Optimal Construction Management & Production Control

D1.1– As-is practices analysis and end-user requirements

WP1 – Digital Building Twin Process

Version 2

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BIM2TWIN Consortium Partners

	Partner	Country
1	CSTB: CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT	FR
2	TECHNION: ISRAEL INSTITUTE OF TECHNOLOGY	IL
3	UNIVERSITY OF CAMBRIDGE	UK
4	TUM: TECHNISCHE UNIVERSITAET MUENCHEN	DE
5	INRIA: INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE	FR
6	FIRA GROUP OY	FI
7	INTSITE LTD	IL
8	FUNDACION TECNALIA RESEARCH & INNOVATION	ES
9	ACCIONA CONSTRUCCTION SA	ES
10	RUHR-UNIVERSITAET BOCHUM	DE
11	SPADA CONSTRUCTION	FR
12	UNIVERSITA POLITECNICA DELLE MARCHE	IT
13	UNISMART – FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
14	ORANGE SA	FR
15	SIEMENS AKTIENGESELLSCHAFT	DE
16	IDP INGENIERIA Y ARQUITECTURA IBERIA SL	ES
17	AARHUS UNIVERSITET	DK

DISCLAIMER

EXECUTIVE SUMMARY

BIM2TWIN is conceived with the objective of applying the digital twin concept to the building construction process through a complete and holistic approach. This will be possible thanks to the design and creation of a digital twin platform of the construction process that will have a set of applications that allow the management of the construction and can provide a complete knowledge of the real situation of the work. The BIM2TWIN platform will bring together multiple data sources from the construction site to provide information on the status of the construction process. Knowing what is really happening on site will allow optimizing construction management. The development of the Digital Twin of the construction process on site will focus on the most relevant activities for the construction phase, such as the control of the execution and quality of the works, the planning and control of the necessary equipment and resources, and the safety of the workers.

To achieve this objective, first of all, it will be necessary to define the starting point and the development of the conceptualization of the optimal construction process enabled by the digital twin. This will lay the foundation upon which the digital twin construction platform and connected tools and systems will be developed.

This document focuses on the analysis of current construction practices in order to identify current inefficiencies occurring in the construction process and the flow of construction site information, especially where cross-domain influences occur. To accomplish this goal, it has been necessary to determine and analyze the general process of the work on site, as well as the agents involved, the activities developed, the exchange of information and the relationship between the process performance and monitoring. Through the study and review of the literature and the state of the art of construction processes, it has been determined the main inefficiencies that occur in the work on site and barriers that prevent or hinder the digitization of this sector. In order to deepen the knowledge on this point, a survey has been conducted and disseminated at European level and different workshops have been held with the personnel related to the construction phase and with BIM2TWIN partners.

All this work has allowed to determine the inefficiencies related to the construction process on site and the barriers that hinder the digitization of the on-site construction process. All this analysis has been carried out with the extensive experience and active participation of the consortium's construction/engineering partners. The result of this work has allowed to define the user cases from which the requirements of the end users towards the Digital Building Twin platform can be defined.

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Abbreviations

AHRS	Attitude and Heading Reference Systems
AI	Artificial Intelligence
API	Application Programming Interface
B2T	BIM2TWIN
BIM	Building Information Model
CAD	Computer-Aided Design
CDE	Common Data Environment
CPM	Critical Path Method
DBT	Digital Building Twin
DBTP	Digital Building Twin Platform
DL	Description Logics
DT	Digital Twin
ECSO	European Construction Sector Observatory
EU	European Union

GA	Grant Agreement
GPS	Global Positioning System
HFM	Heat Flow Meter
H&S	Health and Safety
IFC	Industry Foundation Classes
IoT	Internet of Things
IPD	Integrated Project Delivery
IQ	Intelligence Quotient
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LBMS	Location-Based Management System
LD	Linked Data
LIDAR	Laser Imaging Detection and Ranging
LPS	Last Planner System
MVD	Model View Definition
NASA	National Aeronautics and Space Administration
ODP	Open Data Platform
OHS	Occupational Health and Safety
OWL	Web Ontology Language
PoC	Proof of Concept
PPE	Personal Protective Equipment
PtD	Prevention through Design
QIRT	Quantitative Infrared Thermography
QR	Quick Response
R&D	Research and Development
SD	Secure Digital
SOS	Save Our Ship
SVM	Support Vector Machines
UV	Ultraviolet
WIFI	Wireless Fidelity
WP	Work Package

