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Benefit and performance improvement when using BIM methodology and technologies in construction.

Beneficios y mejora de rendimiento usando metodología BIM y tecnologías en construcción

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TRABAJO FIN DE MASTER

ABSTRACT

There are many technologies worldwide that are changing the construction industry. BIM is among the most important of these. The possibilities of combining BIM with several other methodologies and technologies are increasing by the day. In the Chapter II of this thesis, includes a research of several scientific papers and books that have information about how some projects have been using BIM in combination with other software's and/or methodologies and gives a general overview of the benefits that these combined efforts have brought. In Chapter III, there are 2 case studies of projects that have used some of these technologies combined in order to improve the efficiency of specific goals such as time, cost and quality. In Chapter IV, the FlexQuartier project is introduced and discussed. In this project, a combination of several technologies is explained. This combination of technologies is something that has not been done before. The main goal of the FlexQuartier project is to create a BIM model which builds upon itself from conception to facility management. This model will be the central tool used by all the stakeholders in the project. From architects and designers, to contractors and subcontractors and at the end, owners, end users and facility managers.

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LIST OF ABBREVIATIONS / SYMBOLS / EQUATIONS

AEC: Architecture, Engineering and Construction

AR: Augmented Reality

BIM: Building Information Modelling

bSDD: Building-SMART Data Dictionary

COBie: Construction Operations Building information exchange

HTS: High Temperature System

IFC: Industry Foundation Classes

IoT: Internet of Things

ITC: information and communication technologies

LOD: Level of Development

LPS: Last Planner System

MEP: Mechanical, Electrical and Plumbing

NIST: National Institute of Standards and Technology

O&M: Operations and Maintenance

PCD: Point Cloud Data

QIM: Quartier Information Model

QR: Quick Response

RFID: Radio Frequency Identification

SSC: Sustainable Smart City

VR: Virtual Reality

CHAPTER I INTRODUCTION

1.1 Background and problem description

Building Information Modelling (BIM) is already a common tool in the most innovative Architecture, Engineering and Construction companies. However, many of the companies are mostly focused on the 3D modelling that BIM software provides and although it is already beneficial for a construction project to find out about possible problems before the project begins with the information given by the 3D model, in most cases, the reach that BIM software can have when it is combined with external hardware and/or programs is overlooked.

Thanks to the growth and spread of BIM in the construction industry many technology companies are discovering new areas of opportunity. Many start-up's and companies are working to create sensors for buildings, new networks for better communication, new hardware and software to help monitor and control not only the construction process but also the facility management, programs to obtain data from the building and its users (data mining), augmented and virtual reality, among others. BIM could provide the repository model with the information that make these technologies so useful. BIM has become a fundamental agent for change in construction.

The problem is that most companies do not have the necessary knowledge nor the skills to understand the capabilities of BIM. Most of the AEC companies do not take seriously, in most of the cases due to lack of knowledge, the investment in hiring professionals in the BIM field that help them change their current processes for smarter and more efficient ones. The main question that they ask, and this thesis is aimed to solve is: what are the benefits and performance improvements when using BIM methodology and technologies in construction?

1.2 Aims & Objectives

The main objective of this document is to analyse and describe the benefits and performance improvements when using BIM methodology and technologies in the AEC industry. These benefits are not only limited to the construction phase of a project. As it will be explained in the following chapters, if a BIM implementation is done from the conception of the idea or necessity of the project, designers, architects, engineers, contractors, subcontractors, owners and facility managers can benefit from this early integration. BIM in combination with external tools can also be used for the operation and maintenance of the project. With this in mind, the objectives of this thesis are:

- Give an extensive explanation of the current state of the art in BIM and what technologies and trends are being used with it.
- Describe what are the benefits in each one of the phases of a project life cycle (Planning, Construction and Management).
- Show 2 case studies where the combination of BIM and new technologies have

caused a positive impact and point out the benefits.
- Describe the “FlexQuartier” project that is being developed in Giessen, Germany and propose a series of technologies that can be implemented to improve not only a specific phase, as it is commonly done, but the general efficiency during the life cycle of the project.
- Describe how the use of BIM and other technologies can lead to the creation of new Smart Cities.

1.3 Work/Research Methodology

The research methodology was performed using the qualitative method. The aim of this method was to find the solution to the theoretical question: what are the benefits and performance improvements when using BIM methodology and technologies in construction? The qualitative method was the most suitable because it gives theoretic context of what is the current state of the art and what are the trends that are being studied and that could possibly have an impact in the future of the construction industry.

A wide variety of scientific papers were identified, selected, and analysed. The most recent and innovative technologies from each paper were selected and mentioned. The data bases from which the information was selected were mainly Web of Science website (https://www.webofknowledge.com), the access was given through the Universidad de Cantabria and the Fundación Española para la Ciencia y la Tecnología (FECYT); and ScienceDirect website (https://www.sciencedirect.com), access was given through the Biblioteca Universitaria. Specific content of each paper was selected, categorised and then it was mentioned with the corresponding reference.

1.4 Limitations and Scope

This thesis proposes technologies that are already in use and technologies that are in the process of becoming relevant for the AEC industry. No calculations of any kind were made, the numbers mentioned in this document were taken from the selected scientific papers, reports, and existing projects and are the benefits that resulted from the implementation in those projects. For the FlexQuartier, it is a new district that is in the conception phase, thus, there are only ideas that are being taken into consideration for the construction of a new model of city district and it will be compared once the conception phase finishes and the next phases of the project begin (planning, construction, commissioning and management). In this same project, the High Temperature System, which is a new technology planned to be used, is only mentioned in a general basis and the technical functionality of the system should be analysed thoroughly.

The time and cost of implementing the technologies was not analysed due to many different factors like location, size of the companies to work on this project, local and federal rules, level of maturity, etc. This document aims to provide a general overview of the benefits of several technologies and trends to arouse the reader’s interest for these technologies and motivate the implementation in construction projects.

CHAPTER II LITERATURE REVIEW

2.1 Overview

In the current state of the Architecture, Engineering and Construction (AEC) industry worldwide, in a very broad and simple explanation, there is typically an idea or a necessity for a construction project, then a process of predesign begins where the owner specifies the most important characteristics that are needed with a designer or architect, then comes a tendering process where the best qualified contractor is selected to develop the project and the construction begins. Once the construction is done, the contractor makes sure that everything works properly to deliver the new facility to the owner or facility manager. In practice, the owner and each design participant are not involved with the complete representation of the building's design and construction. Each one of the stakeholders is interested in only a part of the information. While the designers or architects are mostly focused on the owner's idea of what he or she wants, the contractor is mostly interested in having all the details captured in the drawings (which is usually not the case), the owner is only interested in having the facility as soon as possible so that it can begin operations. This whole process can be quite problematic, especially when changes are made to the project due to lack of information from the owner, poor communication between the designers and the contractors, etc.

The continuous need to combine the expertise of architectural and engineering design with the knowledge and experience of construction in the generation of documents necessary to carry out the project has somehow gotten distorted by delimiting the services that each participant provides. Current practice has led to specify that the architect's drawings are only limited to "design intent," with all the specific construction details and coordination of activities being resolved in an additional set of drawings (in some countries called construction coordination documents for managing building system coordination), and shop drawings for fabrication and often the construction of the actual built elements. Actually, the design drawings ("design intent" drawings) exist to isolate the intellectual contribution of architects and engineers from that of fabricators and constructors, and to, somehow, cover designers from liability for design coordination and other problems. This partition and redundant process is an inefficient use of time, resources and money. It has evolved in parallel with a high level of legal problems which in some cases end up in litigation on construction projects. The potential for litigation leads architects to withhold information useful to the contractor and reduce communication and collaboration because the information is not covered in the architect's contract. It also results in contractors relying on design and documentation errors as a basis for profit on a project through the additional charges associated with change orders. The resulting processes are dysfunctional, in the sense that they are not in the owner's interest and negatively contribute to the success of a project. (Eastman, Charles M., *et al.*, 2018).

It is commonly known that contractors and other companies that give their services to the construction industry often point out that owners are one of the biggest reasons for changes in the construction due to their owner-requested changes that ultimately impact on cost, time and quality. These changes are a result of inadequate analysis during the design phase of the project and this brings the necessity for other activities that were not originally planned to emerge. Added to this, usually the changes requested by owners are not fast enough to be implemented in the drawings which also brings additional costs from the designer's side.

One solution that has become widely used in the AEC industry is the use of Building Information Modelling (BIM). Before the implementation of BIM in a project or a company, the contractor should be aware that there is a learning curve to pass. This is not very easy and straightforward because the transition from drawings to a BIM model implicates that almost every process will be subject to some changes in order to dive in the full opportunities of BIM technology. For this reason, it is paramount to plan the implementation carefully by getting the assistance and guidance of experts to achieve the goal. Next, BIM will be fully explained along with the vastly amount of benefits that its implementation brings.

2.2 Building Information Modelling (BIM)

Building information modelling (BIM) is a digital representation of characteristics of the object, which serves as a source of information about the facility, forming a reliable basis for decisions during the entire life cycle of construction objects. Accordingly, the information about the building is represented as its information model. The current state of construction is characterized by the implementation of BIM technology (Ignatova, Zotkin and Zotkina, 2018).

