevance of deploying the technology.

For this, there will be employed the study of (Vincent & Ecker, 2010), which present an evaluation of the current state of laser technology and its applicability, potential accuracies and information content. Their research is employed for the purpose of the project, as the efforts of gathering primary data from current agencies using the technology were not rewarded, and no solid case study could be built thereon.

Traditional Survey Design Costs							
Task	Persons	Hours	Hourly Cost	Labor Cost	Person Days	$/Mile	Notes
Administration	Surveying Manager, PLS	16	$145	$2320	2.0	$331	
Courthouse Research	Survey Technician	32	$75	$2400	4.0	$343	
Utility Research	Survey Technician	24	$75	$1800	3.0	$257	
Establish Horizontal and Vertical Control	Survey Crew Chief Survey Technician	60	$130	$7800	7.5	$1114	GPS
Topographic Survey	Survey Crew Chief Survey Technician	550	$130	$71500	68.8	$10214	GPS
Drafting Mapping	Survey Technician	543	$75	$40725	67.9	$5818	
Drafting Computations	Project Designer	32	$90	$2880	4.0	$411	
QC/QA	Surveying Manager, PLS	24	$90	$2160	3.0	$309	
Total Surveying		1281		$131585	160.1	**$18798**	

Table 13: Traditional Survey Cost Analysis Matrix (Vincent & Ecker, 2010)

Aerial LiDAR Survey Design Costs							
Task	Persons	Hours	Hourly Cost	Labor Cost	Person Days	$/Mile	Notes
Planning	Project Manager	8	$120	$960	1.0	$137	
Survey- Planning	Survey Manager, PLS	8	$145	$1160	1.0	$166	
Establish-Base Station	Survey Crew/Technician	16	$130	$2080	2.0	$297	3 Base Stations
Locate Check Points	Survey Crew/ Technician	40	$130	$5200	5.0	$743	60 check points- no panel
Survey Computations/QA	Survey Manager PLS	20	$90	$1800	2.5	$257	

Field Collection*	Pilot	6	$122	$731	0.8	$104	
	Data Acq. Technician	6	$69	$417	0.8	$60	
Calibration	Sr LiDAR Analyst	8	$194	$1557	1.0	$222	
Point Cloud Creation/Editing	LiDAR Tech 1	120	$68	$8214	15.0	$1173	
Feature Extraction	LiDAR Tech 1	40	$68	$2738	5.0	$391	
	Compiler	80	$71	$5680	10.0	$811	
QC	Sr LiDAR Analyst	60	$194	$11658	7.5	$1665	
Product Generation	LiDAR Tech 2	20	$85	$1693	2.5	$242	
Aircraft		6	$963	$5780	0.8	$826	
Aerial LiDAR		6	$1431	$8586	0.8	$1227	
Total Aerial LiDAR		444		$58280	55.5	**$8321**	

Table 14: Aerial LiDAR Cost Analysis Matrix (Vincent & Ecker, 2010)

*Field collection is removed, as the aerial LiDAR will be performed in this case with the drone (unmanned). This will affect the final plot likewise:

Total Aerial LiDAR		**444-6-6=432**		**$58280-$731-$417=$57132**	**55.5-0.8-0.8=53.9**	**$8321-$104-$60=**$8157

Both scenarios were plotted for a 7miles corridor (Vincent & Ecker, 2010). By a mere comparison between the total traditional surveying cost ($18798) and the total aerial LiDAR cost ($8157), it is clearly observable that the aerial LiDAR costs much less than the traditional method per mile of corridor.

Now that it is deemed feasible to employ the LiDAR technology in favor of the traditional surveying method, the project will continue in further assessing the costs of adopting this technology, plotted in an in-house scenario.

The costs provided in this section are relative, because they are highly dependent on the type of project surveyed and its complexity. However, in this case we rely on an educated estimation of costs from RIEGL company, the only company who answered our enquiries about costs, although they were presented in a rather non-itemized structure.

As mentioned before, the cost estimation will include the initial investment, training costs for operators and operations for running the technology. The initial investment is represented by the acquisition cost of an UAV (drone), the photographic camera(s) and lenses and other peripheral equipment (Wolf, et al., 2015). For the technology referenced in the project, the approximate cost of a complete RiCOPTER UAV system is evaluated around 128500 EUR (Riegl, 2017).

Additional to this cost, there is the laser (VUX-1UAV), cameras (2x Sony Alpha 6000cameras) and software acquisition costs, including the accessories (Applanix AP20 IMU), which is evaluated to be 190000 EUR (Riegl, 2017).

