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Carlos Francisco Lucena Gonzalez, Antonio Manuel Reyes Rodriguez and Francisco Villena Manzanares*

Disruptive method for managing BIM design and construction using Kanban

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Abstract: Companies in the construction sector need effective information management. In particular, the transmission of information within a company is key to improving its management and competitiveness. Currently, many companies in the construction sector are making a great effort to implement the building information modelling (BIM) methodology. Such implementation requires collaborative work through the Cloud between the different agents in the construction process of any project. In fact, information management in BIM projects is related to the creation, storage, transfer and efficient application of information within a three-dimensional (3D) virtual model of the project. The size of the project also determines the optimal management approach. The main problems resulting from poor information management may be a lack of coordination between actors, loss of information or misinterpretation of information. This work has two stated objectives. The first objective is to carry out a literature review of the applications of BIM technology and the importance of managing knowledge according to International Organisation for Standardisation (ISO)-19650. The second objective is to propose a disruptive method based on the Kanban tool to properly manage BIM information in the design and construction phases. This paper has practical implications for the improvement of BIM application for project managers.

Keywords: building information modelling, collaborative work, knowledge management, Kanban

***Corresponding author: Francisco Villena Manzanares,** Universidad de Sevilla SEVILLA, ANDALUCIA SPAIN, E-mail: fvillena@us.es
Carlos Francisco Lucena Gonzalez, Universidad Catolica San Antonio de Murcia (UCAM)
Antonio Manuel Reyes Rodriguez, Universidad de Extremadura

1 Introduction

In recent decades, projects in the architecture, engineering, construction and operations (AECO) sector have undergone constant evolution, both methodologically and technologically, from fountain pen drawing as the main element of expression before the 1980s, to computer-aided design (CAD) in the 1990s, and the challenge of BIM in the first two decades of the twenty-first century. The drawing of plans and the construction of virtual models have served as the means of communication used to communicate the project to the client and build the project in the execution phase (An international standard ISO19650). BIM is the acronym for 'building information modelling.' The National Institute of Building Sciences (NIBS) defines it as the 'digital representation of physical and functional characteristics of an object.' First, it should be clarified that BIM is an operational methodology and not a tool. It can be imagined as a continuous process present in all phases of the project: design, construction and maintenance. This process uses an information model, i.e. a three-dimensional (3D) virtual model that contains all the data of its life cycle, from design to construction and even demolition and recycling.

Applying disruptive methods means generating a disturbance with the intention of changing a system. BIM is an information system, and properly managing information and knowledge sharing between the different phases of a project is relevant to avoid problems. The definitions of BIM do not explain that there are problems in a BIM project arising from inadequate information management, such as: a lack of coordination between stakeholders, loss of information or misinterpretation of information. The main purpose of this paper is to avoid the potential problems derived from inadequate information management of a BIM project by applying the Kanban tool as a disruptive method. Different authors have used Kanban to explain its advantages in the effective use of BIM: for cost control in civil engineering (Qiaolan and Bin 2021), application of the Kanban concept in construction logistics (Zeng et al. 2019); Kanban for Integration of Lean Construction and BIM for the problem of controlling information flow and quantitating the value flow in the process of building (Bi and Jia 2016); application of E-Kanban in the construction industry (Guo et al. 2012); integration of Kanban with the Last Planner System (LPS), as a method in lean construction management (Schimanski et al. 2021);and application of Kanban in the construction phase (Jang and Kim 2007; Ko and Kuo 2015; Tezel et al. 2017).

In contrast to other studies, this paper has two established objectives. The first objective is to carry out a literature review on the application of the BIM technology and the importance of managing BIM project information according to ISO-19650. The second objective is to propose a method based on the Kanban tool to properly manage the information of a BIM project from the design phase to the construction phase. To meet the first objective, the literature is reviewed, going through concepts such as collaborative work, the common data environment and BIM information technology management. To meet the second objective, the Kanban tool as applied to information management in a BIM project is presented. In addition, a successful case study is presented in which the methodology presented in this work is applied to the management of information design and construction BIM.

2 Literature review

BIM implicitly requires knowledge management (KM) techniques for the information and knowledge to be organised, created, shared and distributed by the upstream agents of the supply chain, namely the product manufacturers (Gigante-Barrera et al. 2017). Tacit knowledge could be regarded as (1) experience-driven knowledge, which is not easy to formalise and communicate within information systems, and (2) explicit knowledge, which is considered codified knowledge easily transferred within information systems (Woo et al. 2004). The transition from tacit knowledge to explicit knowledge is the focus of the present paper.

