# An information-based approach to “Digital Twins”

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**Abstract**

Information-based issues are becoming important in all areas. This change has revolutionized workflows, processes, and methodologies in several disciplines (Rifkin, 2012). In the construction field, the digital and information revolution has given rise to BIM technologies, which have changed the processes of design, construction, and building management (Tulenheimo, 2015). This article sheds light on the current construction processes from a different perspective through the analysis of three study cases. Until now, building projects were mainly analyzed through their plans and geometry. We suggest that BIM projects should also be studied through the analysis of the information stored in the “digital twin” of the building. We consider a digital twin as a database linked to the building’s digital geometry. We make the hypothesis that the study of this database and the way in which the actor’s structure and manage this information, will give a better insight on how functions these buildings.

Keywords: **BIM, Database, Digital Twin, Information**

# 1 Introduction

In "BIM" projects, the process of creating and recovering building data is integral to the building construction project. The analysis of exploratory interviews carried out between June 2018 and October 2019 revealed the prominence of the processes relating to the introduction and retrieval of building data in the studied projects, to the extent of becoming a separate project, which we call the Building Data Project; We formulate the hypothesis that the data project of the building, in the multiplicity of its dimensions (economic, industrial, environmental, etc.) is a good observatory of the organization and the functioning of the system of actors across the various phases of the construction project (programming, design, realization, management). In this article we aim to present the historical background and genesis of building data projects and the new insights that emerge from studying building data. First, we present the genesis of building data through a historical lens. Then, we introduce a new emerging actor system identified from the analysis of different case studies observed within a technical design office and finally we present some of the building information-related challenges encountered by these actors. Studies that we previously conducted found a link between information and the system of actors (Gordo-Gregorio, 2020) (Gordo-Gregorio & Guéna, 2019). Through this paper, we build on those findings and further elaborate and describe what we called the Building Data Project and its usefulness on studying the transformation of the construction field from an information-based approach.

# 2 The origin of "building data" and the "building data project"

## 2.1 The history of building data

The history of data classification is much older and independent of the computer tools (Picon, 2010). In the course of the history of architecture and construction, there came a time, at the end of the Middle-Ages, when the master builder was less and less present on the construction site (Fregier, 1983). It was at this point that iconographic data and written data began to be distinguished. The notes on the drawings, originally very informal, became the more and more important. Finally these notes gave rise to the "written documents" of the project.

Authors such as A. Picon and C. M. Eastman, who have worked on the history of architecture from a technological perspective, explained how the process of annotating drawings evolved with the advent of the industrial revolution. Building components and materials became more diverse and led to increasingly complex specifications to the point where their standardization and structuring became necessary. The classification, characterization or prioritization of the building data could be done in various ways. These classifications started on the 50s-60s with the SfB classification in Sweden (1950) and Masterformat in the US (1963) and they had a huge developpement on the 80s and 90s (Afsari and Eastman, 2016). Nowadays, there is a wide variety of classification systems, international classifications such as Uniformat, Omniclass, and Uniclass, created by the Construction Specifications Institute in the United States and the Construction Project Information Committee are among the most widely used. These classifications have been integrated into the ISO building standards (ISO 19650 and ISO 12006) even if they have been developed in the Anglo-Saxon world, and they are linked to the modes of organization of the design process in these countries.

The arrival of information technology also responded to this exponential increase in the quantity of data to be transmitted in the construction process. The research work developed in the field of CAD since the 1980s, in France (INPROBAT team, 1986) and abroad (Eastman, 1999), gave rise to less rigid classifications and proposed separate groups of data according to the type of actor who would have to recover them (Quintrand, 1985). These classifications were reworked in the late 1990s by researchers interested in the management of building description

information (Ameziane, 1998). The computer database projects, at that time, specifically distinguished the dimensional, functional, technical and economic characteristics (Hamani, 2005). The developments in the field of computer science, together with the standardization of construction information and procedures, gave rise to BIM software.