This amount is inclusive of the training facilitated for the operators of the technology, for both collection and data processing days (Riegl, 2017). To achieve consistency in our analysis, the information costs from RIEGL will be converted to US Dollars, in view of triangulating the costs with the operations costs/mile.

Investment	**EUR**	**$***
RiCOPTER UAV system	€128500	$144334
VUX-1UAV, Applanix AP20 IMU, 2x Sony Alpha 6000cameras, Software	€190000	$212910
Total (including training)	€318500	$357244

*per 2/06/2017 conversion rates

Because the training for operators' costs are already included in the initial investment, the only missing cost factor from the cost estimation assessment, is the operation cost, which is already provided in costs/miles surveyed. To achieve a total cost per first year of adopting the technology, the operation cost needs conversion from $/mile to $/year.

This is done in the following way:

1. If we assume the largest sequence of survey work from the study of (Vincent & Ecker, 2010), which is 55.5 days for a 7 miles' corridor surveyed, then the possibility of miles/year is: (250* days x 7miles)/55.5 days = **31.5 miles/year**.
   *250 days are assumed as one year's maximum number of working days
2. With a cost of $8157/mile, then for a full year's work: $8157/mile x 31.5 miles/year= **$256945.5/year**

Following this conversion, the total cost estimation for the 1st year will be:

Initial investment+ training	**$357244**
Operation/mile	$256945.5
Total	**$614189.5**

Table 15 Cost division for in house capabilities for 1st year

If the same length of corridor is surveyed through the traditional method, then the total operation cost/year will be: $18798/mile x 31.5 miles/year = **$592137/year**

From the above analysis, we can draw the conclusion that the adoption (in-house) of LiDAR and photogrammetry technology will almost breakeven the investment from the very first year of operation, when benchmarked against the traditional method of surveying (with a small differential of $614189.5 - $592137 = **$22052.5**). By this analogy, the profit will be registered starting with the beginning of the 2nd year of investment in the technology.

5.1.2 Outsource Costs LiDAR and photogrammetry

The provision fee that LiDAR service providers charge depends on a large extent to the specifications defined by the users (e.g. ground point density and accuracy), the data processing level at delivery, the complexity and level of difficulty of the terrain, site locations and size of the survey job (Wolf, et al., 2015).

'Aerial LiDAR costs for the State of Michigan (for 2013) range from $ 100 per square mile, for surveys of areas larger than 5,000 square miles, to ~ $ 250 per square mile, for survey areas smaller than 100 square miles. Specifying higher or lower quality levels for the data can increase the cost by more than a factor of 2' (Wolf, et al., 2015). This is also the case for the present project, as the surveyed areas will have an increased level of complexity.

'These values are comparable to the aerial LiDAR costs of $ 335 per square mile estimated for Wisconsin in 2014 (McDougal, 2014) and $ 344 per mile, estimated for Vermont in 2015 (Vermont Center for Geographic Information, 2015)' (Wolf, et al., 2015). The study is delimited to the transportation sector, therefore the number of miles accounted for is a major influential factor. In the construction industry, however, the corridor miles are not important because the quality and the complexity of the terrain prevail.

Consequently, the cost of surveying a civil engineering project can substantiate important gains, even compared to the higher rate of $344/mile. With all the complexities involved, the cost can rise up to be $1000; however, the investment amount and the training expenses dissipates in this scenario, leaving the comparison of $8157 from in-house scenario with the max. $1000 through outsourcing.

Cost wise, the choice of surveying is fairly obvious: the LiDAR instruments and photogrammetry used for aerial data acquisition are quite expensive and the expertise involved in operating such **technology lead the decision makers to outsource and choose specialized commercial providers** (Chang, et al., 2014).

The cost benefit analysis has a pretty straightforward direction and it is implied the assessment of both the costs and the benefits of any investment, compared with the alternatives. For the cost structure, we have monetized it so that we can follow a structured logic for these technologies. When considering the benefits within the analysis, having implied that we do not have a case study, these will be inferred in a more qualitative way. Together with the costs assessed, the 'descriptive' benefits will ultimately lead to a better-informed decision making.

5.1.3 Benefits

When discussing the beneficial implications of using this technology, there can be a division between tangible benefits and intangible benefits. The tangible benefits are related to the direct cost savings, as a result of using LiDAR and photogrammetry technology instead of the traditional method of surveying. The intangible benefits are related to the impact brought upon the project execution – defects, health and safety and planning.