As is known, the coordination of BIM design connects with different disciplines (structures, facilities, energy efficiency, health and safety, etc.) through the industry foundation class (IFC) information standard. In BIM, the IFC serves as a data exchange format between agents, processes and applications, which are defined by the ISO 16739:2013 Standard. The IFC is a particular data format that allows the exchange of an informational model without loss or distortion of data or information. It is an open, neutral format, which is not controlled by software producers, and is applied to facilitate interoperability between various operators (Weirui et al. 2015). The IFC has been designed to produce all the information about the project. It is generally accepted that BIM is a technological and necessary tool to improve competitiveness while conferring value to the company (Eastman et al. 2011). Some authors already consider BIM as an innovation without limits, or systematic innovation (Harty 2008; Ahmed and Kassem 2018), but from the point of view of this work, BIM is considered a technology that also requires the application of a change in the methodological paradigm, namely collaborative work (Barrett and Sexton 1998; Elmualim and Gilder 2014; Dainty et al. 2017). As can be seen, a basic premise is the collaboration between the different agents involved in the phases of the life cycle of a construction project, with the aim of adding, extracting, updating or modifying the data; at this stage, it is important to manage the knowledge of the project adequately. The implementation of BIM in the design phase of the project allows for the elimination of possible design errors, reducing the cost of the project and the time spent in the design, resulting in benefits for the designer, the client and the builder (Sudarsan et al. 2005; Sacks and Barak 2008; Alwisy et al. 2014). In addition, this improvement in efficiency reduces both construction waste and resource requirements, thus de facto significantly improving the environmental sustainability of construction (Xue et al. 2021). In the BIM literature, the term ‘dimension’ is used to indicate the information processing capabilities of such technology (Berard and Karlshoej 2012; Koutamanis 2020). BIM has demonstrated its superiority over CAD by allowing the incorporation of physical properties to the elements of the virtual model; therefore, the virtual model of the construction project was called the three-dimensional (3D) BIM. Further, 4D BIM added time as its fourth dimension to perform planning studies, and 5D BIM added price as the fifth dimension to perform project cost studies (Ding et al. 2014; Mayouf et al. 2019; Mesároš et al. 2019). Other capacities refer to sustainability analyses, wherein the sixth dimension of BIM (6D BIM) appears, whereby it is possible to carry out energy and sustainable simulation studies of the project using the model (Oti et al. 2016). The seven-dimensional (7D) BIM was later proposed to integrate all the information and documentation necessary for the proper management of the facilities (GhaffarianHoseini et al. 2017). Finally, the eight-dimensional (8D) BIM was proposed to carry out accident prevention studies using the model in the design phase (Kamardeen 2010).

Information and KM systems make use of available techniques and technologies to make the management of a complex project, such as planning (4D BIM) and cost management (5D BIM), effective in the construction phase. Bearing in mind the need to align the business with the use of information and communication technologies, it is necessary to optimise technology at all levels of the organisation in order to maintain efficient processes and thus obtain reasonable, quantifiable, measurable and predictable costs.

In Spain, the information management systems that support the development of projects have used traditional technologies and classic software. At present, and owing to advances in information and communication technologies, the digital transformation of companies and the way in which a project is dealt with have reached a higher level of complexity, whereby the participation of experts in different disciplines can be combined simultaneously in the development of a project in a much more transversal manner, with a 360° perspective.

Traditionally, this participation has been carried out on the basis of consultancy meetings. Today, it is possible for several specialists to participate simultaneously in the design of a project. Engineers can design and plan on the same file, wherein the construction project is virtually modelled; this is the so-called 3D BIM. This project is located in a common data environment (CDE), i.e. it is not physically in the server of any of the companies involved in the project; it is in the so-called Cloud. This is the basis of the management system for construction projects based on BIM.

This type of system is gradually being implemented in Spain. The competitive advantages of BIM over CAD have been demonstrated by the decrease in budgetary deviations of projects under construction. It is a question of carrying out a change of paradigm. To properly implement BIM at a national level, both in the design phase and in the execution phase, the agents involved in the project life cycle must know and properly manage the project information to avoid possible errors or duplication.