At the end of the 20th century, in "BIM" projects, the creation of the building database transformed into a separate project, what we refer to as the Building Data Project. Following the principle that a project represents a global approach that plans to answer an issue or a problem (Boutinet, 1998) (Prost, 2014), we assume that the data project responds to the owners' informational requirements. In this "project", the actors choose to create and retrieve data during the programming, design, construction, and operation phases. The data introduced by the actors in these digital models is used in many different ways, to obtain quantities, to facilitate energy simulation calculations, to carry out life cycle analysis, to prepare the model for operation and maintenance, etc. The building data project thus shares its temporality and part of the actor system with the building construction project. We have seen that in BIM projects, "iconographic data" and "written data" are distinguished in the same way that they used to be distinguished in the past. These data are evaluated by two scales that are used by the client to measure the level of development of projects in BIM: the LOD (Level of Detail) and the LOI (Level of Information).

## 2.2 The building data project and digital twins

The digital twin is an expression that has been mainly used in the context of heritage (Jouan, 2019) for the control and management of constructed buildings, the so-called HBIM (Historic Building Information Modelling). We consider the digital twin as the addition of the database and the 3D geometry, even if the notion of digital twin is much more complex and inherited from the aerospace field. This concept also includes the further management of the building, the connection between the real and virtual world, simulations etc. (Boje et al. 2020)

However, 3D modeling existed before BIM and we can find 3D software that is not BIM software because they don't integrate the information management. In order to focus on a pure informational approach, we decided to separate the database from the 3D geometry by analyzing the creation of the building database. In a traditional project, the Building Construction Project produces a building. However, nowadays the BIM project produces two outputs: the building itself and its digital twin (Figure 1).

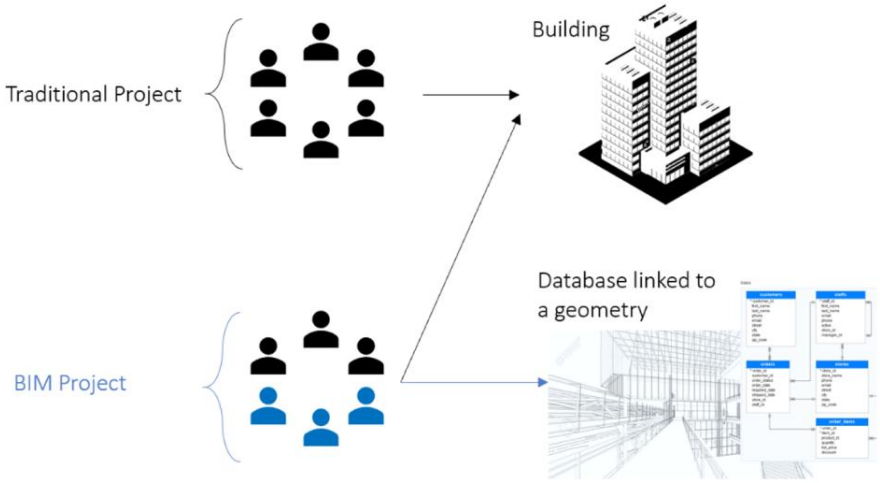


Figure 1. Comparison between traditional Project and BIM project. Source: Gordo-Gregorio, 2020

The analysis of this new project emerging from informational issues gives us a better understanding of the new issues in the construction field today. The division between the level of detail in modeling and the level of detail in information -LoD and LoI- is characteristic of each project (Mavreli ,2018). We also find the expression LoG for the level of detail of the geometry in order not to confuse with the LOD or level of development which is the addition of the level of geometrical and informational detail (LOD=LoI+(LoD/LoG)). Most research in architecture has been based on geometrical questions, which in this case would be related to the LoG of the project. Developing research that is purely based on informational issues in the construction field-, i.e., the LoI of the project -implies a new approach in the observation and analysis of BIM projects.

## 3 The building data project as an observatory of the system of actors

Another consequence of industrialization is the specialization of activities and the emergence of new professions. It produced an increase in the number of actors intervening in the construction project, and the notions of collaboration and cooperation became key words in the semantic field of the construction trades. Emerging work methodologies, new functions, and new trades have appeared and have upset the traditional division of labor between professionals (Teulier, 2017). The new tasks associated to the "BIM" actors in these projects do not correspond to the traditional tasks they used to undertake. Designers and construction companies must therefore face a set of new tasks that did not previously exist: the parameterization, the implementation of Excel tables structuring the data to be retrieved or the verification of the introduction of information. The methodology that we have followed is based on triangulation and we present the results obtained from 3 case studies (2 educational buildings and 1 office building) in which information becomes a problem of collaboration between the stakeholders.