Tangible benefits – cost savings

We have mentioned earlier in the chapter, that according to our scenario, the LiDAR and photogrammetry technology will start becoming profitable with the second year of operation. The investment decision-making should be based mainly on this argument. With regards to the costs savings, the most appropriate metric is the $/mile surveyed; according to (Vincent & Ecker, 2010), the traditional method would yield $18798 per mile surveyed, whereas the LiDAR (aerial) would yield $8157 per mile surveyed. The difference between the two amounts ($18798-$8157 = **$10641**) represents the cost savings a contractor would achieve per mile surveyed of project, should he use LiDAR technology.

Intangible benefits

The intangible benefits represent the unquantifiable benefits to which no fixed amount can be attributed. This does not imply that these benefits do not have value, but the value brought is being evaluated with other metrics than financial; moreover, the intangible benefits can surpass the tangible ones in value.

In civil engineering construction industry, the bids start off with a correct set of data about existing conditions. With regards to the speed and completeness of laser scanning, LiDAR technology is starting to be used more often to address the lack of information within the bids.

Project execution is then achieved faster and leaner through the laser scanning, due to mitigating errors reduced rework scheduling. ‘In greenfield projects, field rework in excess of 1% of the project budget is generally considered unacceptable. However, in brownfield situations, rework today can be in the range of 5% to 10%’ (Higgins, 2004).

By doing so in reducing errors and rework, thus enhancing the project’s responsiveness, this technology can impact greatly the project schedule. When talking about LiDAR surveying, (Higgins, 2004) claims that ‘avoiding the costs of schedule overruns – lost capacity in process and power plants, added days of traffic lane closures in transportation projects, lost production on offshore platforms, lateness to market and lost opportunity in consumer products – can have even greater economic impact than reducing direct project costs’. Amongst all, the lateness to the market is prone to be the most detrimental factor to project execution, bearing the most costs.

With regards to health and safety, the existing conditions within a structure can be captured in a safer way than with traditional methods. The litigation costs in case of accidents or loss of life are far beyond the costs of employing this technology. With LiDAR and photogrammetry, either in-housed or outsourced, the need for personnel to take physical risks is now eliminated. This principle of safety can be also applied not only to large scale civil infrastructure, but to chemical hazards as well, in case there are debris left in the building or imbibed into the walls.

The potential benefit of the technology is greatly enhanced in situations where the same design needs to be employed several times. If the first facility is complete, 'then updating the as-designed CAD model to conform to as-built conditions' (Higgins, 2004) can easily be performed for the second facility so that the project can be executed more rapidly and with fewer defects.

5.2 RFID

5.2.1 Costs

There is a handful of studies with regards to the costs and benefits of RFID (e.g. (Agarwal, 2001), (Li & Visich, 2006), (Visich, et al., 2009)). This type of analysis is made quite difficult for the particular case of RFID, due to the level of complexity involved and the multitude of options available from this technology. Regarding the cost structure of the technology, the authors are itemizing the costs from different perspectives; for example, (Agarwal, 2001) divides the costs of tags, apart from the application process in 6 categories: 'cost of the tag itself, cost of applying tags to products, cost of purchasing and installing tag readers in factories and/or warehouses, systems integration costs, cost of training and reorganization, (and) cost of implementing application solutions'.

However, the most comprehensive study for RFID technology was made by Feinbier in 2008 for the steel industry (Feinbier, et al., 2008); his study is taken as reference point in most articles assessing the costs and benefits of such technology. According to (Feinbier, et al., 2008), the costs considerations for RFID are very dispersed, but they fit in the following categories:

Tags

Tags are the most references costs for the implementation of RFID in any business structure. The types of tags are according to their application in the industry. 'Changes in form factor, packaging, memory capacity, read or read-write capability, active or passive configurations and range, all impact cost.' (Feinbier, et al., 2008) Considering the environment complexities within the construction industry, we envision that active tags should be chosen, with additional capabilities and local power supplies. This will give a higher return on investment in the end, because they can re-programmed. They reach an approximate amount of $100/tag (Gerber, 2011). The scenario for this analysis assumes a number of workers on site of 25, therefore 25 tags are required: $100/tag x 25tags = **$2500**.

Readers

Once again, the readers are prone to a multitude of configurations. 'Reader costs vary as a function of reader type, range, speed, robustness, network readiness and antenna capability. The more capable a reader is — the faster, more robust and long range — the higher the reader's cost' (Feinbier, et al., 2008). The general variation in price is based on their frequency. Upon configuring the technology earlier in the project, the UHF was chosen for this scope; this type of readers costs between $500 and $2000 (Gerber, 2011). Because a total cost estimation needs to be performed towards the end, we can assume the average of these prices range, as the final estimated cost for an UHF reader. This will be calculated: ($500+$2000)/2 = **$1250/reader**.