1 INTRODUCTION

1.1 Scope and Objectives

The objective of the BIM2TWIN project is the creation of a Digital Building Twin (DBT) platform to improve efficiency in the management of building construction processes. BIM2TWIN proposes a comprehensive and holistic approach for the application of the Digital Twin concept to building construction: It will enable the involved agents to know the real-time status of everything happening on site and throughout the supply chain: the current progress and quality of the work, the current location of workers, equipment and materials, safety conditions, etc. This will be achieved by conceptualizing, implementing, and demonstrating a Digital Building Twin process.

The Digital Building Twin (hereinafter called DBT) must be able to capture the physical state of the building and the state of the construction process as it is. It must correspond directly to both, the building design, and the defined construction plan, so that everyone involved has access to reliable, accurate, real-time information on the status of the project, essential information for coordinating their work with others. This will ensure that everyone has a thorough understanding of the status of the project. This will require understanding key performance and situational awareness issues during the construction processes, as well as identifying opportunities for improvement in terms of safety, work progress monitoring, optimal resources utilization (including equipment and people) and scheduling.

As a starting point to achieve this goal, it will be necessary to define and develop an ideal construction management process based on a digital building twin. This will require defining the current construction process, identifying current on-site construction practices, construction procedures, equipment, resources, progress, quality, productivity, etc., which lead to a comprehensive analysis, establishing the basis for developing the digital twin building platform and related tools.

The main objective of this first deliverable of the project is to identify and analyze the current construction processes, diagnose the most relevant gaps and inefficiencies in relation to the knowledge of the construction site situation. Those gaps are mainly focused on the three main BIM2TWIN target areas, which are: progress monitoring and quality control, occupational health and safety and equipment optimization and production planning.

The second objective of this deliverable is to identify the barriers or factors that prevent or hinder the implementation of digitization in the construction process, which will pave the way to define the end-user requirements for the Digital Building Twin Platform (DBTP).

All the work collected in this document gathers all the activities carried out within task *T1.1 As-is practices analysis and end-user requirements,* led by TECNALIA**.** The conclusions obtained will set the basis for the conceptualization of the optimal construction process, which will lead to the development of the Digital Building Twin Platform.

1.2 Relation to other Work Packages

This deliverable provides the basis for achieving the WP1 objective of developing the conceptualization of the optimal Digital Twin and will be used for the development of the other deliverables of this work package, as well as for the other work packages of the project.

The results collected in this document and in the other WP1 deliverables will define the end-user requirements and specifications with which to develop the innovative workflows in the Digital Building Twin platform (DBTP) and to define the data models in WP2.

All the process and platform specifications collected in this WP will have a direct relationship with the developments done in WP3, WP4, WP5, WP6 and WP7, as they will define the on-site data collection requirements for the tools to be developed in those work packages.

Although the project has an EU-wide coverage, it has been focused on the countries where the demonstrators and pilot cases (WP8) will be carried out. Therefore, from the beginning of the project and specifically in this deliverable, the analysis of the current construction processes has been carried out jointly with the three construction companies in Finland, France, and Spain, where the demonstrators will be conducted.

The results collected in this document will fuel the work for the future work packages. Because it links the users' needs, through the insight of pilot sites with the necessary developments for the DBT Platform, strongly considering the user´s perspective in the design.

The following scheme shows the relation between WPS.