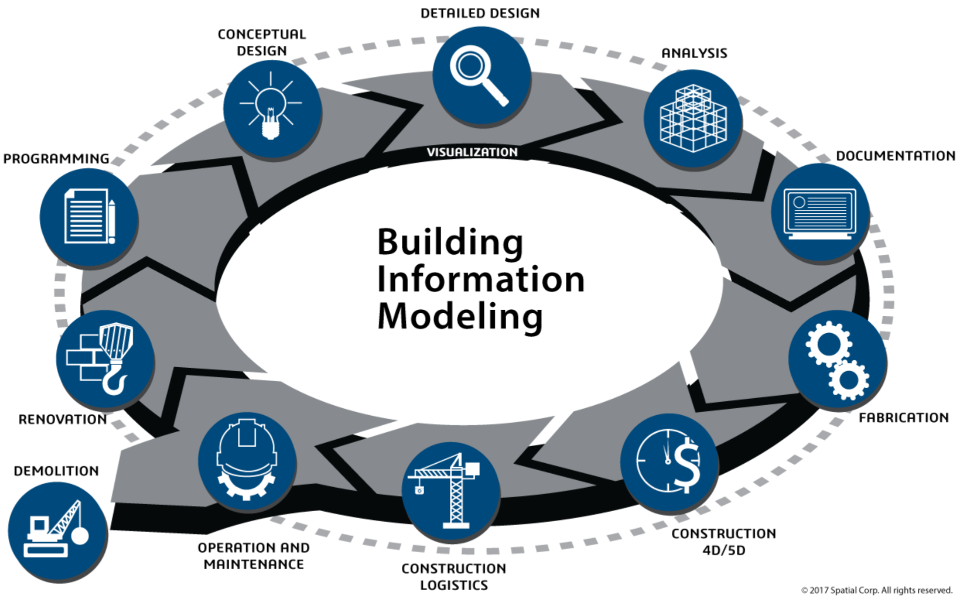

Figure 1. Building Information Modelling (source: https://bit.ly/2MMg2ye)

The problem today with BIM software, is the limitation of its capabilities to process complex information. It is a tool that can easily be used to store information about the physical properties of the buildings and also information about other attributes such as cost of equipment's, name of manufacturers, dates for maintenance, expiration dates, etc. BIM software alone cannot process complex information, however, there are many external programs or plug-ins that are used to take care of these complicated tasks. For these programs to do this, we need to load the information of the buildings, in most of the cases, in a universal standard format or Industry Foundation Classes (IFC). Most BIM applications have the ability to upload data in this format. IFC allows to see the contents of the file in ASCII codes, but it is an object-oriented structure and does not allow to easily find the necessary object parameters. In addition, IFC is not designed for storing information about parameter dependencies between objects in the information model (Ignatova, Zotkin and Zotkina, 2018). With the early implementation of BIM in any project, planners can transfer most of the effort necessary from the planning phase to the conceptual phase, reducing with this, the possibility of errors in later phases of the project.

The National Institute of Standards and Technology (NIST) performed a study of the additional cost incurred by building owners as a result of inadequate interoperability. The results showed that inefficient interoperability accounted for an increase in construction costs by $6.12 per square foot for new construction and an increase in $0.23 per square foot for operations and maintenance (O&M), resulting in a total added cost of $15.8 billion (Eastman, Charles M., *et al.*, 2018). Most of the additional costs were made due to a poor management of the information from owners and facility managers during the O&M phase.

It is important that while architects and civil engineers are already in the process of implementing these tools in their daily basis, owners and facility managers understand that they can get many benefits from the implementation of BIM from very early stages of the projects to the very end of it. The technologies in combination with BIM in each one of the phases of a project will be now explained.

2.2.1 Planning phase

In the planning phase of a project, usually the definition of the idea of the owner becomes real, at least in a virtual model. BIM models are composed of parametric objects which are an important concept necessary to understand BIM. A parametric object can have geometric definitions as well as rules for a specific or several objects. It can be automatically modified when new objects interact with each other. An object can have several levels of hierarchy. It can also detect when a certain rule is not being applied correctly. It also has attributes and has the ability to receive, analyse, modify and change these attributes automatically, as an example of these attributes, if there is a wall in a model, it will have the acoustic data, structural information, insulation data and so on.

Depending on the owner and the rules of the country where a BIM project is developed, a certain Level of Development (LOD) will be demanded. The LOD defines geometric information, general information about a certain object and linked documentation, these define the reliability of BIM elements at different stages or milestones. One common reference for LOD comes from BIMForum and its Level of Development Specification. According to BIMForum: “The Level of Development (LOD) Specification is a reference tool intended to improve the quality of communication among users of BIM about the characteristics of elements in models”. The next definitions were taken from the specification (BIMForum, 2018):

LOD 100
LOD 100 elements are not geometric representations. Examples are information attached to other model elements or symbols showing the existence of a component but not its shape, size, or precise location. Any information derived from LOD 100 elements must be considered approximate.

LOD 200
At this LOD elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservation. Any information derived from LOD 200 elements must be considered approximate.

LOD 300
The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension call-outs. The project origin is defined, and the element is located accurately with respect to the project origin.

LOD 350
Parts necessary for coordination of the element with nearby or attached elements are modelled. These parts will include such items as supports and connections. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension call-outs.

LOD 400
An LOD 400 element is modelled at sufficient detail and accuracy for fabrication of the represented component. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension call-outs.

LOD 500
Since LOD 500 relates to field verification and is not an indication of progression to a higher level of model element geometry or non-graphic information, this Specification does not define or illustrate it.

BIM data application uses is becoming increasingly automated because it is eliminating manual entry which saves time and is potentially error-free. Automated checking during the planning phase is clearly superior to manual checking. Rule sets can be prechecked by comparing the outcomes of automated checking with manual checks of the same model as a form of “calibration” of the rule set. Similar tests can also be compared by running the test on different checking applications. The model aspects can be checked from physical and material correctness on one hand to performance requirements defined in codes at the hand. Qualifying checks are prerequisites that must pass before other checks can be applied. For example, in almost all buildings, rooms must have at least one door in their bounding walls for access, scaffolding, and other temporary structures require walk space and spaces to allow access and necessary work, access to equipment that has maintenance requirements etc. (Eastman, Charles M., *et al.*, 2018).

IFC Open format

Interoperability is the ability to exchange data between applications, which smooths workflows and sometimes facilitates their automation. Thanks to the IFC format, different stakeholders can share information about the same file. This is also used as a team collaboration tool with which stakeholders can work at the same time during the different phases of the project. With this collaboration happening at the beginning of the project (conception and design phases) it enables the early collaboration of the multiple disciplines, this means, that the company that will bring the project into realization can participate in the design process and give valuable input from previous experiences.

Laser Scanning, Photogrammetry and Augmented Reality

Another important aspect that has been studied is the understanding of the building context. This is very important for retrofit and/or remodelling work. Technologies that have been used in the last years and continue to grow in the AEC industry is laser scanning and photogrammetry. These can be used to compile point cloud data (PCD) in real time, providing valuable information on the actual state of the site or building (as-built conditions). First one must scan the place in order to create the point cloud file so that it can be exported into the project coordinate system. There are several software programs that exist already in the market that provide support in the preparation of point clouds to be imported into BIM models. By using photogrammetry, one can program a computer algorithm that identifies anchor points in a series of images, these anchor points can be any marks that the technician decides to use as a reference. Then, they collect whether video frames or multiple photographs of the same place and use them to compute the position of the camera for each image, obtaining with this the position of the reference points in a 3D space. The result is very similar to the one produced by a laser scanning process, it is a point cloud representing the geometry of the scene, the differences are that cameras keep photographic images and can create a mesh that generates from the points by wrapping the images together; scanners save only the location and colour of each point. Information obtained from photogrammetry is usually less dense and accurate than that from laser scanning. By increasing the number of images, the accuracy of photogrammetry can be improved. Also, by increasing the resolution of the images (Eastman, Charles M., *et al.*, 2018).

With current technology, contractors can use laser measurement devices that report data directly to a BIM tool, to check that the elements are built as they are supposed (e.g. verify that concrete pours are situated in the correct location, columns are properly located, etc). Laser scanning can also be used effectively for rehabilitation work and capturing as built construction details of existing facilities. There are a widely available laser scanning services; buildings can be scanned, and operators then interactively generate the building model objects that represent the scanned elements. For infrastructure applications, laser scanners may be carried on a vehicle or with the use of drone technology.

Similar to laser scanning, the use of virtual reality (VR), and augmented reality (AR) is becoming a more commonly tool used by designers to review the current state of the design. It can be used with the help of a variety of hardware (e. g. head mounted displays). Few examples of VR rendering software are: Enscape, V-Ray, and Autodesk 360 Rendering. 3D printing, and digital prototyping is also becoming common during the design and construction phases. All these tools can also help improve the involvement of owners and facility managers, since they have a very visual aid that helps them understand how the building will be made and even show them how the building will behave under given circumstances, saving a lot of time by not performing several iterations.

5D Methodology

A new methodology that is gaining the attention of several technology companies is the construction planning using 5D methodology, this stands for 5 dimensional modelling. and refers to the intelligent linking of individual 3D CAD components or assemblies with time schedule (4D) and then with cost-related information (5D). Custom and commercial 4D tools facilitate the process by linking 3D geometry, entities, or groups of entities to construction activities in schedules. This requires linking a construction plan to the each of the 3D objects in a model and supplementing it with construction equipment objects (e. g. shoring, scaffolding, cranes, etc.). Then it is possible to simulate the construction process and show how the building would look like at any time. This graphic simulation provides considerable insight into how the building will be constructed and reveals sources of potential problems and areas of opportunity for possible improvements (Eastman, Charles M., *et al.*, 2018).

These tools allow designers to simulate the building process. With 3D simulation, planners and designers can execute clash detection between static objects in a model, such as pipes, beams, columns, walls, etc. With 4D simulation, they can execute clash detection with information about resource utilization and productivity information between temporal objects, such as cranes, trucks and special machinery.

For the cost estimation, 5D is used to determine the price of the project by assigning cost for each element in the BIM model. This tool allows owners to take better decisions cost wise during the planning phase so that the project is delivered under the estimated budget. Each BIM software alone have the capacity for exporting quantities of the objects that it has so that one can manually add the price per element, however, there are currently external software programs that can help calculate automatically the price of each element. For example, the software iTWO by RIB software is one tool that is gaining a lot of importance in Germany for the easiness to combine 4D (scheduling) with 5D (cost estimation) in one single tool. It is important to understand that BIM software in combination with cost estimation software can only give a part of the information, it is always necessary some manual input for these tools to work correctly. Other tools for cost estimation, such as Destini profiler from Beck Technology, connect each element of the 3D model with a certain cost, the planners can then simulate the price of the final product in an iterative manner, helping owners make realistic choices that deliver the most suitable price.

The benefits of using this methodology is that planners have an improved communication: they can visually communicate the planned construction process to all stakeholders because the model contains both the temporal and spatial aspects of a schedule and can present this schedule in a more effective way than a traditional Gantt chart to stakeholders; the model allows for multiple stakeholder input: since the models can be worked interoperable, they are often used in community forums to present how a project might impact a community; It improves site logistics: planners can coordinate the expected time and space flow of trades on the site as well as the coordination of work in reduced spaces; Better project control: planners create a tool that helps contractors compare schedules and track construction activities to quickly identify whether the project is on track or behind schedule.