Antennae and cabling

Depending on the base operation frequency and the application, antennae vary in price, just like any other element within the RFID spectrum. The general price for these is estimated around **$200** (Gerber, 2011), although is subject to large variations (Feinbier, et al., 2008).

The other element is cabling, which could easily reach approx. **$15** per linear meter for high-grade cables (Feinbier, et al., 2008). For the purpose of this scenario, we assume a budget of 100 linear meters of cable, which will cost $15 x 100 meters = **$1500**.

Installation

Installing the antennae, power supplies and the readers can easily add up to the costs of adopting this technology. Depending on the location and environmental conditions, the antennae and readers might need concealing or equipped with heating/cooling devices (Feinbier, et al., 2008). For the purpose of this scenario, we assume a full day's work (8h) for a technical engineer at a rate of $75/hr., leading to a total labor cost of 8hr. x $75/hr. =**$600**

Tuning

The conditions of the site will impact the radio-frequency waves differently; thus, tuning will be made necessary, after measuring for dead spots (Feinbier, et al., 2008). The cost of doing so will dependent to a high extent to the expertise needed, but for the scope of this scenario, we assume no tuning will be needed, at least not in the incipient period following the adoption of RFID on site.

Controllers

The controller is, in actuality, a server for the group of readers. 'These servers run appropriate middleware to control the readers. Initial processing, event firing, buffering in case of network failure and some diagnostics run on the server' (Feinbier, et al., 2008). In the proposed scenario, the site environment is not very complicated, considering the RFID application on only 25 employees, therefore a controller at the lower end of the price range will be chosen. According to (Feinbier, et al., 2008), this could amount to approx. **$350**/server.

Software Platform

'Commonly referred to as RFID middleware, a software platform controls the RFID system, though modern RFID solution packages reach well beyond simple middleware functionality. In the simplest terms, the software translates tag reads into business events' (Feinbier, et al., 2008).

The software for RFID can easily become the wild card factor in rising the costs for adopting such technology. 'Considerations should include whether the software is intended to act as middleware by sending information to a back-end application or whether the software is the final product' (Gerber, 2011). Due to the fact that the reads are going straight into BIM, this implies the possibility of the software to send back-end application. For such a feature, it is common for the software to cost approx. **$130000** (Gerber, 2011), including the licenses.

Integration

The costs of integration will depend on the number of legacy systems involved and the set-up of the readers (Feinbier, et al., 2008). In the proposed scenario, the application is not that complex, however it requires integration with BIM. In light of these, we assume a total cost of **$500**, for both man labor and adjustment for real time data.

Maintenance

In addition to all of the above-mentioned costs, there is the cost of maintenance, which includes, but not limited to: hardware upgrades, failed or damaged equipment replacement, ongoing firmware and middleware upgrades and any other software or licensing fees (Feinbier, et al., 2008). A good estimate in this cost sector would be about 10%/year (Feinbier, et al., 2008); this will plot into our scenario with an approx. amount of **$2000/year**.

Process

The last element within the adoption of RFID technology is the human element, which includes the involvement of employees in designing the processes and training them, putting them in a better position to act on information (Feinbier, et al., 2008). Although change management is a major component of the implementation cost of the technology, our scenario assumes that the employees are already knowledgeable about pivoting this kind of data with the existing BIM. However, some training sessions might be required as minimum, with a maximum budget of **$10000**.

For a clear view of the total cost implementation estimation that the company will incur in the first year of operations, the following table will sum together the associated costs:

Item	**Cost/1st year**
Tags	$2500
Readers	$1250
Antennae & Cabling	$200+$1500=$1700
Installation	$600
Tuning	0
Controllers	$350
Software Platform	$130000
Integration	$500
Maintenance	$2000
Process	$10000
Total	**$148900**

Table 16: Itemized total cost (own creation)

5.2.2 Benefits

The benefits obtained from RFID implementation varies across a wide spectrum; like any other technology, it's up to the application that will drive the benefits of using it. For the scope of this project, we have chosen to use RFID in the construction industry for physical count of employees. It is suggested that by implanting RFID into the business structure of a construction company, there will be savings gained. These savings will be achieved through a reduction in labor-hours (Gerber, 2011) and a reduction of budget spending on health and safety.