2.1 'Worksharing' collaborative work in BIM

The BIM methodology is not simply the evolution of CAD. It is a completely new approach to designing and implementing a project. The potential of the BIM application is seen throughout all phases of the construction life cycle, and it is essential for the project design team to properly manage knowledge by phases. This requires sufficient experience to know how to manipulate, manage and make good use of the model. Therefore, the perception of technological learning and experience is vital to be able to use BIM with skill (Mahamadu et al. 2017). The BIM virtual model is not a simple 3D representation, but a dynamic model that contains a series of data on the following: geometry, construction materials, structure, thermal characteristics and energy performance, installations, work costs, safety at work, prevention of occupational hazards, maintenance and operation of assets, demolition and waste management. Due to the wide application of BIM, it is possible to 'build' virtually before the project's execution on site using 3D BIM, 4D BIM, 5D BIM, 6D BIM and 8D BIM through the collaboration and contribution of all the agents involved in the project. BIM is not a common practice in the construction industry in Spain (Loredo Conde 2016). Despite the slow and gradual growth in the adoption of this technology, technological barriers have not yet been overcome for many companies in the AEC sector (Muñoz and Roig 2018). Therefore, some companies still use CAD for the representation of projects, manually drawing an enormous number of lines and polylines to represent objects on plans. They probably do not know the advantages offered by this new technology yet. The literature recognises the following advantages:

(a) Time savings in the design phase as objects provided by the manufacturers are inserted with specific properties and complete information.
(b) Reduction of errors on site owing to documentary consistency: floors, elevations and sections are viewed from different camera positions in the same 3D BIM virtual model.
(c) Modification to the BIM model is reflected in all views and plans are generated in real time.

For effective communication between the different types of software, the IFC file is used, which is a data format that is intended to allow the exchange of an information model without the loss or distortion of data or project information. To allow the sharing of all information, the OpenBIM methodology was created, which is based on the use of open standards. In BIM, the IFC serves as a data exchange format between agents, processes and applications, which is defined by the ISO 16739: 2013 Standard (Weirui 2015).

In the collaborative work, the project information is arranged in blocks or architectural disciplines, structure and installations, known as the mechanical, electrical and plumbing (MEP) environment, and in turn, each discipline can feed from different sub-disciplines.

2.2 BIM and CDE concepts

The CDE is a relevant concept within KM and, in BIM, it is fundamental for the successful completion of any project. Therefore, choosing the right CDE is the first step towards success. The requirements for a CDE have been defined in the standards published by the British Standards Institution (BSI): Publicly Available Specification (PAS)-1192 and British standard (BS)-1192 in the past; and more recently, in ISO-19650 (December 2018). These documents describe the steps that organisations working in the AECO sector must carry out in order to achieve BIM Level 2 compliance in their projects, i.e. maturity level 2 of the BIM, in which the UK has been involved since January 2016.

BIM involves the development of a project in a virtual environment. BIM is extremely beneficial as the companies involved in the project can reduce the number of conflicts during the design phase and significantly reduce costs during the construction phase. It can also have a very positive impact on reducing project delivery times. Figure 1 shows a diagram of the information contained in a CDE according to the UNE-EN-ISO-19650 standard.

A CDE provides a Cloud-based platform and a Cloud-based software, so that these changes to projects, both during the design phase and during the construction phase, are successfully recorded, assigned, reviewed, distributed, ordered and resolved with the greatest possible organisation and control. This results in a more efficient way of presenting projects. Therefore, a CDE is a collaborative environment used by all the agents during the development of the project, following the guidelines of the ISO-19650 standard, which has also been adapted in UNE-EN-ISO-19650, establishing it for communication and coordination with all the members of the project. Therefore, a CDE can be defined as the sole source of information for the project, used to collect, manage and disseminate documentation of the graphic model and non-graphic data for the entire project team (i.e. all project information, whether created in a BIM environment or in a conventional data format). The creation of this single source of information facilitates collaboration between project team members and helps avoid duplication and errors. In fact, research has shown that the causes of clashes in BIM include uncertainty and lack of clarity about other systems (Tommelein and Gholami 2012), as well as the pursuit of specialty objectives in isolation (Plume and Mitchell 2007). Moreover, the iterative nature of data sharing could prolong the design cycle in multidisciplinary teams (Flager and Haymaker 2007). In Cloud-based CDEs and MCS, model harmonisation and synchronisation (e.g. comparing different versions of the model) are necessary features to manage changes before consolidation (Shafiq et al. 2013).

2.3 Information management: BIM life cycle

One of the factors to be considered when studying the viability of a project is that of the sources of financing. This difficulty is present at any level of the project. The type of investment has a significant impact on the economy of the company itself. To give an example: for an engineering and construction company that currently has difficulties in obtaining credit lines from banks, investment in a key, major project can be considered with consequences for its accounts over the next 2 or 3 years. At the same time, for a medium-sized public administration body, the construction of an infrastructure project may account for a large part of the annual budget for planned expenditure. Thus,