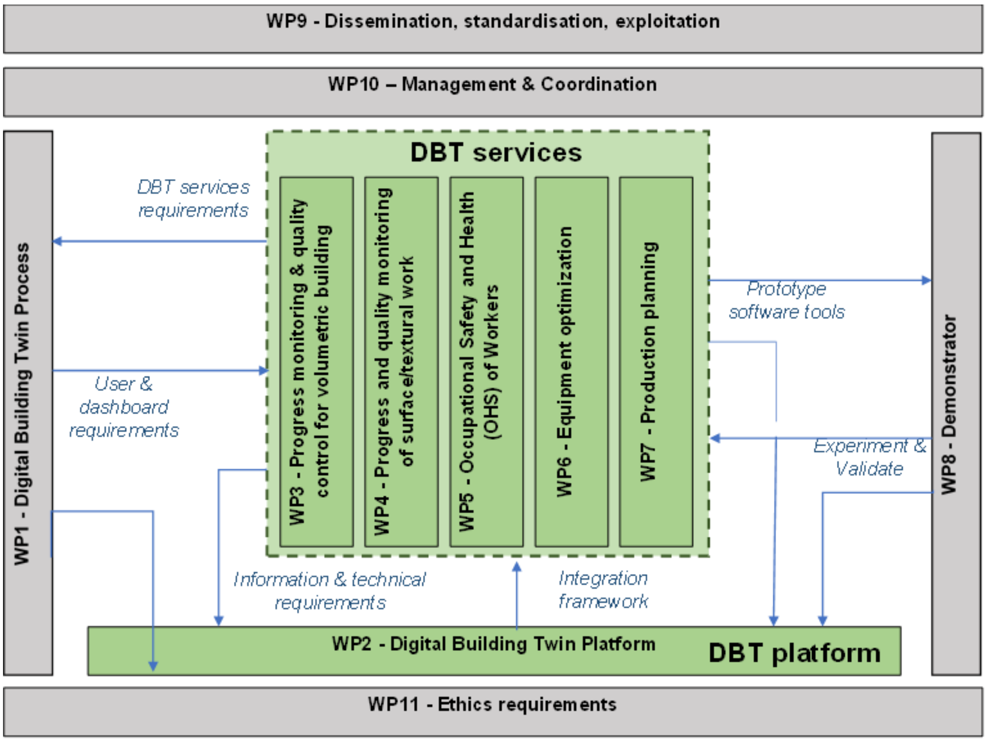


Figure 1. Project scheme and relationship between work packages

Below is a graph summarizing the relationship between the results of the different activities performed within Task 1.1 and included in this deliverable with the rest of the WP1 tasks.

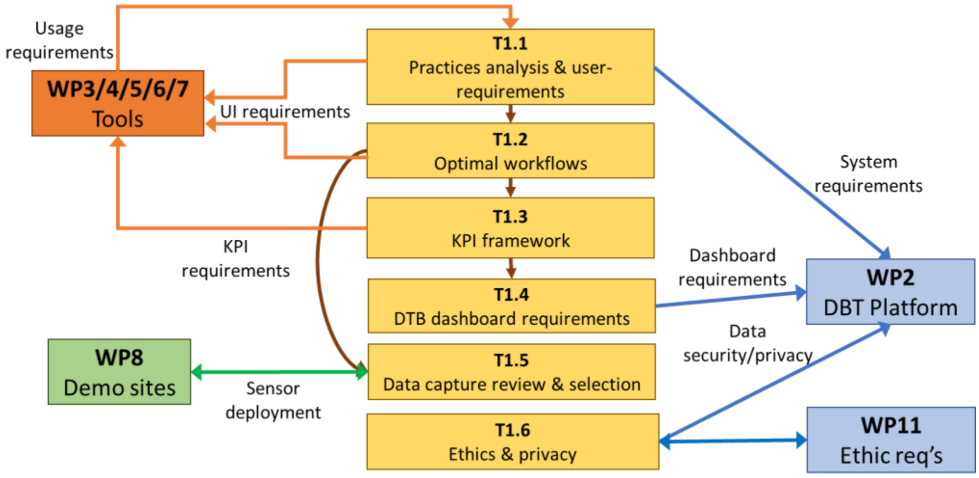


Figure 2. Diagram of the relationship between WP1 tasks and their relationship with the rest of the work packages.

It is remarkable that the user requirements, which will feed the developments in WP3, WP4, WP5, WP6 and WP7 are roughly addressed in the current Deliverable, D1.1. Nevertheless, they will be detailed in Task T1.2 and integrated in the different workflows once the uses cases from the pilot sites are deeply defined.