Feinbier (2008) has created in his study a general overview of benefits from RFID implementation:

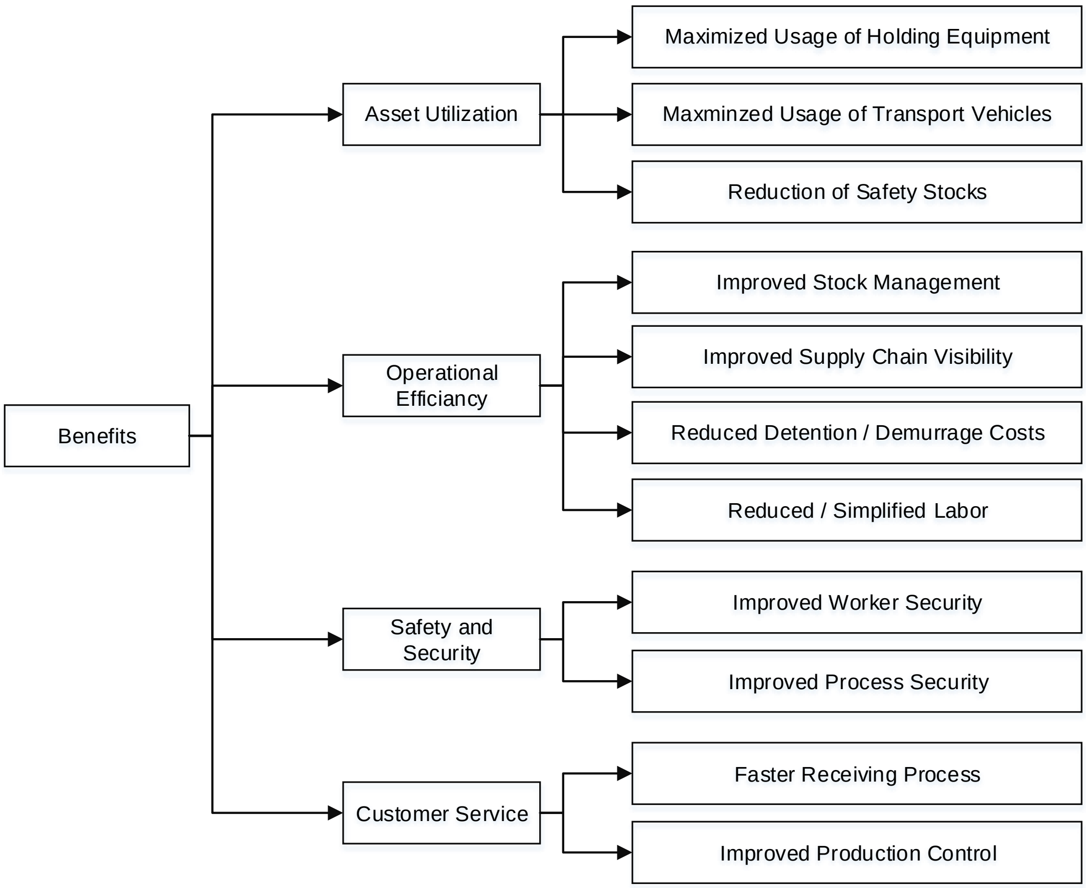


Figure 23: RFID Implementation's Benefits (Feinbier, et al., 2008)

From all of the above-mentioned benefits, our scenario is concerned with operation efficiency through reduced/simplified labor and safety and security, achieved through improved worker safety and improved process security.

a. Operation efficiency through reduced/simplified labor

These savings can be obtained by refencing the average hourly cost of labor and multiplying it by a difference factor (Gerber, 2011), meaning the change in labor hours from traditional method to the RFID method. This physical count will follow the model**: L1 x ∆H**, where:

- L1 represents the hourly labor rate
- ∆H represents the change in the number of labor hours

For simplicity reasons, we assume uniformity across the hourly labor rate of all 25 employees plotted in our scenario, with an average amount of $50/hr. (BLS, 2015) We also assume a standard number of working hrs./week of 40 through the traditional non-RFID method. This means there is an approx. of 41 weeks/year (without the 2 weeks for holidays). Thus, in one year time, the total number of labor hours is: 40hrs./week x 41 weeks/year = 1640 hrs./year

If we multiply the number of working hours/year with the hourly labor rate, 1640 hrs./year x $50/hr. = **$82000/year** in total costs for labor, with the traditional non-RFID method.

The specialty literature is accounting for a 40% reduction in labor costs in average, of course, this percentage will depend to a great extent to user specifications and how exactly is the RFID configured (AMG, 2014). For simplicity reasons, we'll assume the same 40% reduction. This implies: 1640hrs./year - (1640hrs./year x 40%)= 984 hrs./year

If we multiply the number of working hours/year with the hourly labor rate, 984 hrs./year x $50/hr. = **$49200/year** in total costs for labor, with the RFID method. Then ∆H becomes: $82000-$49200=**$32800,** this will be the savings in labor per year.