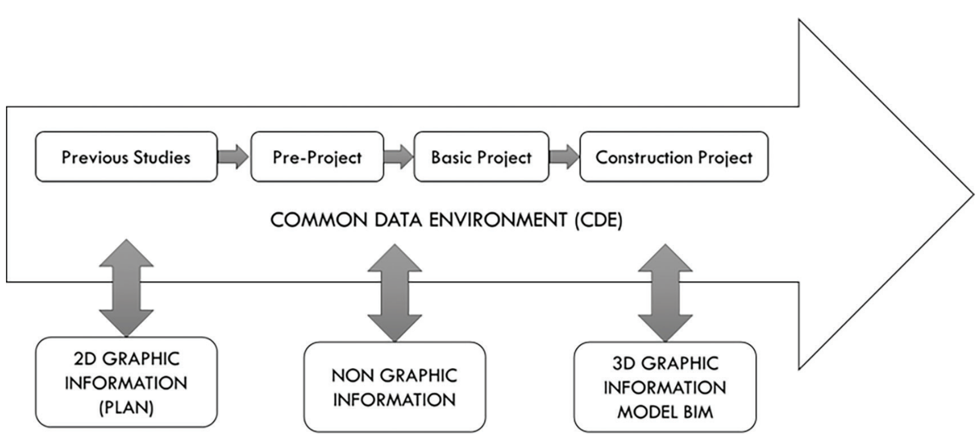

Fig. 1: Types and levels of information in the exchange processes in the CDE (ISO-19650). BIM, building information modelling; CDE, common data environment; ISO, International Organisation for Standardisation.

Fig. 2: The life cycle of project management.

a project usually faces the need for long-term funding. The Project Management Body of Knowledge indicates that project management is the application of techniques, skills, knowledge and tools to the activities of a project to achieve its requirements. The literature recognises that regardless of the type of project to be dealt with, the five processes that form the project management life cycle are initiation, planning, execution, monitoring and delivery (Wysocki 2014). In Figure 2, the project management life cycle is represented, as this conceptualisation is important for BIM management.

The project's success lies in the excellence of managing knowledge properly, as well as in the capacity for innovation, customer relations and relations between collaborating companies. This implies that there must be an effective management system that always allows for correct and updated information in real time for quality assurance and for decision-making for adequate conflict resolution. BIM allows this if information management is carried out correctly and efficiently at both the project conceptualisation and execution levels with planning and cost control. Thus, 4D/5D BIM allows the project planners the capability of managing and rehearsing different construction options before the construction starts in order to improve the efficiency and productivity of construction processes (Chavada et al. 2012). The concept is complex and is applicable to the entire intrinsic complexity that exists in the construction sector. The confluence of different interests to materialise objectives, both general and specific, that lead to the successful development and construction of a project is governed by many variables: economic, technical, administrative, legal, environmental, contractual, etc. The levels of demand in the projects are increasing. As far as technical specifications, regulations and competitiveness are concerned, they have increased in the past 5 years in our country, and it is a curve that will continue to grow as demand from private clients and from the Public Administration in the tenders that can be consulted from the State Contracting Platform (state, autonomous, provincial and local levels) increases. Making use of efficient information management during the development of the projects carried out in BIM is one of the keys to success, and in this scenario, the use of a CDE becomes vital, as has been stated for years in the British Standard Institution (BSI) rules and in the UNE-EN-ISO-19650. Therefore, digital transformation as a strategy to ensure quality in the construction projects implies the structuring of the information management in each of the project phases. BIM systems are designed to manage all the information at all stages of the life cycle: investment in project, construction design, analysis and calculations, verification of compliance with contractual requirements, work, specifications, etc.

2.4 CDE to improve BIM KM

BIM has become a necessary part of daily workflows for any AECO-sector-based company that implements it. The benefits that BIM brings are eminent and proven. However, many companies still struggle with proper implementation in their projects and organisation because of the inherent challenges that BIM brings. Some of these challenges are the high cost of software licences and the cost of renewing hardware, lack of trained BIM staff within companies and customers who do not recognise the benefits of BIM and have great difficulty in standardising their work processes. The UK's National Building Specification has already described them in 2014. Many of them persist even today, but as technology has evolved and become more democratic, there is a good opportunity to overcome these problems with the use of information management tools in BIM projects. The concept of using software for process management is relatively new in the AECO sector industry in Spain. However, 3D BIM models are only one part of the equation. For a project to be successful, there are three integral components, namely people, processes and technology. In order to administer information management related to all these factors in the most optimal way, the use of a CDE is indispensable, mainly for these three reasons:

- To make sure everyone is using the same up-to-date information:

Collaboration is key to the successful implementation of BIM as there are several complex processes involved, and professionals from different disciplines interact with each other. Furthermore, the fact that there are many different standards and that everyone likes to apply their own internal standards as a business protocol it does not help. Even the slightest misinterpretation can cause excessive delays, resulting in high costs to the company. BIM execution plans (BEPs) are very important for defining the scope of work and other standards, but a BEP no longer needs to be just a project document, but it also serves as a contractual document. An enterprise could leverage the power of the Cloud to create documents in real time, i.e. intelligent documents that keep pace with projects. In addition, with intuitive ways to define project information, the level of development (LOD) and other key aspects of a BEP, the use of a CDE helps provide clarity to all participants involved in a construction project.