### 3.1 Methods

The methodological choice during the analysis of the case studies is based on the triangulation analysis (Denzin, 1978) between the contractual documents (BIM specifications, BIM protocol and BIM notice), the BIM model databases and the semi-structured interviews carried out with the project actors. Even though in this article we present the general background of the case studies, the hypotheses and observations are based on the results of each study case and the participant observation within the company ALTO Ingénierie from 2018 to 2021. Participatory observation in these projects involves all project stakeholders beyond those working at ALTO Ingénierie.

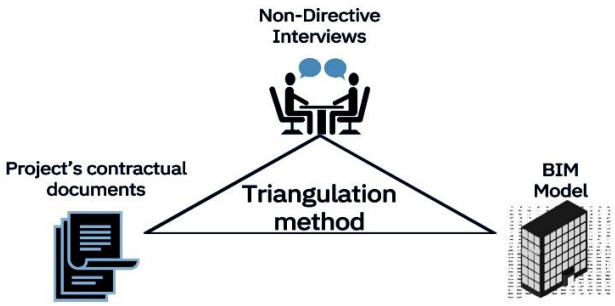


Figure 2. Qualitative research methodology based in triangulation. Source: Prepared by the author 2020.

The analysis of the projects started with the documentary analysis (Figure 2). The protocols and specifications give the context of data collection at the "contractual" level. Then, the interviews bring the mental representations of the actors and their experiences. Finally, the study of the digital models allowed us to verify the informational stakes described in the contractual documents and in the actors' statements.

### 3.2 Findings: A new system of actors

The person in charge of implementing BIM methodology is the BIM manager. In most cases, project owners do not have the skills required for the completion of the associated tasks and call upon the BIM assistant (AMO BIM in France), a kind of "BIM manager", to supervise the progress of the BIM project and in particular the information relevant to the client's interests. While the BIM manager becomes, in general, a full-fledged job, the new missions of BIM coordinator and BIM modeler/producer, are adapting in most of the observed projects to the traditional jobs of project manager and draftsman through the addition of new tasks related to the introduction of building data in the BIM model.

Currently, not all project stakeholders work within the building data project. This project is developed in parallel only with a part of the actors of the building construction project. Beyond the issues related to purely geometric modeling in so-called "BIM" projects, we focus on the informational tasks developed by each "BIM" actor. From the typical diagram of a BIM project – BIM Manager, BIM Coordinator, BIM modeler- (Davies et al., 2017), we have created a "hypothesis" diagram (figure 3) that represents the informational tasks of the system of actors in the building data project. The observation of the actors included in the diagram provided us with answers about the mutations in the stakes and work methodologies of the actors in the construction field nowadays.

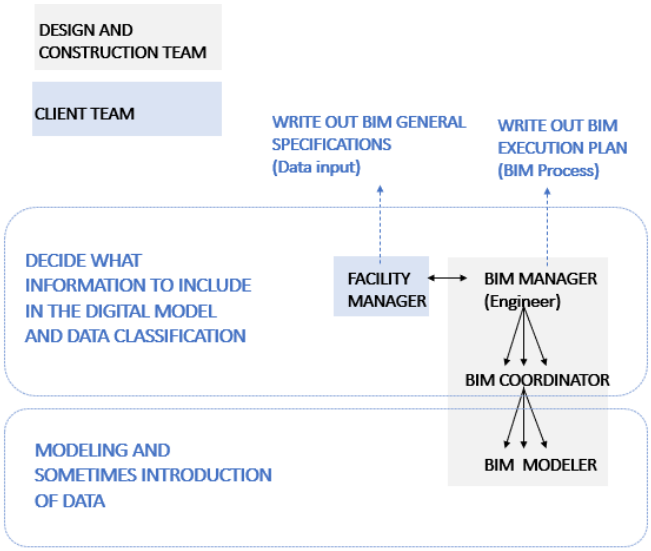


Figure 3. Adaptation of the BIM flowchart to the tasks developed by the Building Data Project stakeholders. Source: Prepared by the author, 2021.

The building data project is the main difference between the traditional construction project and the so-called "BIM" projects because the 3D modelling already existed in some traditional projects and it didn't change or modify workflows, tasks or methodologies. The project starts from a "list of needs" requested, normally, by the owner, the future operator of the building or the entity that sets up the "BIM" process from the drafting of the BIM specifications. Then, the BIM manager by drafting the "BIM Protocol", will set up a whole process of data creation and recovery. These two documents become a record of the evolution of the client's interests and his discussions with the rest of the actors (economist, architect, environmental design office, etc.).