Design optimization is a tool that designers are exploring. With a design optimization software, it is possible to develop several design options with one single model. For example, one can design a façade for a building with different types of windows or with different shapes to analyse the behaviour of the building. These tools generally work with the attributes and parameters that objects have.

2.2.2 Construction

The contractors that develop their activities in the construction phase can have great major advantages by using BIM technology, these major advantages usually are represented in the saving of time and money. An accurate building model benefits all members of the project team. Thanks to it, contractors can develop activities in a smoother and better-planned process and reduces the potential for errors and issues. As it has been mentioned before, by having a building model, the contractor can perform a virtual “first-run” of the construction process itself. Nowadays, this is done with software such as **MS Project** or **Primavera** which only allows to see a Gantt chart visual schedule with little information about the model.

During construction, on site, contractors can use BIM to deliver specific information directly to the construction crew. This can be done using mobile devices, having the advantage of having the most up-to-date information in real-time, and it also gives an opportunity to the construction crew to provide an effective feedback of information about the activities back to the model. These tools can also be programmed to process information, creating a strong synergy between the contractor, the construction crew and any important stakeholder.

BIM tools can help to collect and deliver project status information to construction crews on the site, maintaining a smooth workflow by adapting their plans to conditions on-site as construction progresses, which is completely dependent on the quality of information they have about the conditions on-site and the procurement of the materials and/or equipment's. This can be a cloud application, which means that the information is immediately available at all times and to all stakeholders. The most basic function of collecting information from the job site is the ability to take photos of site conditions and associate them with building objects in the model. Many applications also allow users to load more information about physical conditions, and a few also enable reporting of process status. To mention a few examples, there are apps in the market such as **Fira's SiteDrive** and **VisiLean**, which include mobile reporting interfaces for crews to report work status. Most smartphones on the market today can read barcodes, Quick Response (QR) codes, and Radio Frequency Identification (RFID) tags, enabling workers to report the status of building components as they move through further enriching the status information.

As it has been studied, the use of BIM with the **Lean Methodology** is becoming of great importance in the construction industry. Lean provides the principles to be followed and when used correctly, it can help by getting quality right the first time, improve upstream flow variability, reduce production variability, reduce inventory, increase flexibility, reduce change, use an appropriate production control approach, use pull systems, standardize, promote continuous improvement, use visual management, simulate production processes, design the production system for flow and value, among others. With the combination of BIM and Lean, contractors are able to enhance teamwork by improving the ability to coordinate construction activities with a high level of detail among different trades. The **Last Planner System (LPS)** is a Lean construction tool that helps create pull driven schedules. The main focus of this tool is to prepare work packages to make sure that all constraints have been studied before the work packages are assigned to a construction crew to begin execution.

The software **iTWO**'s platform uses a database to store model objects, cost information for estimating and scheduling information in an integrated database. One or many models can be imported from various BIM platforms and coordinated using iTWO's BIM manager. iTWO enables estimation, tendering, subcontractor management, cost controlling, and invoicing processes (Eastman, Charles M., *et al.*, 2018).

Prefabrication

Prefabrication can help significantly in the reduce of waste in construction. It means to build elements of a project on another place different from the construction site, usually carried out in a shop or factory, and made into modules. When the differences between modules are minimal, the prefabrication process becomes easier than modules that have great differences. 3D modelling has encouraged the development and application of prefabrication. The costs that need to be taken into consideration to assess the feasibility of using this technology are the cost of prefabrication itself, the cost of transporting the modules from the shop or factory to the job site, the costs of the machinery or equipment that will be used for the logistics on site. Another benefit of prefabrication is the quality control of the elements. It becomes easier to control the environment inside a shop or a factory so that the prefabricated elements have minimal variances with the required quality.

Simulation

Simulation of different systems is another great tool that many companies are implementing in their designs. By doing so, they can analyse and simulate the behaviour of the fire system, in case of an emergency; the water system to make sure that every service gets the necessary amount and with the sufficient pressure; the structure of the building, so that builder make sure that the structure they are building has enough resistance; the HVAC system, to make sure that all the rooms that require either heating or cooling get the right level of comfortability. The electrical system, to be certain that there are enough circuits and the loads are well distributed. Another important feature of the simulation with BIM tools is for the cost estimation. There are programs or plug-in's that can be used with BIM software in order to calculate, in real-time, the cost of each one of the elements in the model.

Augmented Reality

Augmented Reality (AR) can overlays information from a model onto a scene in a mobile device or tablet on the construction site, this means that a user can view content from a BIM model (graphic and/or alphanumeric) overlaid directly on the view of the building in the correct context in space and in time. This helps construction workers to review, for example, where ducts and piping are to be installed in a building; perform a quality inspection to compare what has been built to what was designed; accessing maintenance data about an object within a building by looking at it; It allows contractors to view hidden objects, such as the reinforcement in concrete or electric installations behind a wall; contractors can receive step-by-step directions for the construction of a special element or view animated sequences of construction in preparation for their execution.

Machine-Guidance

A new technology that is still under development but is gaining some attention is machine-guidance technologies. With this, contractors can use computer-controlled earthmoving equipment that can be guided and verify grading and excavation activities based on dimensions that were either manually loaded or automatically calculated from a BIM model.

IFC Open format

Thanks to the IFC format, during the construction phase, the contractor and subcontractors give real time input that gets loaded in the model, giving the advantage that at the end of the construction, the facility managers will have the most accurate model to work with for the rest of the lifecycle of the new construction. The data can be linked to the objects in the model and be available for handover to the owner or the facility manager so that it can be checked that all systems are working as designed before the building gets turned over. Most of the BIM software today is changing their use from a system base to a web or cloud base system. According to Charles M. Eastman *et al.* (2018): “the functions that benefit from the use of BIM in combination with a web or cloud system are: contract tracking, version control, search capabilities, design issue management, user management, notifications of work orders, design issues, and RFIs, generation and management of transmittals, meeting minutes, work orders, change orders, and other reports; workflow management; and project management dashboards.”

Companies that support BIM have been making great efforts to help standardize the transference of information between stakeholders. Like the IFC, there is another format that is currently used by several countries for the transference of information from the design and construction phases, to the facility management phase. The format is called the **Construction Operations Building information exchange (COBie)**, it addresses the handover of information between the construction team and the owner and is used for the Operation and Maintenance of the building by outlining a standard method for gathering the necessary information from the design until the construction processes, this information becomes a part of the deliverable package that is provided to the owner during commissioning and handover phases. With the given information and the use of BIM, owners and facility managers can monitor the facility operations, possibly capturing sensor data from one or more facilities, with a control in real time and a lifetime commissioning.

Dynamo

With plug-ins, like **Dynamo** for Revit, it is possible to retrieve information from the BIM model, process it to obtain an analysis or a result, and then to load the new information to Revit. This way, the possibility to make complex analyses and store the results becomes possible, even the possibility of storing data in “real time”. With tools for sustainability assessment, one can link the BIM model to an external software or plug-in and calculate the energy use during the different phases of the project.

Contractors can program algorithms to report efficiently the activities being carried out during the construction and with this to keep track of construction progress in real-time. This tool can be even programmed to generate automatic reports that can then be send to the stakeholders everything using the same BIM model. Also, with dynamo, architects have a tools that can modify in a quick manner the design in case of change orders.

2.2.3 *Facility Management*

BIM allows owners and/or representatives to automize payments for the finished activities from contractors and subcontractors.

After the construction is finalized, the commissioning of the project has to be done. The commissioning consists of making sure that all the systems and equipment installed in the project are working properly (e. g. electrical, plumbing, HVAC, etc). It is in this phase where the turnover of the data that was generated from the beginning of the project so that it can be used for the facility management. The data and its format given to the owner and/or facility manager is very important because it is what will determine the usage of it. There are currently tools to help facility manager integrate project systems in BIM for FM services such as **Ecodomus** and **DAD** software. This has many benefits for building management, but to use the full potential of it, the model must include all the equipment and systems in the project with the correct connectivity information.

Energy Management

Heating of buildings requires more than 25% of the total end energy consumption in Germany (Bär *et al.*, 2015). In the U.S., the lighting, heating, and cooling of buildings accounts for roughly 40% of total energy use (Eastman, Charles M., *et al.*, 2018).

The energy generation in smart cities has been widely studied. There are several ways of producing energy, some using renewable sources and some still using fossil fuels or natural gas. The most efficient and commonly used technologies are: Photovoltaic panels, thermal collectors, wind turbines, biomass, geothermal energy and the conventional generation of electricity like the combined cycle power plants. Recent studies have determined that by optimizing the operation and management of the energy can save up to 20%-30% of the energy consumption. All of this can be made without changing the buildings structure and/or the hardware configuration (Guan, Xu and Jia, 2010). The intermittency of renewable sources, the increasing demand, and the necessity of energy-efficient transport systems, represent important energy challenges that are better addressed together instead of separate issues (Calvillo, Sánchez-Miralles and Villar, 2016).

For the energy storage of cities, several technologies have been created and used. Some of them have a lot of advantages over the others. Some of these technologies are batteries, the superconducting magnetic energy storage (SMES), the super-capacitor, and the flywheel. Batteries are devices that can store energy in a chemical compound, the problem with batteries is that their life cycle is very short, and they represent an environmental hazard when disposed improperly. The superconducting magnetic energy storage stores electricity in a magnetic field with a superconducting coil. The flywheel is a very innovative technology that is capable to store energy in the form of mechanical energy. There are also systems that can store excess energy from renewable sources in the form of heat. One system is the High Temperature Borehole Thermal Energy Storage which basically stores heat in the underground rocks by pumping hot water during the summer through on of the pipes. To use this stored energy, one can pump water in the opposite direction for when it was being stored so that it then uses the heat contained in the underground rock materials, the only constraint for this system is that the location where it is built must have a negligible groundwater flow at reservoir depth so that the induced thermal plume is not dissipated (Bär *et al.*, 2015).

Passive systems can be implemented as a complement. These systems are designed to collect, save, and/or distribute thermal energy within a building. Elements to be considered can be thermal insulation, materials with a specific thermal mass, location of windows and the glazing type, solar shading, etc. These elements, in the context of design are sometimes referred together ase the “building envelope” (Calvillo, Sánchez-Miralles and Villar, 2016).