- For the organisation of and to maintain standards in projects:

Companies usually experience stress when there is a lot of 'information chaos' in a project. There are too much quantities of data, too many models, too many files and none of them are properly structured. Even when one decides to make sense of it, it becomes very difficult to rationalise. Some companies follow their own standards, while others do not even have them. The definition of line styles and line thicknesses in drawings, e.g. is defined in a portable document format (PDF) document, but it is very difficult to verify whether it is being followed and whether there are any deviations; nobody bothers to update the document just for a small change. This leads to many gaps that become progressively bigger as the project progresses. Even the BIM components are created on the fly, as they are needed, and there is almost no documentation during a project, because there are better things to do at the time. This is where the role of a CDE as a protagonist in information and KM in the development of a BIM project comes in. A CDE helps to standardise all types of information. Taking the case of BIM components, users can not only use them as a Cloud library but also track which components are being used in which projects, by whom and how often. Together with tools to determine the work, the productivity gains are evident.

- To improve the quality of BIM models:

In today's world, quality assurance in virtual models is increasingly important. It is no longer enough to create a 3D + 4D + 5D BIM model for a construction project. The quality of the BIM model is equally important and there are several methods to evaluate how efficiently a project has been modelled. In fact, it is not surprising that, soon, there will be BIM quality testers for the management of project information. Some of these quality aspects to be monitored relate to the individual BIM components that are used. Whether the components have the right amount of information needed according to the BIM objective is an important factor. In addition, both insufficient and excessive modelling are detrimental to the project. Assurance that the LOD required at various stages of a project is met becomes crucial. Literature suggests that the LOD depends on the use or application of BIM (Staub-French and Khanzode 2007). The CDEs help to define these requirements in a dynamic way. A CDE provides the ability to load and manage BIM components in the Cloud, as well as provide features to track the status and quality of BIM models. Moreover, quality manuals can be uploaded to the CDE as documents in the Cloud for all to see, in real time. Figure 3 shows information management according to PAS 1192-2 and UNE-EN-ISO-19650.

Prototyping was not traditionally a common tool in the construction industry. BIM together with lean management allows the prototype to be tested as many times as necessary before being transferred to the construction site. The virtual model is used to collaboratively

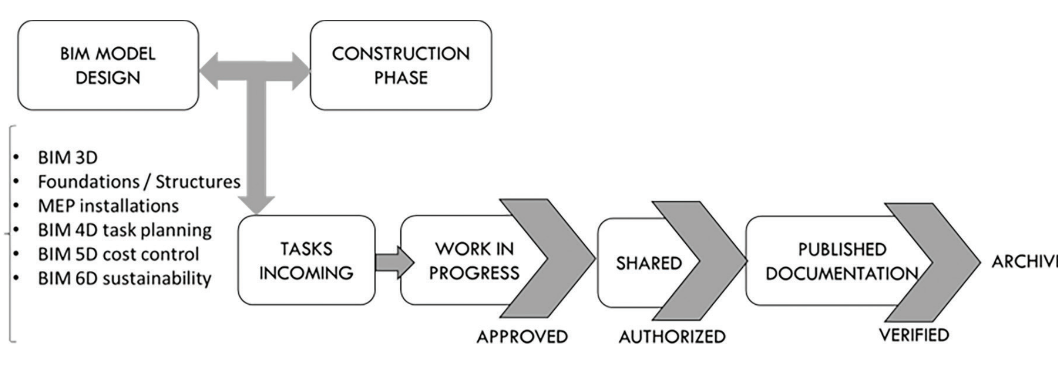

Fig. 3: Information management according to PAS 1192-2 and ISO-19650. BIM, building information modelling; ISO, International Organisation for Standardisation; MEP, mechanical, electrical and plumbing; PAS, Publicly Available Specification.

analyse the feasibility of the construction and to solve possible problems that are detected. The aim is that when construction begins, most of the problems will have been solved (Pons Achell and Rubio 2019).