Important observations here indicate the fact that **the investment amount ($148900) will breakeven in approx. 2 years of operations, when compared with the traditional cost of labor hours ($148900/$82000=1.81)**, after which the investment will become profitable with $32800 per year of operations, when accounted are only man labor hours. However, within the same cost of investment for RFID implementation, there are also included the safety and security, through both improved worker safety and improved process security.

b. Safety and security through improved worker safety and improved process security

The safety and security protocols are not easily quantifiable, to determine a tangible beneficial effect for the investors. Although there are exhaustive studies regarding these protocols, most of them are refencing the reduced number of accidents as the most important metric. This is the more relevant for the construction industry, as it has been identified with the highest occurrence of accidents and life endangering fatalities compared to other industries (Tahir, et al., 2015)

A reduced number of accidents cannot be attributed a fixed measurement, as the final losses incurred as a result of the accidents are dependent, to a great extent, to the nature of the accident and the liabilities involved. However, safety and security are of paramount importance for any site (Feinbier, et al., 2008), and the RFID technology can mitigate the exposure of the employees to dangerous areas, where accidents are easily prone to happen.

Within the scope of the proposed application for RFID, there is the monitoring of workers/employees. For this application, the RFID tags can be fixed to their protection helmets or in other construction materials that the workers are using. Therefore, when an employee wants to activate an equipment, the access control reader fixed to the equipment will read the tag on the safety helmet of the employee and transmit the data to the server for authorization. This will impede the unauthorized use of site equipment, thus mitigating the possibilities for an accident to occur.

In addition to this, the RFID implementation provides an improved process security (Feinbier, et al., 2008). This can also be attributed to the client perspective, as a Health and Safety assessment has important implications on attracting potential clients and the way the relationship with them is being nurtured. Furthermore, the bank interest for the running project is also a major factor in achieving a solid foundation for the health and safety evaluation. The rating provided for the company's Health and Safety Evaluation will become a major influential factor on how the bank's interest fluctuates; if the project is subject to a health and safety evaluation with higher liabilities, then the bank's interest will decrease and vice versa.

For example, Denmark's Work Environment Agency, Arbejdsmiljøstyrelsen, makes use of the Smiley rating for the health and safety evaluation of any Danish company or operating within Danish borders. This rating is made public and the bank will have access to the results of this evaluation and rating. (Busck, 2015)

6. Findings and conclusions

Within this report, it has been examined the way innovations in the construction industry can communicate and work together for enhancing the experience of a construction project and further to improve the results of it.

Building Information Modelling has been categorized by some researchers, Crotty (2011) or Poirier, et al. (2015), as being a disruptive innovation due to its characteristics of changing the paradigms of the construction industry, moving it from a fragmented and segregated type to a more collaborative and sharing type. Yet, not all researchers view this as being true, as some argue, Gladson (2005), that Building Information Modelling simply appeared from the industry's need for better management and resource allocation.

Internet of Things represents the method through which two instances can become connected over the internet with the scope of producing and receiving data. These instances can be either virtual or physical and for the concept to function, these must be in permanent awareness of each other.

IT technology today allows for every individual and machinery to be connected to the cloud for better management of information, connectivity to databases and recording and tracking of information.

Professional organizations and juridical persons active in the construction industry today, should not adhere to the standard say proposed by Christensen et. al (Christensen, et al., 2015), that the construction industry is a conservative one running on the old saying “this is how it was done before, this is how we will do it”. Looking for competitive advantages in a complex and stringent market, innovative solutions should be employed with the prospective of enhancing productivity, quality and resources allocation.

Looking at the defining characteristics of BIM of managing data and the defining characteristics of IoT of transfer of data, we look at a new set of technological solutions meant to bring benefits to an industry struggling to improve.

Technologies pertaining to the Internet of Things umbrella have been examined to observe which has the most potential to improve works in three areas of interest, defects, health and safety and planning.

From the examined IoT technologies, Radio Frequency Identification has showed great potential for improvements. Previous research on this has revealed that other industries, such as transportation and logistics, already benefit from the use of it in their supply chains.

RFID solution is represented in the proposed scenarios by a system comprising of RFID tags, RFID readers and analysis and interpretation software. By analyzing the available literature, a set of improvements is expected to be seen if the solution would be adopted in an organization.

Additionally, a technology that does not fall under the IoT umbrella has been analyzed under the condition that, through an internet connection, it can instantly communicate data captured from the field to the cloud/ server.

An UAV has been examined for this purpose. The device that has been considered comes from the vendor, Riegl. This vendor is the only one that has supplied useful information in the timeframe of the project, information that has been used for the analysis. The device, a RiCOPTER with laser scanning and photogrammetry capabilities has been examined for the use on a construction site.