Internet of Things (IoT)

Pärn, Edwards and Sing (2017) researched the great area of opportunity for BIM and the use of internet-connected sensor devices and concluded in their work that: “This early integration of both geometric and semantic data would prove invaluable to the FM team during building occupancy, particularly with respect to monitoring building performance. In turn, a more accurate measurement of building performance in-use provides a virtual circle and invaluable knowledge-based feedback opportunity for designers and contractors to improve the development of future projects commissioned”.

2.2.4 Reproduction of the BIM model

With the use of BIM, it is possible to use the same processes and techniques used in one project into another. There are several problems with this due to the differences of software, norms, languages, etc. For example, the word “Door” is “porte” in French, “Tür” in German, and “門” in Chinese. An object used in a project has properties and attributes, if it is to be used in another project in a different country, must likely the attributes and properties will have different names and maybe be in different languages. In order to solve these problems, the building-SMART Data Dictionary (bSDD), which is also known as International Framework for Dictionary, was created. The bSDD has the responsibility of creating mappings of terms between different languages, so that projects can be widely used in different models and interfaces. Also, the bSDD is developing standards for building product specifications, so these can be used in different applications, such as cost estimation, energy analysis, carbon footprint, etc.

One can create a “carbon copy” of a previous project. When BIM is used in a company, one goal should be the reproduction of the same ideas that were already developed in previous projects. With the use of open formats such as IFC, one can reuse same ideas in new projects. As it will be shown in Chapter IV, in the FlexQuartier project, the design team is creating a model that will be used as a basis for new projects not only in Germany, but also in other cities around the world.

2.3 Smart Cities

The United Nations (UN) projected that 66% of the world population will be urban by 2050 (Bocquier, 2009). A smart sustainable city is an innovative city that uses information and communication technologies (ITC) to improve the quality of life, the efficiency of urban operations and services, and the competitiveness of the local economy, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects (ITU-T, 2015).

According to Yadav *et al.* (2019), the core elements for a Sustainable Smart City (SSC) development consists of:

1. Adequate water supply
2. Uninterrupted electricity system
3. Advanced sanitation facilities
4. Urban mobility and fast public transportation
5. Affordable housing
6. Strong IT infrastructure
7. E-governance
8. Sustainable energy development
9. Smart city monitoring and security system
10. Modern healthcare and education facilities

The link between BIM and smart cities can be easily relatable. The city can be intended as a dynamically and complex system that evolves in space and time following trajectories that are hard to predict (Fistola and La Rocca, 2013), and it is where BIM can help to solve or attenuate this complexity by giving the city managers a tool that helps them manage all the processes with one single file.

Smart city is a complex of software and technical solutions and organizational measures aimed to increase the efficient use of all resources (electricity, water, gas, heat, time) and to create conditions for a comfortable stay in the city, living and doing business (Ignatova, Zotkin and Zotkina, 2018). Also, city planners and local authorities should consider in their plans for future expansions and/or renovation to the city, the emissions that these processes will bring to the environment. There are some tools that can work with BIM software that simulate and analyse these emissions and other effects that the regular processes of the cities cause.

Anand *et al.* (2017) reported that consumption of renewable energy resources, recycling of used resources and emission control system for vehicles and industries are the most crucial energy-oriented enablers that influence the smart sustainable city development. Developing smart solutions for sustainability, optimizing efficiency in urban systems, and enhancing the quality of life of citizens can occur by connecting urban systems and assessing their sustainability performance; eliminating redundancy in urban operations and services; and pinpointing which urban domains, facilities, and networks to couple, coordinate, and integrate (Bibri and Krogstie, 2017).

CHAPTER III BIM APPLICATIONS AND BENEFITS IN PAST PROJECTS

In this chapter, three examples of how 2 different countries are implementing BIM technology to improve different processes inside the life cycle of the project. The first example, is the National Children's Hospital, located in Dublin, Ireland. The second example is the Hyundai Motorstudio Goyang, located in South Korea.

In these projects, some tools were implemented in different phases and benefits were obtained because of this.

3.1 National Children's Hospital, Dublin, Ireland

3.1.1 Introduction

The National Children's Hospital is one of the biggest investments in health care of Ireland. It is located in Dublin. The National Pediatric Hospital Development Board (NPHDB) is responsible for overseeing the building of the hospital. For the project it was requested the use of BIM because that would be beneficial for design and coordination of information. It was expected that during the construction phase, BIM would improve cost, value and environmental performance thanks to the use of open information. Each member was required to have its own 3D model instead of having a cloud-based system to share one between all stakeholders. BIM was used from a very early stage of the project and it was important to obtain the necessary permits.

Due to the nature of a children's hospital, the design team was challenged with the task of getting valuable information for design from staff of the existing hospitals, clinical leads, to even local residents, people that are not typically used to architectural or engineering terms. Nevertheless, BIM offered them a model which helped them visualize the spaces and improve the design by letting these nonspecialized end users to contribute more effectively.

The building will be four stories tall and it will provide several recreational areas. It will also have state-of-the-art operating rooms (heart surgery, neurosurgery, and orthopaedics). The building will have several landscaped and recreational areas, including gardens at ground level and a garden covering mort of the building footprint at level 04. It began construction in 2016 and it is planned to finish by 2020.

The selected designers of the project are BDP, a major international company with activities in architecture, design, engineering and urbanism; and O'Connell Mahon Architects as the co-lead designers in collaboration with ARUP (M&E Engineering), Linesight (Cost Consultant), and O'Connor Sutton Cronin (OCSC), among others. The original estimate for the project was 650€ million, excluding fit out costs.

3.1.2 Planning phase

Due to the contractual requirements, a BIM execution plan was requested by the client on the advice of BDP who had successfully implemented BIM into his projects since 2011. At the beginning, in order to have the topography, surrounding buildings, site features, visible services, etc. a series of **laser scans** were performed by Murphy Surveys.

The contractor was requested to produce and update a full BIM model that includes all relevant trades for the project. Each trade would be responsible of generating their own models. Because the project is quite large, the model was split by different trade specific models (e. g. for site, Mechanical and Electrical, external envelope, Fixtures Furniture and Equipment). All the information generated by the models have to be compliant with the NPHDB facility management software. The client also required an Employer Information Requirements (EIR) document, which helped the design team to understand what the client's needs from the beginning are.

The NPHBD required that the model was downloadable at any time in the **IFC format**. Several visualisations were made where important stakeholders could pay attention of the impacts that the new construction will have with the surroundings, for example, the interaction between the hospital and the light rail system that has a stop near the site. For the visualizations during stakeholders' presentations, BDP used Google Cardboards as the primary visualizing tool. They were placed inside a virtual representation of the building, which allowed them to understand the design proposals and further let them to engage with the design.

By using **Dynamo** software, planners were able to reduce the requirement for manual and repetitive tasks as it allows the establishment of custom workflows in Revit. As it extends BIM using the data and logic environment of a graphical algorithm editor, it was used for rapid design development. For instance, the external consultant for building services used Dynamo software to analyse the roof panels based on their slope angle. Within Dynamo all curtain panels were selected by family type. This panel area was then computed, and the now remapped result range was linked to a colour range that enabled automatic overriding of panel colours within the view (Figure 2).

For the clash detection during the planning phase, **Navisworks** was used. Monthly meetings for clash resolutions were held and where every clash was designated into one of three levels: services vs. structures and architectural, services vs services and all other clashes. All involved participants were able to keep track of the progress of the resolving clashes per designated clash. The quantity surveyors made sure that the correct information was embedded in each one of the elements, allowing an effective analysis in **CostX** and a close approximate calculation of quantity take-offs. With these approximations, the client had a better understanding of the design iterations and the cost related with each.

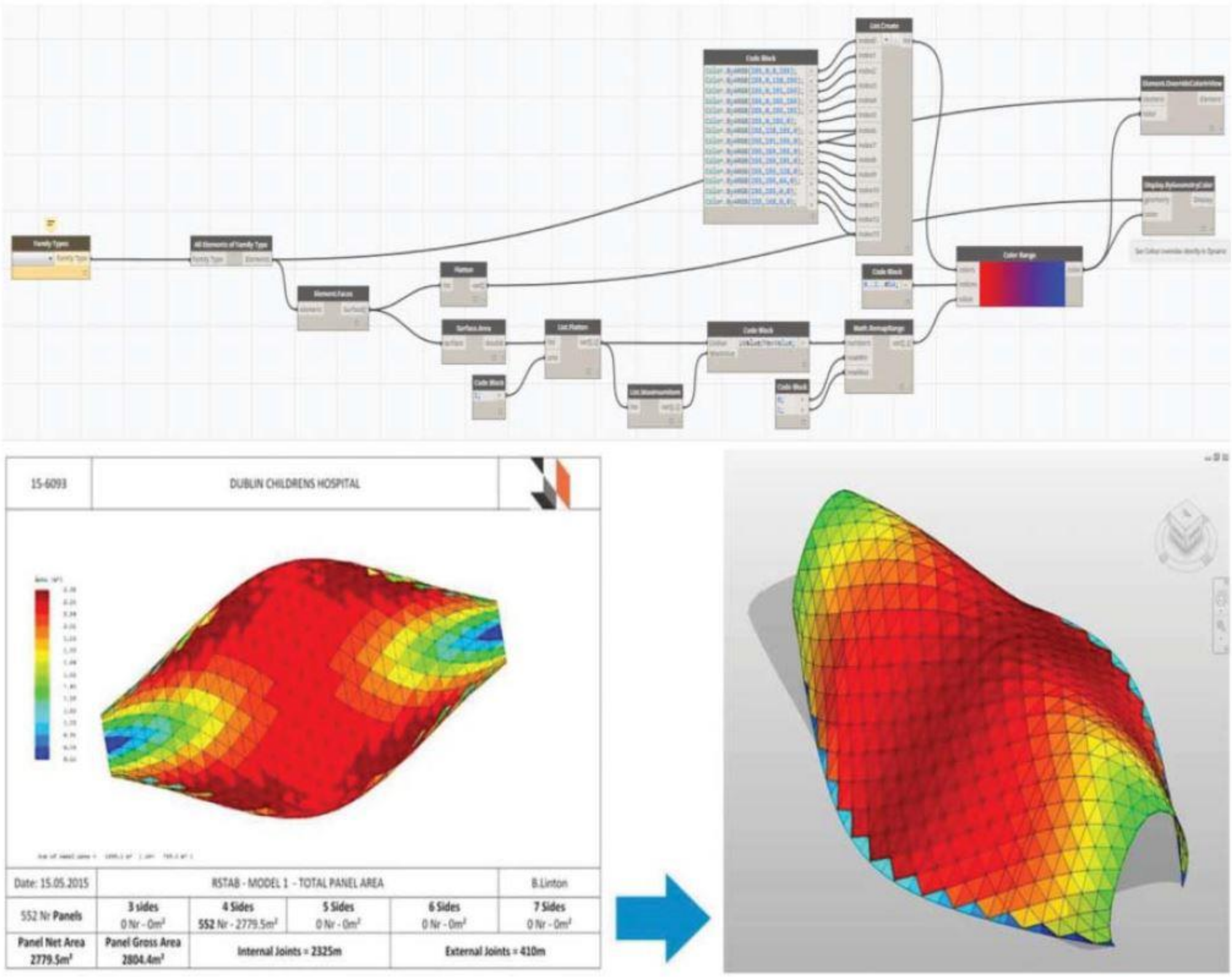

Figure 2. Analysis of roof panels performed with Dynamo (Source: Eastman, Charles M., et al., 2018).