1.3 Structure of the Deliverable

The current document has been structured in 4 main parts, according to the activities done in the Task T1.1, as it is showed below.

Firstly, the main areas of the construction process on which the development of the Digital Building Twin platform will be focused are drawn. Secondly, the methodology followed to achieve the objectives has been explained, ranging from literature review and state of the art of digital twins, to conducting surveys and workshops with staff related to the construction phase and BIM2TWIN partners expert in user requirements.

With all the research work, the as-is practices analysis in the construction process has been carried out. The analysis has led to identify, categorize, and prioritize the inefficiencies related to the general construction process and related to the specific sub-processes, focused on the 3 Pilots. Furthermore, the main technologies used for the digitization of the construction phase helpful for solving the low productivity have been identified, as well as the main current barriers for the digitalisation of the process. The findings of this section conclude in a prioritization of the barriers of the construction phase and hinders of the digitization of the process for each pilot.

Finally, knowing the barriers that hinder the digitization of the on-site construction process, and based on the functionalities expected from the platform, the end-user requirements towards Digital Twin Building Platform have been preliminary tackled, as a first approach of the DTB Platform specifications, which must meet the project expectations, and particularly the Demonstrators needs.

2 CONCEPTUALIZATION OF THE BIM2TWIN DOMAINS WITHIN THE CONSTRUCTION PROCESS

This chapter provides an overview of the construction process focused on the on-site work phase and a description of the main domains on which the BIM2TWIN (B2T) project developments will be focused.

The BIM2TWIN project aims to improve efficiency on the construction process management by focusing on the on-site work phase. To achieve the optimization of the construction phase, the project developments will focus on 3 specific domains tackled on the B2T project which are: Execution monitoring and quality control, Occupational Safety and Health and Production planning.

2.1 Execution monitoring and quality control

The first field drawn on the project to be addressed through the Digital Building Twin platform (DBTP) will be based is the Execution monitoring and quality control (WP3 &WP4)

This phase, activity or domain of the construction process deals with the verification of the progress of the work, to the project. This field is not only focused on verifying that what is executed corresponds to what was specified in the project design, but also verifies the quality of what has been executed, checking that the execution has the necessary technical characteristics, thus ensuring the quality of the final product. In summary, it can be said that the objective of Execution monitoring and quality control is to guarantee that the work execution is being carried out in accordance with the execution project, and this is done through qualitative and quantitative control of the work and the quality of the built product.

A large number of different agents are involved in the execution monitoring and quality control process of a building. The most common ones are the promoter, the designer, the constructor or subcontractors, the construction manager, the material execution manager, the building quality control entities and laboratories, the product suppliers, etc. All of them are involved in one way or another in the Execution monitoring and quality control. In addition, in recent years other new profiles and agents have emerged that intervene in the construction phase, such as:

- Asset Manager: real estate asset manager who represents the investment part, and therefore usually acts as the developer's representative.
- Project Manager: manager of the scope of the project to guarantee the deadline, cost, and quality. He is the one who sets the objectives, identifies the stakeholders, manages the risk, and assesses the uncertainties.
- Facility Manager: manager of assets during their useful life. Manages maintenance, use and operation.
- BIM Manager: digital Model Manager. Frames the objectives in the digital platforms, establishes the collaborative environment, defines the strategies related to the technological processes and procedures.
- Building Control checks and verifies regulatory compliance, technical compliance and the requirements specified in the project.
- Commissioner: verifies the definition, existence, and compliance of the executed for the reception of these in the contractually agreed terms, either in the physical environment or in the digital model (as built and / or digital twin).

2.2 Occupational Safety and Healthy

The second field of the project, on which the Digital Building Twin platform (DBTP) will be based, is focused on the Occupational Safety and Health.

The provisions established in the European Union [1] for construction sites have determined a specific prevention regulatory framework for this activity, in which architectural, organizational or planning decisions have a direct impact on the occurrence of accidents.

The particularities involved in construction work, such as the complexity of the on-site construction processes on the site, the participation of a large number of actors at different times and places, the variability of tasks and activities and their associated risks and the simultaneity and temporality of companies working on site, require a thorough surveillance of the occupational risk-prevention.