In the case studies analyzed, we have observed that the system of actors can vary from one project to another, particularly with respect to the actors who work on the selection of the

building data (Figure 4). We also observed that the different distribution of roles in the choice of data produces very different situations of power struggle. Consequently, the creation, storage and retrieval of building data give rise to many situations of negotiation: who chooses the types of data, who enters them, who verifies them, how the actors will retrieve them and when, etc.

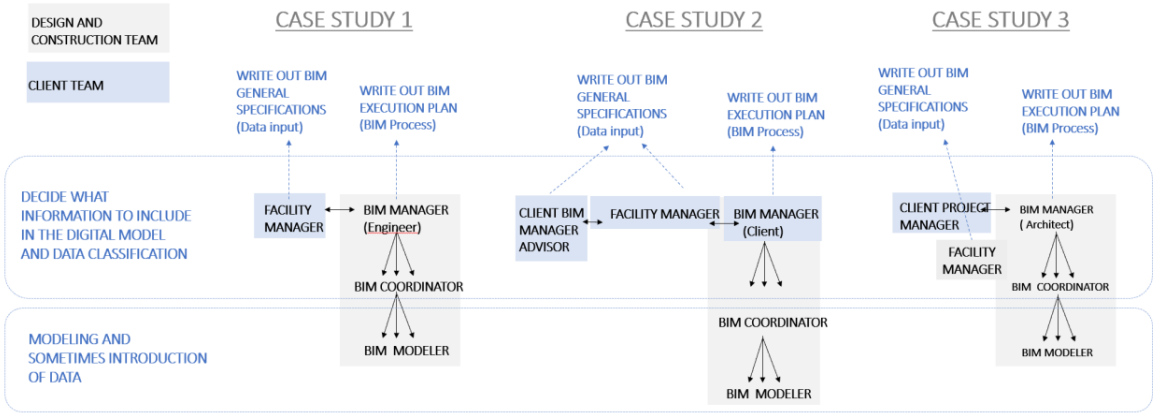


Figure 4. Diagram of the stakeholder system in the three case studies analyzed. Source: Prepared by the author, 2020.

### 3.3 Findings: BIM information problems

In the data project, there is a set of tasks that are distributed, and a coordinator, the BIM Manager, who verifies the smooth running of the project. Not all actors integrate the needs of the other actors in their approach because in most cases this causes an overload of work. Consequently, this coordination is based on a constant negotiation arbitrated by the BIM manager and in which one actor asks another to model in such and such a way, or to provide such and such information so that it can be recovered. These are new tasks which, in general, according to the actors interviewed, are not remunerated as added value. These tasks usually become an additional workload which generates problems, discussions and changes in work methodologies. Moreover, the power relationships will become key during these negotiations, in which the BIM manager and the client will be dominant in relation to the other actors, also giving prevalence to the entity in which the BIM manager is registered (architectural studio, engineering company, etc.).

We have seen that the development of the design process of the data project is also conditioned by the construction phases of the building (programming, design, construction, operation and demolition) (Table 1). The initial data are created by the project owner in the programming phase to allow a follow-up in the design phase (surfaces, functionalities etc.). However, other data such as economic data or data related to materials are produced during the design phase by the designers. Not all the data are permanent in the project, for example, data that refer to the location of equipment or structural beams during the construction phase will not be useful during the operation phase and will disappear at the end of the phase for which they were designed (Case Study 1). This study therefore highlights the need to identify the data lifecycle, in all phases, in order to better understand its creation and evolution throughout the construction project.