With approximately 6500 rooms, the hospital maintenance database requires more than a half a million Fixtures, Furnitures and Equipment (FF&E) objects that must have information about each one. A software was designed specifically to produce room data sheets from the BIM model for the facility management, the software is called Codebook.

During each stage of the project, all the generated information was structurally stored in the form of Asset Information Requirements and the **COBie** format, which has been of great assistance for the facility managers to have a control of the asset requirements of the client in real-time.

3.2 Hyundai Motorstudio Goyang, South Korea

3.2.1 Introduction

This project took place from 2013 and 2016. The main contractor was Hyundai Engineering and Construction (E&C), which has developed several applications of smart construction processes using BIM. Hyundai Architects and Engineers (HDA), was the domestic architectural firm which undertook the construction documentation. Delugan Meissl Associated Architects (DMAA), an international architectural firm provided the design services, including conceptual design. The original budget of the project was 120 million USD. The original schedule for construction was 39 months, however, because of several changes requested by the owner, Hyundai Motor Group, this was extended to 44 months. Due to these changes, the final budget was incremented to 170 million USD. The owner's main goal was to build the most attractive exhibition facility for automobiles in the world.

The building consists of several exhibition halls for automobiles and automobile products, car showrooms, theatres, a 3D experience room, automobile repair facilities, a cafeteria, childcare facilities, sports facilities, and more. The main structure was made of steel frames with free-form exterior panels. One of the challenges in the developing of this project was the irregular geometric shape. The main 5 challenges of this projects were: 1. A complex spatial arrangement, 2. Free-form-patterned exterior panels, 3. A mega truss structure, 4. A perception gap between project participants, and 5. Schedule reduction.

3.2.2 Planning Phase

Since Hyundai E&C and HDA belonged to the same company, the project became basically a Design-Built project. This was quite beneficial because Hyundai E&C participated from the beginning in the detailed design from the constructability side, as well as the major subcontractors of the project (e. g., steel, concrete, and MEP).

<u>*Challenge 1*</u>: Meetings with many participants were held, so a coordination process had to be designed for the right streamline of the decision process. Two-tiered coordination process was created and used. Tier 1 meetings were held with the owner, designer, general contractor and major subcontractors and the meetings were based on constructability issues and major design errors. In these meetings, owner and designer agreed on the development of detailed shop drawings. For Tier 1 meetings, a BIM model at **LOD 250 to 350** was used for coordination because details, such as miscellaneous materials and minor clash detection (because this was a responsibility of the general contractor), were not important for the owner during these meetings and it allowed for the BIM model to be prepared faster. Tier 2 meetings were held with the general contractor and the subcontractors, owner and designer would sometimes participate on these meetings, but not mandatory. These were focused on construction clashes and minor design errors. For these meetings several BIM models at **LOD 350-400**, developed by

subcontractors for 3D shop drawings, were used. Two-tiered meetings were successful because only the necessary stakeholders were called to the meetings where they were relevant according to their function.

Challenge 2: The design team had to design an area of approx. 13,940 m^2 of free-form-patterned exterior anodized panels. Due to the complexity, each panel hat to be designed independently. A software was used to carry out the parametric modelling of the panels. Each panel was designed with a specific number and a zone. The designers created a zoning plan.

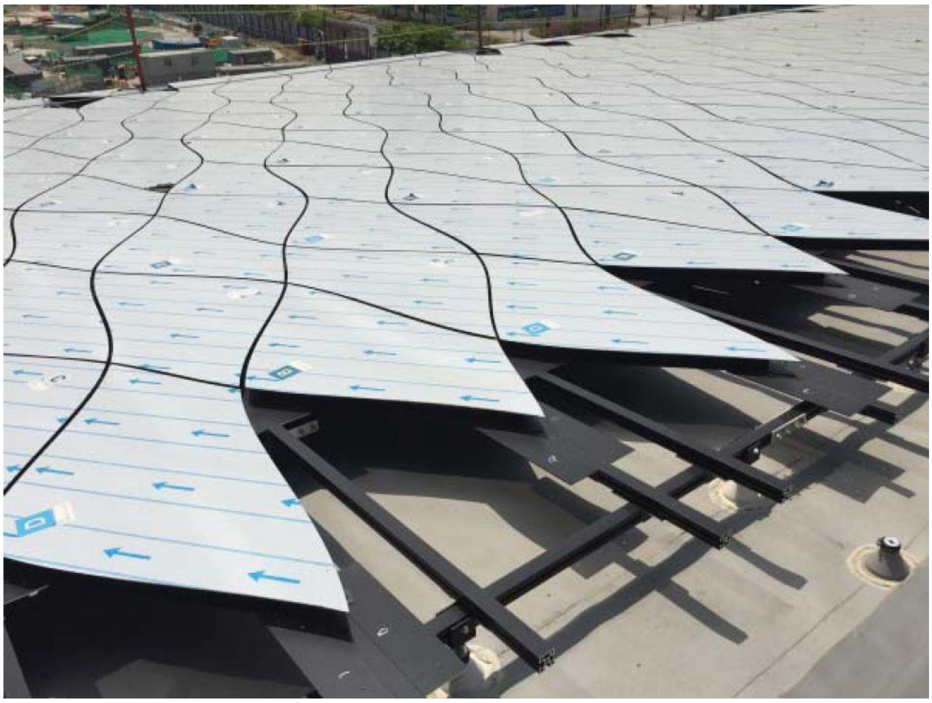

Figure 3. Panel colocation on façade (Source: Eastman, Charles M., et al., 2018).

The BIM panelizing method allowed the optimization of the number of panel types by changing the shapes of the façade (iterative design). For the owner, it was more important to connect the panels smoothly than cost so, Hyundai E&C applied different designs on every edge of the façade, instead of reducing the number of panels.

3.2.3 Building Phase

Challenge 1 cont.: During this phase, the two-tiered meetings were continued in order to solve the issues that occurred. Construction objects that could be resolved in the field were not included from the scope of BIM modelling because it was not very efficient to solve all clashes and errors through BIM as they came along. Many change orders were made during this phase, however, thanks to BIM, all were attended properly and orderly.

Challenge 2 cont.: For the installation of the free-form-patterned panels, the BIM model developed during the design phase was used. The contractor SteelLife, specialized in façades, took care of the panelization through the model.

Challenge 3: To maintain a good quality control of the more than 3,000-ton mega truss structure, two main features had to be continuously monitored: 1. The floating structure had to be approx. 12.3 m above ground level, and 2. The longest length of the structure had to be 32.2 m. A deflexion of about 50 to 100 mm was expected due to the analysis in the design phase. For the exterior panel and windows contractors, the deflexion was of the most importance, so, the project team used **3D laser scanners** to monitor the deflexion of the truss during construction. There were 40 different scanning stations on the site. Each laser scanning took about 20 minutes per station, the total scanning time was two days. After each scan, the information was transferred to a cloud-based system using Trimble RealWorks, then the data was combined with the BIM model to compare between the planned model and the actual construction. Once the information was analysed and the deflexions were measured, the information was sent to the subcontractors so that each one would take care of their own issue according to their trade.

Challenge 4: As it is commonly known, there are perception gaps between what one person sees in comparison with others, even if it is the same image. The first gap during construction was on the perceived textures or colours of the finish materials in a model. This problem affects little to experienced contractors that use the same finishes over and over, however, for an inexperienced owner or manager, this can be a challenging task. These gaps may incur in delaying decision making during construction. The solution of the designers and the main contractor was the use of a software called Fuzor, which rendered with a high level of detail the BIM model, allowing the owner to clearly see the specific areas of concern.

The initial design of the exterior panels for air vents was planned to use approx. 30 perforated panels on the side wall of the structure. The owner and designer were concerned with this design because of its potential to spoil the beauty of the building. The BIM model was rendered on an **Oculus Rift VR** headset and this provided more realistic visual services for the owner, allowing a better understanding of the current design. The use of VR was of great importance for both the owner and the contractor, the owner could see the design in a clear and understandable way and the contractor could make the owner take faster decisions.

Most of the building was covered by the mega truss structure and during its construction, activities and material storage under the structure were prohibited due to safety reasons. The construction sequence and the material movements were adjusted to the schedule of the truss structure. The construction of the structure was coordinated by different colours using a **4D simulation**. The visualization of the construction process and movement of materials and personnel was presented during the coordination meetings helping subcontractors with little experience on steel construction to understand how the new schedule had to be performed. In this study case, it is important to point out that the use of 4D simulation was beneficial only in the case where several subcontractors had to understand a specific trade of which they have little to no experience, if some activities are to be performed by a single contractor, it is of no much use to develop a 4D simulation.

Challenge 5: When the owner of the project required the team to incorporate new design trends, it was done at a cost of increasing the construction schedule by more than 5 months. Even with these changes, owner wished that the schedule was reduced to allow early opening to the public. The solution of the contractor was to deploy **multiple prefabrications**. The greatest issue was in the corridor ceilings where all the MEP installations go. The contractor manufactured all the corridors MEP systems as prefabricated racks at a factory and then were installed on site. The final benefit of the multiple prefabrication was that after the installation of the MEP systems on the four floors, the schedule was reduced by one-month total.