According to Directive 92/57/EEC [1], the basic obligations and responsibilities related to health and safety in construction lie in several of the participant stakeholder.

The obligations of the involved stakeholders to manage the construction site are presented below:

Promoter

- Designate the health and safety coordinator.
- Ensure that, prior to the implementation and organization of the work, a health and safety plan is drawn up.
- Inform by prior notice to the competent authorities before the start of the work; date of dispatch, site address, promoter, type of work, site manager, health and safety coordinator during the project preparation phase and during the execution phase of the work, construction company, planned start date, planned duration, estimated maximum number of workers, planned number of contractors and self-employed workers and details of contractors already chosen.

Health and safety coordinator during the execution phase of the work:

- Coordinate the general principles of prevention and safety.
- Coordinate the most relevant provisions to ensure that companies apply the principles of prevention.
- Supervise compliance with the health and safety plan.
- Propose and supervise any necessary adjustments to the health and safety plan during the work execution.
- Supervise that work procedures are being correctly applied.
- Take the necessary measures to ensure that only authorized personnel are allowed access to the site.

Contractor company (and subsequently subcontractor companies), generally acting through the site manager, work supervisors and designated preventive resources:

- Ensure the safety and health of workers.

- Adopt the necessary measures for the protection of the safety and health of workers, including the prevention of occupational hazards and the provision of information and training, as well as the provision of the necessary organization and means.
- Assessing occupational safety and health risks, including those faced by groups of workers exposed to particular risks.
- Decide on the protective measures to be taken and, if necessary, the protective equipment to be used.
- Keep a list of occupational accidents occurring to workers who are unable to work for more than three working days.
- Write reports on occupational accidents suffered by your workers for the authorities.
- Take into account the indications of the health and safety coordinator.
- Adopt the minimum health and safety requirements for construction sites.
- Consult workers and/or their representatives and allow them to take part in discussions on safety and health at work.
- Ensure that each worker receives adequate training.

Workers:

- Take care, as far as possible, of their own safety and health and that of others affected by their actions, in accordance with their training and the instructions given to them by the employer.
- Correctly use machinery, tools, hazardous substances, transport equipment and personal and collective protection equipment.
- Inform the employer of any work situation that represents a serious and immediate safety hazard and of any defects in protective devices.

2.3 Production planning

The last domain, on which the project is focused for the Digital Building Twin platform (DBTP) development is the Production Planning.

A construction project planning is the group of activities necessary for setting all the necessary tasks and activities and the definition of their appropriate sequence. The planning tries to define the execution calendar of the set of activities required to carry out the work, as well as the management of the resources, both material and human to be handled in a cost-effective way.

3 Research Methodology for eliciting information

3.1 Purpose of the methodology

In order to achieve the objectives established in this deliverable, and to be able to identify and analyze the current construction processes, identifying the most relevant gaps and inefficiencies, the Design Science approach [2] has been used. This research methodology incorporates the principles, practices and procedures necessary to carry out this type of research and is focused on the following aspects: To be consistent with previous literature, to provide a model and methodology with which to conduct the research, and to provide a system for presenting and evaluating the research data.

For this purpose, first of all, a review of the existing literature related to construction processes has been carried out, focusing on the main fields of action of the BIM2TWIN Project.

The construction practices and procedures on site have been analyzed, identifying the current procedures, the inefficiencies they present and the tools or systems that exist in the market to carry them out.

Then, based on the conclusions obtained from the literature review and the analysis of the state of the art, a questionnaire has been designed to deepen the knowledge of the inefficiencies that affect the construction phase and that prevent the optimization of the construction process and the barriers that hinder the digitization of the construction process on site. This questionnaire was launched to different countries through the Consortium contacts and social networks to have an overview perspective about the as-is process.

After analyzing the results of the questionnaire, several workshops were held around the BIM2TWIN pilots in Finland, France and Spain with personnel involved in the on-site construction phase. They are aimed at establishing the current practices in the on-site construction process in the pilot construction companies, and identifying the main inefficiencies affecting them and how they could be resolved through the use of technology and the digitalisation of the construction processes.