| CASE STUDY 1 | CASE STUDY 1 | CASE STUDY 2 | CASE STUDY 3 |
|---|---|---|---|
| Educational building (University) | Educational building (University) | Office building | Educational building (High School) |
| SITUATION | SITUATION | SITUATION | SITUATION |
| This project was chosen within the framework of a Circular Economy Project on buildings. The project considered analyzing the traceability of the steel of the beams. The selected project had BIM mockups that corresponded to the end of the construction site. | The facility manager helped the designers to structure the database in order to produce retrievable Excels for its maintenance operation tool. | Since the beginning of the design phase of the project, the owner has established a table that structures the data for the operation of the building. An exhaustive parameterization is integrated since the beginning of the design in the model. The specifications require the recovery of quantities from the model. | Within the framework of an environmental mission of life cycle assessment (LCA), the project manager tries to obtain information on the building materials from the digital model. The environmental project manager establishes a specification for the information of materials |
| INFORMATIONAL ISSUES | INFORMATIONAL ISSUES | INFORMATIONAL ISSUES | INFORMATIONAL ISSUES |
| 1. Devices (for exemple: lamps, air conditioning machine etc.) very well described and with maintenance schedules however rest of the information had very different levels of detail. | 1.The client decides to change the facility manager and everything had to be reconfigured. For the new facility manager, the data for maintenance had to be filled in by month (time parameters) and the tasks to develop every month had to be introduced as the information of the month parameter. However, the previous parametrization introduced the maintenance tasks as parameters and they were filled with the data "periodicity. ". As a result, the data are the same but the structure is completely different. | 1. Designers describe the model as unreliable. It lacks quantitative data. | 1.The construction materials are not well detailed. |
| 2. Very little information about the steel or the supplier and it was impossible to establish a traceability from the database of the | 2.In the models, each object has about ten parameters and codifications introduced in the BIM model. This situation has caused an overload of work for the designers. | | 2.The parameterization of the model has been done for the operation and maintenance of the devices. |
| WHY? | WHY? | WHY? | WHY? |
| Lack of circular economy concerns from the design team and the owner. The companies are not yet ready to this kind of analysis on BIM Models and lack of specifications from the owner. In addition, the BIM Manager belongs to the engineering consulting firm and he cared more about facility management information than about materials. | Facility management' tools are not adapted to the BIM process. Before, the facility manager's job and the designer's job were not linked but now they need to work together if they want to retrieve data from the BIM model. In addition we can find IT problems on this process. | Different BIM Managers for each phase of the project, less communication between the BIM Manager and the designers. The BIM Manager belongs to the client company and he is disconnected from the design team. | Absence of concerns related to LCA and BIM, the BIM LCA specifications are a request from the design team (the environmental company) and not from the client. In addition, the BIM Manager works for the architectural firm who is in charge of introducing the characteristics of materials, and it would produce a workload to his firm. |

Table 1. Analysis of informational conflicts in the case studies. Source: Prepared by the author, 2021.

# 4 Discussion: Building data in BIM project research

## 4.1 Building data in BIM project research

The building data project is not a concept that we usually find in the BIM literature, however, building data and building databases are very recurrent notions. The repetition of these notions in BIM research highlights the importance of information and data in the construction projects nowadays. The kind of research that takes into account information in BIM projects usually addresses the new technologies of information and communication (Tulenheimo, 2015), the energy performance of the buildings (Lange, 2012) or the facility management (Dao & Forgues, 2013) and the management of the built cultural heritage (Jouan, 2019).

The level of information of the BIM project (LOI) gives us an insight about how much information is taken into account in the project and what are the parameters that are created and filled with data. The LOI can be requested by the BIM Manager or the future owner of the building by sending an Excel File with the most important parameters (Figure 4). On this kind of files we can introduce parameters that will help on facility management or that will provide us with information to run energy performance simulations and consequently, information became important on these research topics.