3 Case study: adaptation of the Kanban system to control BIM knowledge

The main purpose of this work is to avoid the potential problems derived from inadequate information management of a BIM project by applying the Kanban tool. The tools currently applied in construction with BIM, to control production and assembly on site, come from lean management techniques, coming from the industrial field and successfully incorporated into the planning and management of projects in construction, as they add value to the customer. An example of these tools is the LPS, which is a production system that incorporates the lean methodology in construction to achieve time reductions of 30%, reducing costs and increasing quality and safety. On-site production is, in general, unpredictable and very complex. The LPS manages to simplify it and increase its reliability. So, it works towards structured and collaborative production so that the tasks follow a process (they are planned, prepared, released to be carried out, committed and accounted for). This lean philosophy is a management system for construction projects that seeks continuous improvement and maximisation of the value of the final product defined by the client. With the development of the integrated management of the Integrated Project Delivery (IPD) approach, lean and BIM are integrated, whereby the production control protocols are established in the virtual model. Another tool is Value Stream Mapping (VSM), which allows the entire flow process to be visualised, identifying in a flexible manner the activities that do not generate value, in order to eliminate waste. The previous tools are applied in both the design and execution phases of the construction elements, wherein task control is carried out to manage the information contained in the BIM model. Lean construction is another increasingly well-known management tool associated with production processes in construction and it offers the opportunity to improve construction as a process through reduced losses, increased efficiency, and added value for the client (Koskela 1992). Furthermore, applying techniques from lean management reduces waste and errors, in addition to resulting in fewer accidents. Unlike these techniques that are currently being implemented and are well received, in this paper, we present a new method based also on factory management for information control and knowledge of tasks, such as the application of Kanban, to minimise possible errors in the creation, management and manipulation, updating and control of BIM information.

Conceptually, there are significant synergies between lean construction and BIM. The use of BIM is understood as an efficient technological solution, and lean construction is considered as a methodology that contributes to optimisation of performance in companies (Pons Achell and Rubio 2019).

Kanban is a concept that can be considered as a visual system, in that, immediately, we can get an idea of how advanced the project is and the degree of progress of each of its members. It was born in the Japanese post-war industry and is today encompassed in the Japanese philosophy of production. It is still used in many types of production equipment not only for asset production but also for software production. Kanban is presented as an effective method for KM in projects developed in BIM environments that can be perfectly complemented with other techniques in information management during project development. Analysing the principles of both systems, we find numerous similarities that allow to relate them to each other for the purpose of applying Kanban to BIM workflows. The Kanban system is based on the following three basic objectives:

- to make visible the work done by each production unit (production line);
- to delimit work in progress according to the capacity of each production unit;
- to maximise the efficiency of workflows, for which it is very helpful to know what everyone is doing and how much they can do.

To achieve these three previously mentioned objectives of the Kanban system, we have the following components (Anderson 2009):

- Visual signals (cards): Each task in each production unit is arranged on a real or virtual card. The real ones are usually in the form of a small Post-it sticker with different colours to build a Kanban project board with cards placed in Kanban card boxes. The virtual ones are elements created with any software in use. The duration of this task does not have to be divided into production units, but the time it takes for that task to be done is predefined, and it can be any.
- Workflows (columns): The cards on a Kanban board are grouped in columns, which symbolise the different stages through which a certain activity (visual card)

must pass in order to complete a project or a complex part of it. It is common to have columns of the type 'To be done', 'In progress' and 'Finished'.
- Limits to work in progress: These are the maximum number of cards that can be in a given column at any given time. The aim is to size and organise the work well so as not to create bottlenecks in production. This value for the limit to work in progress indicates the degree of use, but also saturation, of the production process.
- Point of compromise: This is what is called the kick-off of the project, the beginning of the project.
- Delivery point: This is the moment when the project, or an important part of it, is delivered, in short, the deadline of a project.

For its part, the BIM workflow, once organised, is based on the contribution of each modeller of a particular discipline, entrusting them with the modelling of that discipline, whether in part or in the whole project. These one-off deliveries may well resemble Kanban, i.e. visual cards. However, in a BIM process, the actions of the BIM coordinator, the BIM Manager, the Lean Manager, the Project Director, the different engineering departments and, in short, all the agents in the project, would also be units of activity. In large-scale projects, it is necessary to include the new roles of Lean Manager and BIM Manager within the site team (Pons Achell and Rubio 2019).

A clear parallelism can be found between the columns of a Kanban board and the flow of information that must be carried out between the different documents of a construction project (PAS 1192-2). They are as follows: Incoming, Work in Progress (WIP), Shared and Published. In other words, we would change the columns to Do, Doing and Done to Incoming, WIP, Shared and Published. Therefore, the project is divided into parts that are assigned to people or production subgroups by placing the corresponding Kanban card (real or virtual) in the Incoming column of each person or production unit. When those people see that Kanban on their board and have the capacity to take up work, they take that Kanban card to their WIP cell, where it remains until they have finished that work and share it with the BIM coordinator, whether it be a coordinator for a specific discipline or a general coordinator. Each BIM production unit has its pre-assigned production units. When the BIM coordinator validates the work received from the production unit to which it belongs, he/she passes the Kanban card of that work to the Published folder, which means that this work has resulted in the requested deliverable, in the minimum viable product. The process is constantly repeated with other jobs and, many times, with evolutions of the job that has just been delivered. One of the main problems encountered in the KM of a project in the BIM is the incorporation between the different MEP disciplines in the BIM through the IFC for Data Sharing in the Construction and Facility Management Industries, defined in the ISO-16739 of 2013, subsequently ratified in 2016 and 2018. Examples of these problems are interference between facilities, non-compliance with material or equipment specifications relating to the specification and failure to communicate information from one discipline to another for proper functioning during the execution and operation phases. The information flows between the design phase and the construction phase, together with the different stakeholders involved, are shown in Figure 4.