CHAPTER IV COMBINATION OF TECHNOLOGIES FOR PROJECT LIFE CYCLE IMPROVEMENT

In this part, the FlexQuartier project and a proposal of several technologies and benefits will be described. These proposals are made from the starting point that the project is already using tools to improve the initial stages of the project. As it has been seen, there are many tools that exist today in the market and many of those have been already used in projects such as the National Children's Hospital and the Hyundai Motorstudio, mentioned before, to improve specific phases of a project, however, a combination of these technologies and methodologies that build upon themselves from conception, planning, construction, commissioning and through the entire facility management phases of a project has not been fully explored. The FlexQuartier project is important because it promises to become the spearhead in terms of smart cities and sustainability for Germany. As it will be shown next, it is an innovative design that, at the time of writing this thesis, it finds itself in the conception phase. A broad overview of the planning of the project will be explained and also proposals that can be useful will be given and the possible benefits taking into account the benefits already seen in Chapter II and Chapter III not only for planning, but also for the construction and facility management.

4.1 FlexQuartier Project

4.1.2 Introduction

As a part of the Energy Research Program of the Federal Government of Germany, in the State of Hessen, a new district is planned to be built. This new urban district with a total of 7.9 ha. will be built on an inner area of the city of Giessen with over 400 residential units and more than 38,000 m² of floor space. The project is being designed forming an energy efficiency district with contemporary features as well as innovative solutions in the field of energy and system services. It is called "FlexQuartier" (Figure 4).

For the first time in Germany, there is a combination of the concepts of BIM, 5D methodology, energy efficiency, innovative technologies, and Smart Cities planned altogether following a new methodology gathering the needed information continuously. The key technology of the FlexQuartier is an innovative hybrid storage system consisting of a novel high-temperature storage device (HTS) in combination with a state-of-the-art battery storage for electricity and a large-volume hot water stratified storage tank for the waste heat of the HTS. The innovative high-temperature storage system (HTS) will be used to take care of the fact that the volatility of renewable energies requires innovative and cost-effective energy storage. The possibility to include this HTS system in the market of energy storage devices has to be analysed and proved.

Figure 4 FlexQuartier preconcept (Source: Own illustration).

In the planning phase, a system for the representation of the entire neighborhood in a virtual neighborhood information model, a “Quartier Information Model” (QIM) based on the Building Information Modeling (BIM) methodology, will be developed and applied, also including aspects of energy monitoring in order to obtain an integral methodology for the planning process and management of the “FlexQuartier” project. The requirements of the monitoring of the urban district must, therefore, be considered in the concept and in the planning phase as well as in the realization phase. The QIM will be created and used at the beginning of the project and in this phase the model will be called Conception Model; during the planning and construction, three models will be created sequentially, these will be the Planning Model, Realization Model and Commissioning Model; and at the end, for the management of the new district, a Management Model will be created. The operation of the energy system will be carried out with the Management Model.

All the models will be built upon themselves, this means, the Conception Model created at the conception phase will then become the Management Model at the end of the project. These models will be compatible with the open source format **IFC** so that they can be transferred and used in other software so that a series of simulations and analyses can be performed, e. g. to quantify the size of the energy storage system and the whole usage of energy in general. An important objective of the project is developing a methodology that is capable of being replicable outside of Germany, and not only in the European context but also in any other city around the world.

There are several stakeholders from the state involved in the project, these are: the Technische Hochschule Mittelhessen (THM): for the High-temperature storage, reconversion, heating networks; the network serviceability, energy and system services; and for the developing of the Quartier Information Model (QIM) and Building Information Modeling. Also, the City of Giessen as main beneficiary of the implementation of these different technologies and Smart Power GmbH & Co. KG as one of the main contractors for energy supply in the State of Hessen.

The city of Giessen, which is located in the State of Hessen, and SWG AG, as a municipal utility company, are seeking an answer to the question of what the energy-efficient, as renewable as possible-supplied and energetically integrated urban district of the future can look like. Due to the long useful life of neighborhoods (more than 200 years) (Figure 5), planned neighbourhoods should already be measured against the energy policy goals for 2050. The participating institutes contribute with their interdisciplinary scientific expertise for the development of sustainable solutions.

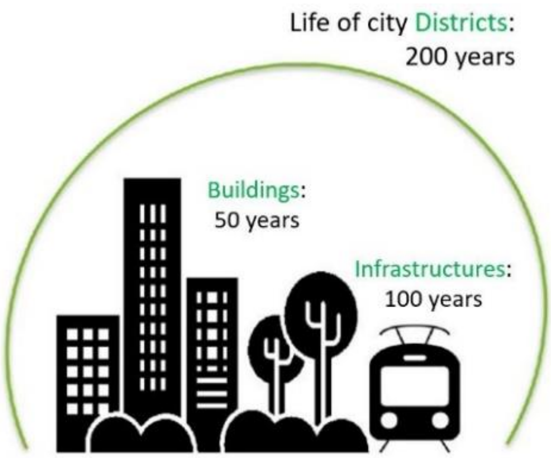

Figure 5 Lifespan of urban neighborhoods: Development of a new, sustainable and intelligent urban district with at least 200 years of imputed life expectancy (Source: Own illustration).

The interoperability of the whole district has to be considered from a holistic point of view. There are necessary intermediate steps achieving a sustainable operation of the neighbourhood. These are the virtual step-by-step development of a conception model, a planning model, a realization model, a commissioning model and a management model. These models must all build on each other and be integrated together. The models are to be created in different phases: District phase, Building Phase and Management Phase (Figure 6).

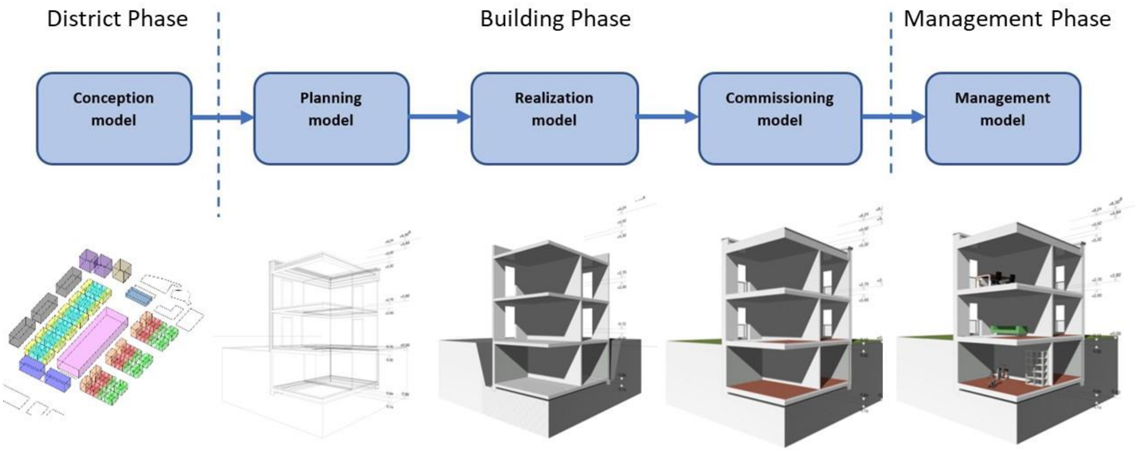

Figure 6 Different models and phases (Source: Own illustration).

Each of these different models have a series of steps to be followed in order to achieve complete integration between one another:

1. Conception Model: assessment of boundary conditions (such as local climate data, urban planning, etc.), agreement/definition of minimum energy standards, building typological differentiation in groups/clusters (e. g. terraced house, multi-family residential building, public institution, etc.) on the basis of basic urban planning data, definition of cluster typical energy profiles, conception/creation of a district model (QIM), transmission of cluster typical energy profiles - specific energy needs, definition of cluster-typical energy gains (PV, solar radiation, etc.), integration information storage technology, definition/integration of control systems, evaluation of the overall model with forecast of the energetic behaviour.
2. Planning Model: definition requirements for individual buildings according to minimum energy standards, definition of requirements components according to the minimum energy standard, definition of integration sensor technology in components and anchoring in the overall system, integration in model of sensors, definition requirements modeling/planning of individual buildings, consulting planning/modeling, integration of the individual building plans as replacement of the clusters (building instances) with changes/optimizations in the overall model, gradual evaluation of the overall model with forecast of the energetic behaviour.
3. Realization Model: preparation based on the detail of the building modeling and definition of the execution-specific requirements, tender of the project (based on model).
4. Commissioning Model: realization of the “As-Builts” in order to be transferred to the QIM, integrate all the communication connection scenarios into a Quartier Information System (QIS).
5. Management Model: transfer of the Quartier Information System (QIS) into the operating phase, optimization during operation.

The use of the QIM makes it possible for the first time to taxonomically relate the formerly separate disciplines of power generation, distribution, storage (energy system technology) and energy requirements at district, infrastructure and building level (architecture and building infrastructure) together (Figure 7). The different models that will be developed must be interoperable between different software. The THM team, involved in the planning part of the project, is working on the compatibility with the IFC format. The project can be used serving as a basis for other cities around the world who may want to replicate this kind of project.

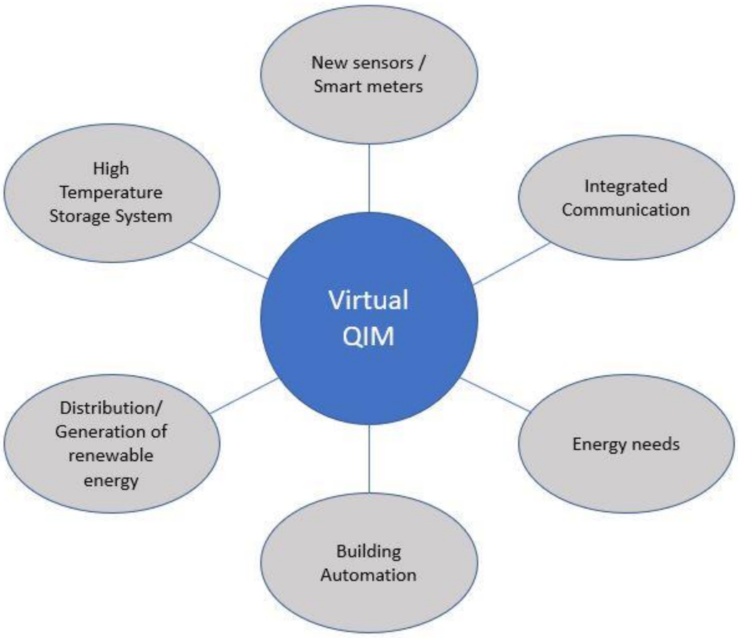

Figure 7 Taxonomy of the QIM (Source: Own illustration).