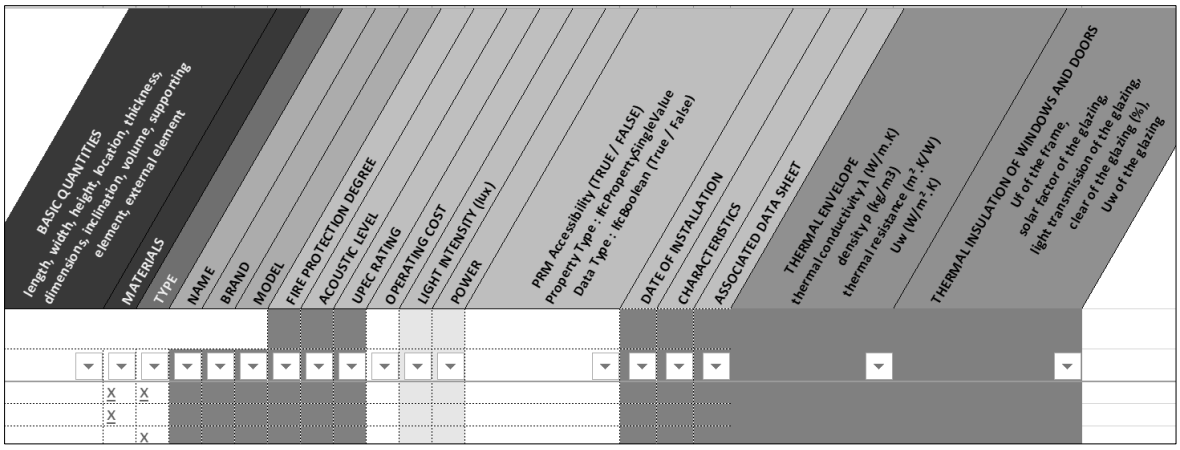


Figure 5. Example of a LOI Table. Source: Case Study at the company ALTO Ingénierie.

In addition, facility management and the management of built cultural heritage are based on data and excel files. Facility management and BIM research are focused on how to connect the BIM model database to the facility management and the heritage management tools, but also on how to enhance occupants' comfort (Alavi et al., 2021). For the energy performance and other environmental analyses, this data is extremely important because in a traditional construction project, these actors spend a lot of time searching for information about materials, energy coefficients or measurements. However, if the parameters that these actors need to run the simulations are properly filled into the BIM Model, it will facilitate their tasks. We can observe that in all these approaches we find an interest in understanding certain aspects of the building database. Nevertheless, in the building data project our goal is to be able to understand all the important aspects related to the building database for all the project stakeholders.

## 4.2 System of actors in BIM project research

The complexity of the system of actors in BIM projects is also linked to each profession. The difficulties of the actors will be linked to the constraints of their field of work, and we will find different constraints between architects, engineers, facility managers, economists etc. In the field of architecture, it is possible that architects' fears about BIM are rooted in the profession's historical background and its connection to hand-drawing. Nevertheless, these practices are

changing and currently there are many architectural firms, regardless of their size, that are implementing BIM work processes (Hochscheid and Halin, 2020). The sociologist Guy Tapie (2000), observed that young architects were the real driving force behind the early days of CAD computerization in the architectural firms. This effect, which is linked to the youth of the people involved in the project, could also be applied in the technical design offices for the engineers' profession.

The constraints encountered by the actors of the project are linked to the jobs they develop but also to the phase of the project in which they intervene. In the case of facility managers, their difficulties are more related to the lack of connections between the digital models and the facility management tools, and to the fact that facility managers are very little present during the design process (Liu, 2013) (Motamedi, 2014). Nowadays, their involvement from the beginning of the project is very important because it allows to structure the project data from the beginning. Currently there is a lot of research going on to establish the best way to connect the building management with the digital twin by taking the data that has been filled in, with the data collected from the sensors placed in the building (Motawa, 2018) (Dave, 2018) (Akcamete, 2010). This kind of research projects aims to capture/retrieve the information for the operation of buildings, which is already stored in the digital model. Part of this research is focused on the classification of information in order to find classifications, such as the COBIE format, in order to classify the information and to structure it in the same way during the construction phases and during the management phases (Lavy & Jawadekar, 2014).

## 5 Conclusion

In this article we have not been able to go into the details of the analysis of each case study in order to give a general picture of the layout of the building data project. In this context, we are also developing, as part of this research project, a classification or analysis grid that allows us to classify the project information according to the concerns of the project actors.

We propose to the observation of work methodologies through the building data project, as it represents the singularity of BIM projects compared to traditional projects. By taking "building data" as the object of study, we sought to understand the impact of the introduction of information in so-called "BIM" projects on the construction field. Through the case studies, we have observed that these data included information on the characteristics of materials, dimensions, energy simulations of the building, maintenance schedules of equipment, surfaces, occupancy modalities or functions of spaces, etc. As these data are quite heterogeneous, their classification and organization are necessary.

The data project also provides an opening to new quality issues, which will add complexity to the design process. The influence of the data project on the construction project could be directed towards notions like circular economy, health, energy performance, cultural heritage etc. A whole set of new concerns that, through the building data project, find a way to be integrated into a design process that previously was much more focused on purely geometric issues. Thus, the building data project appears as a promising opportunity to analyze new perspectives on the building design process.