In general, there are problems in the KM of a BIM project for the control of its different BIM dimensions from the design phase to the execution phase, e.g. non-real-time planning, cost planning that deviates from the previous budget for each phase of work, etc. The Kanban application helps the optimisation of the project.

In this case, the Kanban model would work as before, although the steps would obviously be different. Similarly,

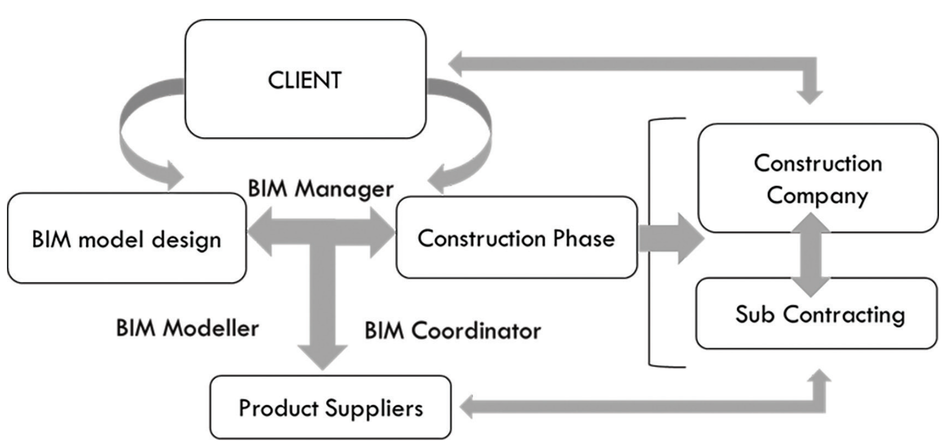

Fig. 4: The information flows between the design phase and the construction phase. BIM, building information modelling.

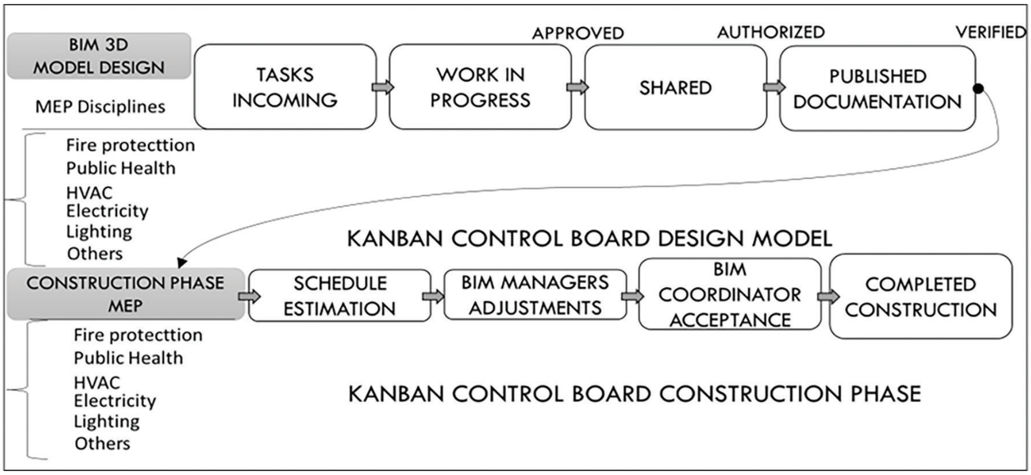

Fig. 5: Adaptation of Kanban to control the workflow design model and the construction phase. BIM, building information modelling; HVAC, heating, ventilation and air conditioning; MEP, mechanical, electrical and plumbing.