With the use of the IFC format, there will be different kinds of exports during the lifecycle of the district. During the Conception Phase, the IFC exports will be used for, for example, the purposes of simulating the districts energy behavior and also the different attributes of the whole elements inside. During the Building Phase, the IFC exports will be made for the planners to have the precise scope of the project and they can create the 3D models accordingly; contractors and subcontractors to have the necessary information to develop schedules and cost estimations as precise as possible; for building owners to have the required information for a smooth commissioning of the properties and also for them to be able to quantify their new spaces for leasing, selling or operation purposes. During the Management Phase, the amount of information contained in the model will be so high that not every stakeholder will be interested or have the permission to access to this, it is for this reason, that the IFC exports can be customizable for the different purposes. For example: in the Management Phase, the project team can easily program the BIM software to create three different types of IFC exports: IFC_Ow for owners, IFC_FM for facility managers and IFC_EU for end users, each one of this models containing the right information for the right stakeholder without risking any breach of private information.

4.1.3 District Phase

The first QIM is the Conception Model, in this, different clusters of buildings will be created according to the requirements of the project. In figure 8, for example, the red cluster are residential buildings with two walls that are adjacent to another building and two walls in contact with the exterior. The green cluster are residential buildings with one wall adjacent to another building and three walls in contact with the exterior. This information is important for the calculation of the energy consumption of the buildings. The information has been made using **Revit**, which has allowed the project team to create different cubes containing information about the possible uses.

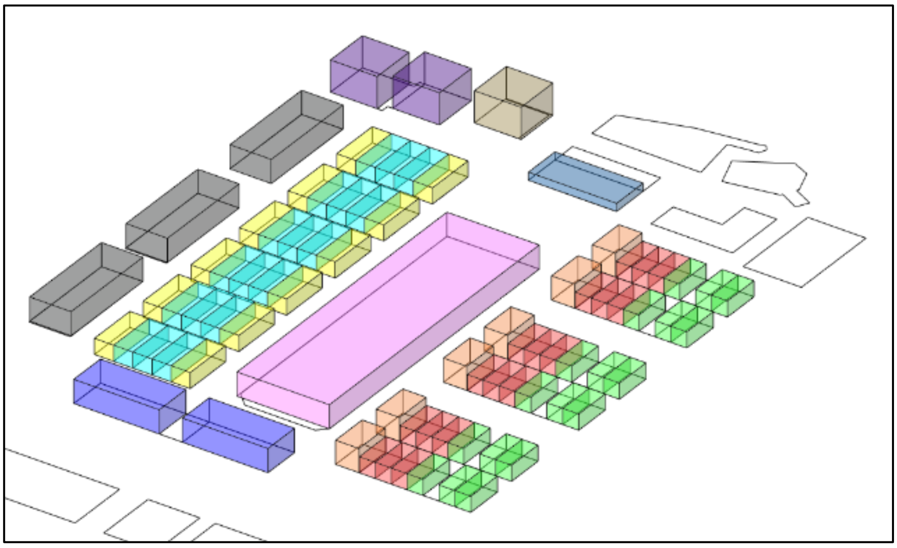

Figure 8 Different cubes in clusters (Source: Own illustration).

In order to create a QIM that will be used and improved, a series of information inputs have to be taken into consideration in each one of the different phases. For the first model, the Conception Model, characteristics that are mandatory according to German law, characteristics of the site, characteristics of the usage of the buildings, etc., were taken into consideration.

The "Grundflächenzahl" (GRZ) (in English: Site occupancy index) and the "Geschossflächenzahl" (GFZ) (in English: Floor space index) are two inputs that are given by the German law "Verordnung über die bauliche Nutzung der Grundstücke § 19 Grundflächenzahl zulässige Grundfläche" (in English: Ordinance on the Structural Use of Land § 19 Base area number, permissible ground area). The GRZ is the base area number which indicates the area proportional of a building site that may be overbuilt, it is a dimensionless number. Example: for a GRZ of 0.6 it means that maximum 60% of the land area may be overbuilt. In this same scenario, if a building inside a property has a floor area of 300 m² and the area of the property where the building is equals to 500 m², then the ratio between the two numbers is 0.6.

The GFZ is the number that indicates the ratio of the total floor area of all solid floors of the buildings on the area of the building plot, it is a dimensionless number. Example: a property has an area of 500 m² and a GFZ of 1.0, the sum of the floor area in all buildings located on the property must therefore also be 500 m², this means, one could build a four story building with 125 m² of floor space per floor (4 × 125 m² = 500 m²). In the same example, if the GFZ is 0.5, the maximum allowed total floor area would be 250 m² (500 m² × 0.5 = 250 m²).

Other important values considered are: the number of people that will use the building ("Bewohneranzahl"), the width of the building ("Breite"), total energy demand ("Gesamtenergiebedarf"), number of story's ("Geschosse gesamt"), ground area ("Grundfläche"), construction area ("Konstruktionsfläche"), among others. Figure 9 shows the information in Revit for one of the buildings or "cubes" in the Conception Model and how the information is stored.

Due to the current nature of the land purchase agreements, photovoltaic systems will be installed on at least 50% of the residential roof areas. Depending on the design of the commercial buildings in the district, between 500 and 1,500 kW of photovoltaic capacity will be installed, which is going to be available as a secured installed capacity within the project.

With a tool like **Dynamo**, the design team can automatize the process of modifying the design of the Revit model due to a change on these factors. Like it has already been explained, Dynamo can be used to develop algorithms that ease the modelling of buildings.

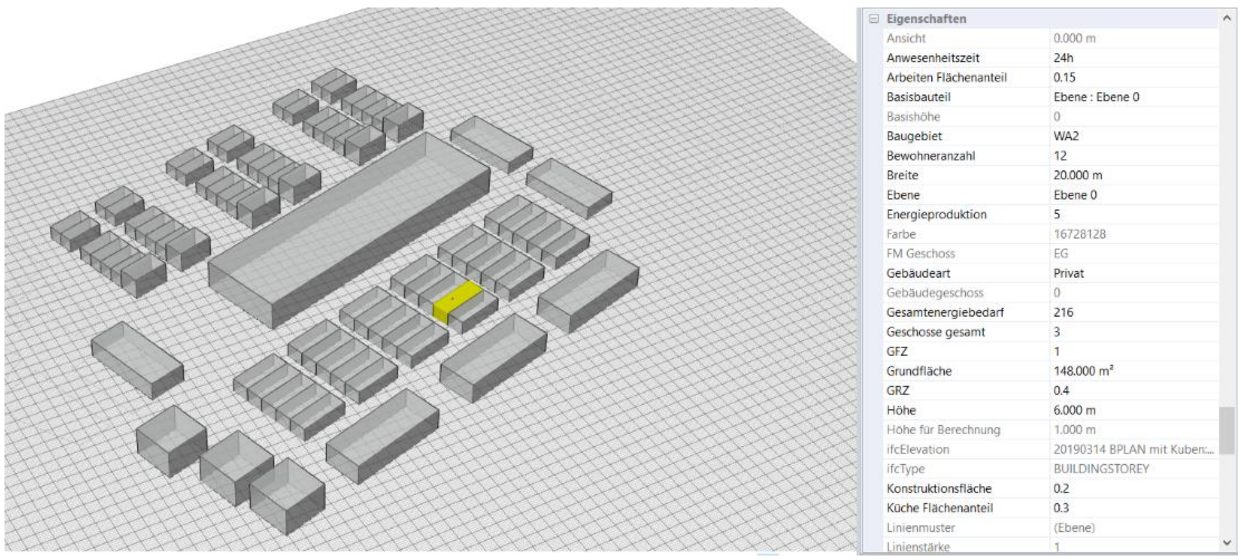

Figure 9 Attributes of one cube (Source: Own illustration).

The hybrid storage system that will be build has to be capable of storing the necessary energy for the proper operation of the new district in the times when the energy will not be produced from the PV panels (e. g. at night and during cloudy days). The district's energy supply, which has to be as renewable as possible, combined with efficient building services, results in temporary energy surpluses, which can be stored in the hybrid storage system both in the short and long term (Figure 10). The city of GI is also planning electric cars charging points in the western part of the district, the THM will set up four charging stations directly at the power station. There will be further charging stations in the planned parking garage in the eastern part of the quarter. These charging stations force the district to have an amount of available energy at all times.

An evaluation will be made from an overall urban planning perspective in order to work out connections between urban development, municipal energy supply infrastructure, sustainable housing and the mobility sector and inner-city integration. The use of electric chargers located in different points of the district for electric vehicles must also be taken into consideration. Conceptually, the use of new information and communication technologies must already be taken into account in the planning of the district in order to control the entire energy system technology including the high-temperature storage during later operation. In the conception model, the electric mobility and the associated charging infrastructure of the modern urban quarter, which must also be included in the concept, can then be considered. Future requirements must be implemented, and new technologies integrated.

Figure 10 Hybrid Energy Storage System interaction (Source: Own illustration).

Another technology that is already considered in most of the buildings is the installation of different sorts of **sensors** to help in the future with the monitoring and control of the district. In this conception phase, three sensors are already taken into account in the model: "Sensor 1 – Temperatur", for temperature; "Sensor 2 – Wasserzähler", for water consumption; and a non-compulsory sensor, "Sensor 3 – Gaszähler", for gas consumption. The plan from the project team is for this data to be sent in real time directly to the QIM model for the district managers to have the input as accurate and timely as possible. It is important to mention that all the information will be stored in Revit and for the specific analysis that this software cannot perform, external software will have to be used.

4.1.4 Building Phase

Planning Model

Once the Conception Phase concludes, during the Building Phase, the Conception Model will be first converted into the Planning Model, with all the gathered information, the city planners will have a broad understanding of how the district will perform with the given conditions. Also, if there is an unexpected change, thanks to the nature of the model, city planners will have the ability to change the configuration of the district if they need to. This process can be as iterative as the district requires. With all the data included in the conception model, it is possible to simulate the energy production, transportation, consumption and storage of the entire district. Figure 11 shows how it is possible to get the sum of the residential building's rooftops from the entire district.