As mentioned above, part of the report was to examine the conditions under which, through an internet connection, these two technological solutions can communicate data to a BIM model for analysis and processing and the results to be further transmitted to key stakeholders in the project.

It resulted that the review BIM software, Revit, does not possess capabilities of receiving, analyzing and interpreting data from RFID tags. Yet, with the supply of an additional software, for instance as an add-in to the Revit software, one can interpret real-time data from RFID tags where position of the tags can be observed on the model 3D model from Revit.

Data captured through the use of the UAV under the form of a point cloud data file or set of photographs allows BIM operators (these can have various positions in an organization) to model data based on real-life situations. This data can further be used for the calculation of quantities, update 3D models and conducts analysis procedures such as clash detection and preparation of as-built documentation. Additionally, scans of locations allow project managers to better manage the site, manage assets and quantities and identify critical areas leading to an improvement in health and safety and planning.

Looking at the cost benefit analysis conducted on the two selected technologies revealed that there is a series of benefits associated with it, yet, there are aspects that seem daunting at first.

For a firm to consider a UAV with a laser and camera will represent an initial investment of $357.244 (RIEGL). This is the cost only for the equipment, software and training in the use of the solution. Following a study conducted on the benefits of implementing UAV surveying technology, it revealed that, with the initial cost of the equipment, the investment in this type of technology would be recovered in just over 1 year, while looking at approximately 300% increase in productivity of surveying services. Yet, when comparing the costs of using the technology in-house versus the costs of outsourcing, it is observed that the costs considerably drop in the favor of outsourcing the services to a professional sub-contractor.

Implementation and use of RFID systems for a construction company presents a set of benefits. It was observed that, through the use of localization and tracking software, companies can look at up to 40% reduction in labor costs. Additionally, when looking at the planning benefits that the system offers, by monitoring the manpower present on site, project management can ensure a reduction in defects and increased security on site. These latter aspects cannot be quantified as these will can be considered as intangible benefits. Together with these, knowledge that is created through the use of the system on the behavior of the construction site allows project management to be improved from one project to another.

7. Project limitations

7.1 Organizational limitations

Although it is based on the principle of the “red thread” on which, Aalborg University puts a great emphasis, as it has showed great results in offering readers a structured read, the report has been constrained by various factors.

This report represents the work that students must conduct in their fourth semester in MSc in Management in the Building Industry program. This semester has taken place between 1st of February and 8th of June consisting of 18 weeks and 1 day or the equivalent of 127 calendar days out of which 86 have been working days.

The report has been prepared in a group of three students from the same study program, yet, differences in culture and language have been observed between the members of the group. Coming from three different counties, Romania, Greece and Iran, the students possess different levels of knowledge and different perspectives on the construction industry.

The language in which the report has been written is English, this being the language in which the program at Aalborg University has been conducted and thus, the middle language between the three students. It has been observed that the levels of English knowledge were different and as such, a middle ground for expressions has been found so as to offer the reader a cursive flow in the text.

For the first part of the fourth semester, the students have participated in full time work which was part of the third semester of the study program. Although, it was recommended that the internship period ends before the start of the last semester, a great number of companies in search of interns do not offer these positions based on the school conditions but based on their organizational requirements.

7.2 Limitations of the literature review

The review of available literature follows a thematic pattern which leads to information being overseen and further affects the integrity of the report. The search strings have been constructed on keywords extracted from the research statement so as to find relevant research articles and papers, yet, when comparing to the perspective view on the literature that the systematic literature review will offer, the thematic one will push to a narrower view on the perused documentation.

It is acknowledged that having a larger project timeframe, more resources could have been employed into the search and analysis of more research papers, thus offering a more varied perspective on the reviewed literature.

When conducting the literature search, the students have search only for papers in English. However, there was only one version of the English language that has been used, that being the U.S. version as this is the standard one, which is also installed in Word processing software as basic language.

It is expected that, when employing different versions of the English language, more results would be found. Differences in the spelling of words between British English and American English such as in colour and color or as in analysed and analyzed limit the availability of research information through the use of only one version.

Another limitation of the reviewed literature refers to the production of information. Although the search for information focus on obtaining the information from journals and articles, especially peer reviewed, there is a certain amount of information that has been taken from websites, reports and articles published by vendors or other commercial bodies. It is acknowledged that this information might present a certain percentage of bias and that it could have been build and presented in such a way to enhance the capabilities of the commercial entities and improve the perception on them.