Fig. 6: Practical application of Kanban boards and use of BIM methodology during the construction phase. BIM, building information modelling.

we would work with disciplines, e.g. the MEP disciplines of the project. In this case, each specialist in each of the disciplines makes a time estimate, both execution time of their specific discipline and those other disciplines that have to be done before theirs. In the second phase, the BIM Manager proposes adjustments between disciplines to temporarily relate the group of each of these disciplines with the remaining parts of the work. The third phase corresponds to the BIM coordinator, who finally accepts or refines the proposal from the BIM Manager. The final task integrates the 4D BIM analysis of these disciplines in a final report and can be concluded with an attractive and enlightening graphical simulation of the timed progress of the work with its MEP disciplines. Adaptation of Kanban to control the workflow design model and the construction phase shown in Figure 5. The required Kanban board model would look like that shown in Figure 6.

3.1 Hospital *Polivalente Arnau de Vilanova* (Lérida, Spain)

The methodology presented in this work has been applied in the construction of projects carried out in Spain. The following project built during 2020 is an example:

- Project: Hospital *Polivalente Arnau de Vilanova*, Lérida, Spain
- Developer: Catalan Health Service (CatSalut)
- Gross floor area: 4,500 m^2

- Designers: (https://www.pmmtarquitectura.es/)
- BIM coordination: (http://www.eipm.es/es/)
- Lean coordination: Juan Felipe Pons Achell (http://www.juanfelipepons.com/)
- Project delivery time + execution (works): 4.5 months.
- Construction year: 2020

The project presented is a successful case in which the methodology proposed in this article was applied. The contract deadlines were met, optimising continuous improvement and decision-making. The construction company, the developer and the suppliers were satisfied when working with a methodology that is committed to improving performance. This was possible because everyone was able to participate in decision-making and problem-solving in a more active way (Pons Achell 2017). The proper application of the proposed methodology and the collaboration between the agents involved in the construction process is fundamental. Owing to the high degree of prefabrication, very significant savings were achieved in terms of the production of unnecessary waste on site. The result was a highly sustainable construction project. A photograph of the hospital project in Lérida is provided herein (Figure 7). In the construction phase of this building, lean approach, Kanban boards, BIM, industrialisation and integrated management of waste generated on site were applied together.

Fig. 7: Photograph of hospital project in Lérida applying BIM. BIM, building information modelling.

4 Conclusions

The concept of a BIM and combined BIM–Lean system is presented, to be used as a knowledge exchange platform in construction projects wherein the common point is the concept of the CDE, which is fundamental within the BIM methodology. The application of a 3D knowledge map in the BIM approach mainly allows the technicians in the projects to find the necessary knowledge in an easy and effective way to solve conflicts. This work proposes a practical methodology, based on the lean construction philosophy applied by Kanban, to control workflows between the MEP and BIM environments. It has been proven that Kanban is effective in controlling and for properly managing MEP knowledge to incorporate it into BIM, and on the other hand, in a similar way, the Kanban application has been presented to incorporate the different dimensions of BIM by properly managing knowledge in the project. Kanban boards are effective in organising and representing knowledge of the construction project by using an approach closely linked to the methodology proposed by BIM. Knowledge management is the organisation, creation, exchange and flow of knowledge within a company. Knowledge can be shared and reused among engineers and other technicians involved to improve the construction process, as well as to reduce the time and cost planned or to solve problems on site. By applying the Kanban approach, all project participants can track explicit and tacit knowledge through the knowledge map based on the dashboards. The results show that the proposed Kanban method based on production lines and dashboards can be used as a visual BIM KM platform and can also be used in real time combined with Cloud technology (CDE). By developing the project under a BIM environment controlled by Kanban, engineers, architects, investors, etc., can track the KM visually for each production line in the virtual environment and see the knowledge tracking as it is incorporated into the 3D virtual model. This paper deals with the application of Kanban boards for BIM KM, valid in both the design and execution phases of the project and proposes a KM system based on lean techniques applicable to BIM. To verify our proposed methodology, we have used the most updated sources such as the UK National BIM Reports, in which conclusive figures have been collected after 4 years of BIM Level 2 maturity in the UK.

This work aims to provide an answer to many companies that need experience to correctly apply the BIM methodology, since many companies in the sector do not interact with the model, but only have it as a virtual repository and do not take advantage of the information contained or the collaborative linkage that is established in ISO-19650. To improve the situation, this work develops a methodological proposal, not unknown, but applicable to the set objectives. The Kanban application must be carried out under a very visual platform (CDE), to improve the exchange of knowledge, experiences and information between the different agents participating in the project, joining 'technology, processes and people.' Therefore, the approaches of this work are applicable to the control and management of knowledge for all the phases of design (3D and 6D BIM), construction (4D, 5D and 8D BIM) and maintenance (7D BIM). In summary, our study contributes to the existing literature in two different aspects:

- Adjusted production control mechanisms are related as a valid process to establish a visual map in the Cloud that manages the knowledge of the project by dimensions and by disciplines.
- This paper has practical implications for the improvement of BIM application for project managers.

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