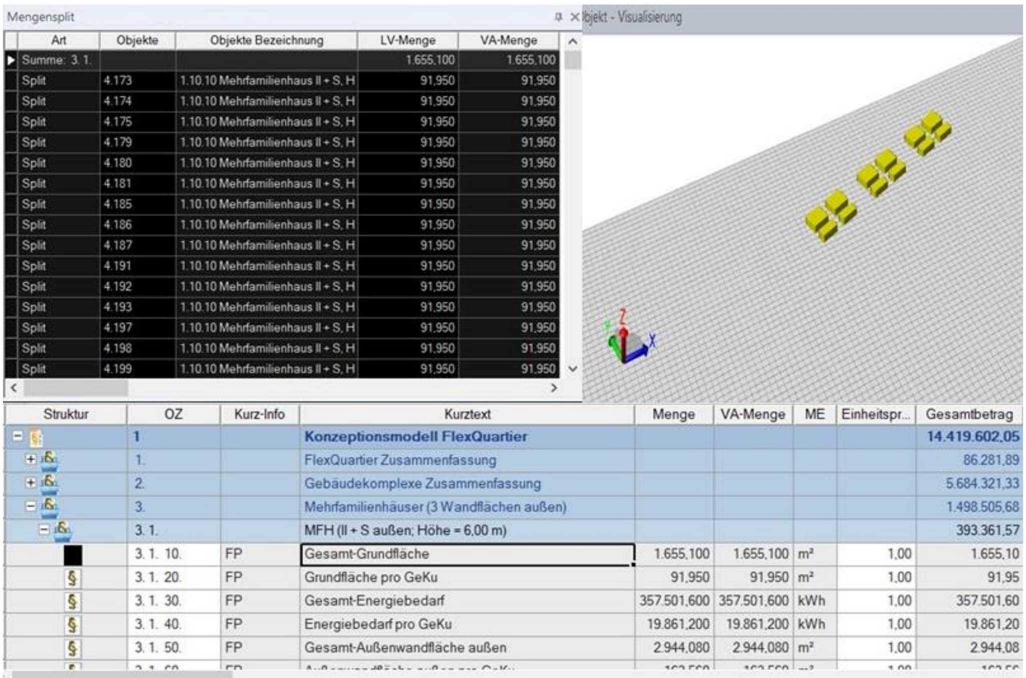

Figure 11 Programming of residential rooftops in iTWO (Source: Own illustration).

The **iTWO** software from RIB is being used to analyse the influence of the PV panels in terms of energy generation and cost of installation. Then the model can be programmed to have 50% (or any other input that the planners want to give it) of residential rooftops as PV panels. Having the amount of PV panels, planners can then simulate the amount of energy production of the district by changing several inputs such as the percentage of PV panels in roofs, and the GRZ and GFZ ratios. Then a simulation of the whole district can be performed. For the FlexQuartier project, it is of great importance to determine the size of the HTS for the energy storage, with a simulation, the project team will determine the size of the device as well as the performance that it will have for the next 200 years of operation.

During this phase, the use of **Virtual Reality** technology would mean a great improvement in terms of regulation compliance. Since the city of Giessen is one of the most interested parties in this project, the use of VR could improve the input of information in order to prevent mistakes from planning. With Dynamo, several lists of **prefabricated** elements can be created. These elements can then be sent to a provider with an adequate LOD for beginning of prefabrication.

Realization Model

During construction, the model will become the Realization Model. As it has been studied, the use of BIM with methodologies like **Lean** is becoming of great importance in the construction industry. Lean provides the principles to be followed and when used correctly, it can help by getting quality right the first time, improve upstream flow variability, reduce production variability, reduce inventory, increase flexibility, reduce change, use an appropriate production control approach, use pull systems, standardize, promote continuous improvement, use visual management, simulate production processes, design the production system for flow and value, among others. With this approach, contractors will have a model that will provide with all the necessary inputs that may be needed in order to carry out the construction process with the least amount of changes or unexpected issues. Subcontractors can benefit from this too, since they can start with the production of the necessary materials from a very early stage of the project. Simulations made in iTWO can provide valuable information to contractors when a problematic construction process takes place.

Commissioning Model

District managers and the city of Giessen will make sure during the commissioning of the project that all systems and components were designed, built, installed, tested, and maintained according to the operational requirements. Thanks to the information in the model, the city of Giessen will be sure that the handover is performed in a safe and orderly manner from the contractors to the end users, guaranteeing its operability in terms of performance, information traceability, reliability and safety. With the help of the **IFC** and the **COBie** formats contractor can handover the information between the construction team and the owner and is used for the Operation and Maintenance of the buildings by outlining a standard method for gathering the necessary information from the design until the construction processes, this information becomes a part of the deliverable package that is provided to the owner during commissioning and handover phases.

The Commissioning Model can help in the logistics of the delivery from the contractor to the owner since they can easily create punch lists to detect any possible missing document, object or information. The attributes mentioned before can help the facility managers to control which equipment was recently maintained, when does it needs to be maintained, how much can it cost, who will be the technician to make the job and how long will the equipment be useful, all with one single model.

4.1.5 Management Phase

Once the building is delivered and the operation and management begins, end users and owners can get help from the Management Model, they can easily plan, perform and keep track of the maintenance of the facilities, assess the impact of system failures and taking quick decisions to solve them, visually assess the areas that can be affected with future renovations or adaptations, etc. District managers will have in real time inputs from the sensors installed along the district, helping them with the monitoring and control of water, gas and temperature (for the energy consumption). Facility managers will have a visual tool to assess all the elements of the buildings before city inspectors or auditors can detect any problem regarding any component of the building.

This same model can later be used by facility managers not only for the energy management, but also for simulations such as crowd behavior tools and emergency evacuations or response to certain events (e. g. a terrorist attack, an earthquake, a flooding). They can, for example, use the GRZ and GFZ values as an aid to calculate the possible renting spaces (e. g. in the case of an office building). With these same values, facility managers can determine how much area needs to be cleaned and calculate the amount of people to do the job or determine the price that it will cost to pay an external company to do the cleaning.

With the amount of information contained in the Management Model, facility managers can calculate the cost of maintenance per floor of used space in the same way that district managers can calculate the cost of maintenance of the whole district per building and house. The model can then be utilized until the end of the life cycle of the building and it can even aid in the improvement of the disposal process.

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

Conclusions

Nowadays, drawings in 2D are used worldwide and it is very likely to remain like this for some more years, however, at some point, they have to stop being the main source of information when it comes to design and we should focus more, if not, only on the BIM model. An example of this is the code of standard practice of The American Institute of Steel Construction, which has implemented in some of its contracts a text that indicates that if the steel structure is represented by both a model and drawings, the design of record is the model. If more and more companies use 3D models not only in the design phase of a project, but also in the construction and facility management, a reduction of paper can be achieved. With more devices in the market each year for reading PDF's and 3D models, project managers, construction supervisors and people on the work site in general can significantly the need of printing documents every time a change is done or when a report needs to be delivered to several stakeholders.

While buildings, roads and infrastructures are the bones and skin of a city, the physical and functional systems are the blood and neural system that makes everything work together. A smart city should be capable of spending less resources without reducing the quality of the services offered to the citizens. It should be able to react and monitor to any phenomena that may occur (such as terrorist attacks, earthquake, a car accident, etc.). and also have the processing capacity to help make decisions in real time. As we saw, one of the objectives of the implementation of these tools is to avoid the effect known as urban entropy which in simple terms mean the uncontrolled management and growth of urban systems inside a city.

Recommendations

When city planners and local governments make decisions about urban planning, citizens should be involved in the process of data sharing and data gathering. They should be included because as the end users of the new infrastructure, they can provide important information that at the highest level of urban planning can be overlooked. With the use of application in smart phones, citizens can contribute real time information whenever they see a problem, for example, they can send a text message to a central service, or through an app developed specifically for the city to report something happening and getting immediate response from a specific department. These systems of data sharing offer us a wide range of benefits though often in exchange for our data and intelligence around our habits and preferences.

The success of a project using BIM as the ruling management tool depends on the engagement of all participants, from client to suppliers. An area for great improvement is the contract's management, some owners believe that if they change the contracts to require new types of deliverables that need the use of BIM, they may not receive competitive bids, limiting somehow their potential pool of bidders and lastly increasing the price of the tenders, nevertheless, with BIM being implemented by a large majority of architects, designers, engineers, and even facility managers worldwide, more in the developed countries than in the developing ones, this is not generally a problem, actually, companies dealing with larger projects, would probably not be considered by many owners if they did not use BIM. I consider that the biggest challenge, from my personal and professional point of view, is changing the mindset of the owners. Most of the design problems come from the short sight of owners regarding the design. Owners, in most cases, are the key factor to either the success or failure of many projects.

The mindset of the stakeholders must change. Everyone has to understand that the processes must evolve to be more efficient and to be aware that improvements done in the initial phases of a project could bring many benefits in the long run. For example, during the construction of the electric grid, developers can easily consider extra pipes in case of future ampliations. While building a centre for processing information, they can consider the connections for a possible expansion of the city. During the construction of roads, they can leave the preparations to install sensors to be used in the future.

With a simulation of the entire energy use of the district, it will be possible to understand the urban dynamics. These simulations should include the full cycle of energy, generation, storage, transportation and finally, consumption, just like the FlexQuartier project is aiming to do so. It will also be possible to determine the type and size of the storage system that can be used. By having a full understanding of the energy generated and used, it is possible to combine smart devices that interact with the smart grid in real time. For example, when an extraordinary event happens, the smart grid can send a signal for not vital devices to shut down, to prevent possible malfunctions of the system. It is possible to reduce the energy consumption by installing smart meters that can provide end users with accurate precision and in real time information about how much energy they are using and in which devices they are wasting the most. This way, one can influence and, in some way, alter the consumers behaviour.

Future Work

In the years to come, more companies will adopt BIM technology and tools. BIM will lead to a higher number of prefabrication materials and/or modules, it will improve flexibility and variety in building methods and types, fewer printed documents will be required, far fewer errors will be made in the design and construction phases and there will be less waste, fewer claims, and fewer budget and schedule overruns. Building projects will perform better, because there will be more tools that allow companies to make better analyses and explore more alternatives. The pressure to leverage BIM models to provide datasets for operation and maintenance is growing. In the future, there is an idea that the enrichment of BIM technology will be done by artificial intelligence. It can be used to add semantic information, interpreting their contents in the way that a human brain would do it. Human creativity will never be replaced by a machine and for this reason, I am confident that humans cannot be removed from the construction process totally.

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