On future works we propose the analysis of the collaboration/cooperation processes within the system of actors developed for each data project should shed light on the main collaboration constraints that exist today in this new type of construction project. The working methodologies around a building data project tend to converge in order to arrive at a semantic and methodological understanding common to all the actors of the project. The term collaboration appears today in almost all the publications of the professional or scientific about "BIM", however this collaboration is not yet real and it remains one of the most important constraints since each actor has different concerns and needs.

Another interesting question to explore concerns product related data, and the main standards (ISO 23386 and ISO 23387). Even if these standards become too technical and do not raise enough information about the concerns of the actors, the huge variety of parameters to be filled in these objects highlights the importance of thinking about the information content of the objects.

Finally, we also propose a third approach that concerns the life of the data and the analysis of information that disappears during the project, in order to understand what is intentional or what is the result of poor project management.

## References


Afsari, K., & Eastman, C. M. (2016). A comparison of construction classification systems used for classifying building product models. In *52nd ASC Annual International Conference Proceedings* (pp. 1-8).

Akcamete, A., Akinci, B., & Garrett, J. H. (2010, June). Potential utilization of building information models for planning maintenance activities. In *Proceedings of the international conference on computing in civil and building engineering* (pp. 151-157). June.

Alavi, H., Forcada, N., Bortolini, R., & Edwards, D. J. (2021). Enhancing occupants' comfort through BIM-based probabilistic approach. *Automation in Construction*, *123*, 103528.

Ameziane, F. (1998). *Structuration et représentation d'informations dans un contexte coopératif de production du bâtiment* (Doctoral dissertation, Aix-Marseille 3).

Azhar, S., Hein, M., & Sketo, B. (2008). Building information modeling (BIM): Benefits, risks and challenges. In *Proceedings of the 44th ASC Annual Conference* (pp. 2-5).

Biau, V., & Tapie, G. (2009). *La fabrication de la ville: métiers et organisations* (p. 208). Marseille, Parenthèses.

Boje, C., Guerriero, A., Kubicki, S., & Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research. *Automation in Construction*, *114*, 103179.

Boutinet, J. P. (2018). *Anthropologie du projet*. Presses universitaires de France.

Dao, L., & Forgues, D. (2013). Transformer la gestion des équipements avec le BIM: une étude de cas. *GEN*, *223*, 1.

Dave, B., Buda, A., Nurminen, A., & Främling, K. (2018). A framework for integrating BIM and IoT through open standards. *Automation in Construction*, *95*, 35-45

Davies, K., Wilkinson, S., & McMeel, D. (2017). A review of specialist role definitions in BIM guides and standards.

Denzin, N. K. (2017). *The research act: A theoretical introduction to sociological methods*. Transaction publishers.

Engelbart, D. C. (1962). Augmenting human intellect: A conceptual framework. *Menlo Park, CA*.

Eastman, C. M. (1999). *Building product models: computer environments, supporting design and construction*. CRC press.

Ferries, B., Meilhat, V., Pelegrin F., & Couillet A., (1985), Définition et validation d'un système de gestion de base de données spécifique au projet de conception-réalisation du projet architectural, CAOMIP

Florenzano, M. & Blaise J.Y., Modèles et représentation a l'échelle architecturale : une expérience à Cracovie, MAP-Caen 11.

Fregier M. (1983) Etude sur la représentation des composantes morphologiques de données du projet architectural dansun contexte de C.A.O. GAMSAU, Plan Construction

Gordo-Gregorio, P., & Guéna, F. (2019). Data classification in building data projects: an information-based approach to BIM projects in France. In *EUBIM 2019-BIM International Conference*.

Gordo-Gregorio, P. (2020). Le processus de négociation autour des données entre les métiers dans les projets BIM. *Le BIM et l'évolution des pratiques: Ingénierie et architecture, enseignement et recherche*, 119.

Guena F. & Leininger J.P. (1986), X2A : Pour un système de conception assistée par ordinateur en avant-projet sommaire de bâtiment. Direction de la construction, Ministère de l'Urbanisme, du Logement et des Transports.

Guéneau, J. (2019). Le métier d'architecte et le BIM. Nouvelles répartitions des tâches et des responsabilités dans les métiers de la création. *Techniques & Culture. Revue semestrielle d'anthropologie des techniques*.