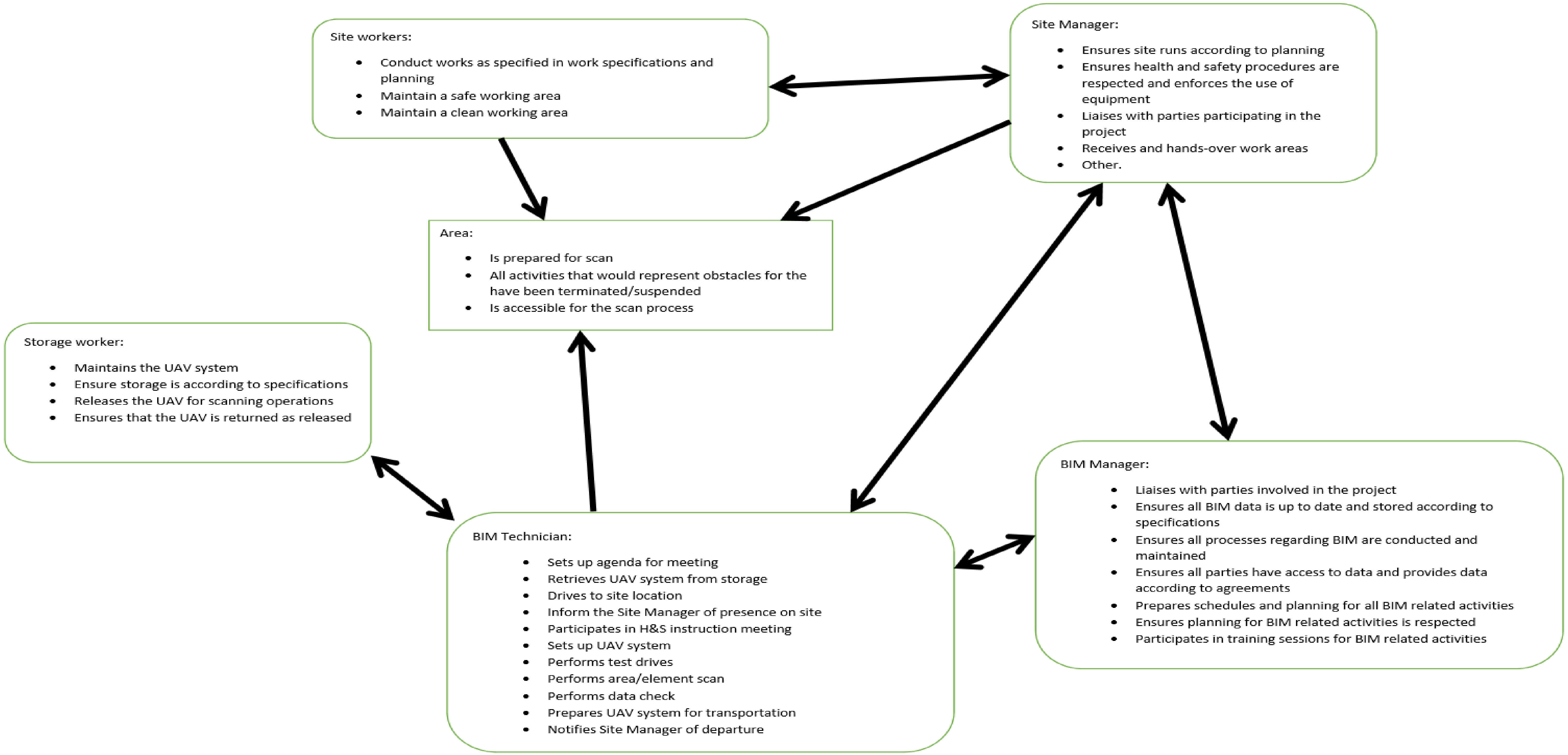
7.3 Limitations of the research methodology

The research methodology for this report has been structured as an explorative study of the available literature. Bryman and Bell (2015) recommend that, when conducting analysis of a subject, an author should make use of primary data as this type provides most accurate results and offers a higher level of validity to the report. Yet, in situations when gathering primary data is not possible, due to various constraints such as location, time or funds, authors can employ the use of secondary data.

Secondary data is data that has been collected from review of literature and analysis of reports, articles, research papers and case studies conducted by other researchers and professionals. However, secondary data is prone to subjective interpretations and manipulations by the ones that have produced the data in the first place, this being the initial researcher. Validity of secondary data is being diminished if it being used as a citation within a report leading to a second layer of interpretation on the data. (Bryman & Bell, 2015)

When conducting this report, due to constraints that have applied to it, students have made use of secondary data gathered in the literature review phase.

8. Annexes
8.1 Annex 1



Picture 16: Drone scenario flow model chart, Creation based on model from (Holtzblatt & Beyer, 2017)

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