Hamani, D. O. (2005). *Un système d'information pour le bâtiment-Elaboration d'un modèle conceptuel de données pour les ouvrages façonnés en place issus de la production de bâtiment* (Doctoral dissertation, Aix-Marseille 3).

Hochscheid, E., & Halin, G. (2020). Baromètre BIM: une enquête sur l'adoption du BIM dans les agences d'architecture en France. In *SHS Web of Conferences* (Vol. 82, p. 02004). EDP Sciences.

Jouan, P. A. (2019). Jumeau numérique: Une méthodologie basée sur le HBIM pour soutenir la conservation préventive des biens historiques par la considération des valeurs patrimoniales.

Kensek, K. (2015). *Manuel BIM: Théorie et applications*. Eyrolles.

Lange, B. (2012). *Visualisation interactive de données hétérogènes pour l'amélioration des dépenses énergétiques du bâtiment* (Doctoral dissertation, Université Montpellier 2).

Latiffi, A. A., Brahim, J., & Fathi, M. S. (2014). The development of building information modeling (BIM) definition. In *Applied mechanics and materials* (Vol. 567, pp. 625-630). Trans Tech Publications Ltd.

Lavy, S., & Jawadekar, S. (2014). A case study of using BIM and COBie for facility management. *International Journal of Facility Management*, *5*(2).

Levan, S. K. (2016). *Management et collaboration BIM: Management, organisation, processus et travail* collaboratif en mode projet BIM. Editions Eyrolles.

Liu, R., & Issa, R. R. (2013). Issues in BIM for facility management from industry practitioners' perspectives. In *Computing in Civil Engineering (2013)* (pp. 411-418).

Macias F. & Ferries B. (1988), Rapport final Krèpis, Centre de documentation, Ecole d'Architecture Paris La Villette

Mahmoud-Jouini S., (1999), Pratiques de projet et Ingénierie, PUCA Recherches, Paris, pp. 116-133

Mavreli, E. (2018). Level of Development vs. Level of Detail for BIM. *TUM, Munich*.

MEDIACONSTRUCT, (2016), Guide méthodologique pour des conventions de projets en BIM, BuildingSmart France

Morozov, E. (2013). *To save everything, click here: The folly of technological solutionism*. Public Affairs.

Motamedi, A., Hammad, A., & Asen, Y. (2014). Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management. *Automation in construction*, *43*, 73-83.

Motawa, I., & Almarshad, A. (2013). A knowledge-based BIM system for building maintenance. *Automation in construction*, *29*, 173-182.

Negroponte, N. (1996). Being Digital. New York, Vintage.

Picon, A. (2010). *Culture numérique et architecture: une introduction* (p. 224). Editions Birkhaüser.

Picon, A. (2013). *Smart Cities: Théorie et critique d'un idéal auto-réalisateur* (p. 120). B2.

Poyet, P. (1993). Évolution des pratiques informatiques dans le secteur de la construction. *Les Cahiers du CSTB, Livraison*, *340*.

Prost, R., & Chaslin, F. (2014). *Pratiques de projet en architecture: le tournant silencieux: essai*. Infolio.

Quintrand, P., Autran, J., & Florenzano, M. (1985). *La conception assistée par ordinateur en architecture*. Hermes.

Rifkin, J. (2012). *La troisième révolution industrielle: comment le pouvoir latéral va transformer l'énergie, l'économie et le monde*. Editions Les liens qui libèrent.

Tapie, G. (2000). *Les architectes: mutations d'une profession*. Editions L'Harmattan.

Teulier, R. (2017). La coopération: processus fondamentaux et implications pour le travail collaboratif dans une démarche BIM. *S. Riss, A. Talon, R. Teulier, Le BIM éclairé par la recherche*, 59-74.

Tolmer, C. E., Castaing, C., Diab, Y., & Morand, D. (2017). Adapting LOD definition to meet BIM uses requirements and data modeling for linear infrastructures projects: using system and requirement engineering. *Visualization in Engineering*, *5*(1), 1-18.

Tulenheimo, R. (2015). Challenges of implementing new technologies in the world of BIM–Case study from construction engineering industry in Finland. *Procedia Economics and Finance*, *21*, 469-477.

Vaudou, S. (2017). *Utilisation de la gestion des exigences pour capturer les données nécessaires à l'exploitation des bâtiments lors des phases de conception et de construction* (Doctoral dissertation, École de technologie supérieure).