With all the above information, the last step of the methodology followed has been to hold an internal workshop with some of the BIM2TWIN partners involved more deeply in the areas to handle in DBT. The purpose of this workshop, besides sharing the results from the survey and pilot workshops, was to start defining preliminary user requirements for the DTB platform from the stakeholders' elicitations.

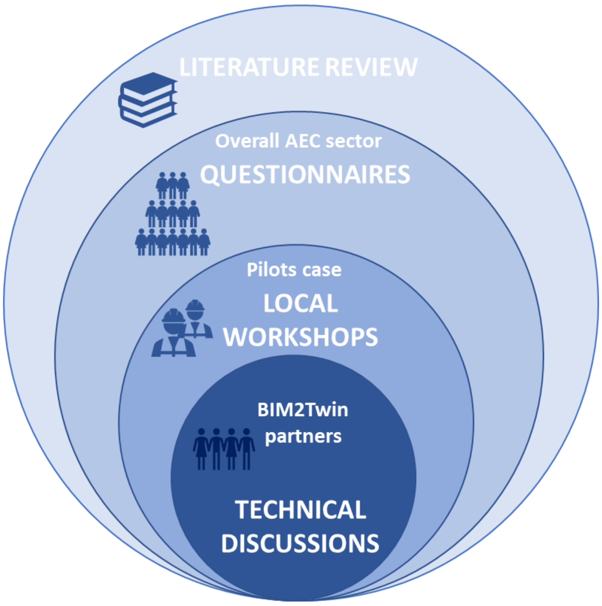


Figure 3. Scheme of the methodology

Through this research methodology, we aim to develop the conceptualization of the design of the ideal digital construction process enabled by digital twins and the identification of key challenges to develop the digital twin platform and connected tools for the domains of the site process targeted in this project which are safety monitoring, progress, quality and equipment utilization.

3.2 Literature review

Following the formal steps of design science methodology, firstly, a review of the existing literature on all aspects related to the target development of the BIM2TWIN Project has been carried out. In addition, an analysis of the state of the art of subjects related to the BIM2TWIN purposes, such as the usual practices and procedures in the construction phase, digitalisation of the on-site construction, identification of inefficiencies, methodologies or systems for the work management, stakeholders involved, relationship between processes, etc.

For this purpose, the most relevant existing literature about the main subjects tackled in this report has been reviewed. In particular, the bibliography that has been analyzed has focused on the following topics:

- Current processes in on-site construction.
- Monitoring of the progress of the work
- Work progress/quality control
- Safety and risk detection and prevention
- Scheduling and control of equipment use
- Planning of resources and tasks
- Digital twins.

The detailed result of the analysis of the state of the art of each of the points is shown in section 4 of this document. The main objective of the literature analysis carried out has been the identification of the main inefficiencies that occur and affect the construction phase and the identification of the main barriers that hinder the implementation of digitization in the construction process, which will serve as a basis for the definition of the user requirements of the DBT platform.

3.3 General Questionnaires

Following the proposed methodology, based on the conclusions obtained from the literature review and analysis of the state of the art, a questionnaire has been designed to deepen the knowledge of the key inefficiencies that occur and affect the construction phase and that hinder the optimization of the construction process. Another objective for the questionnaire is to identify the main barriers that hinder the implementation of digitization in the construction process. All this will serve as a basis for the definition of the DBT platform user requirements.

In order to obtain the necessary information and to be able to collect and interpret it in an agile and simple way, the questionnaire has been created with the Google Forms tool. This tool has made it possible to create a simple interface in which to ask the different questions and facilitate the answers by the respondents. In order to achieve greater dissemination of the questionnaire and thus obtain as much information as possible, the questionnaire has been designed in English, French, Finnish and Spanish.

With the aim of collecting all the information and data necessary to achieve the objectives of this study, the questionnaire has been categorized in 4 sections:

The first section has been designed with the objective of knowing the profile of the respondent, and to be able to filter and analyse the answers by different criteria, thus being able to perform a detailed analysis of the answers obtained. In this way, it has been possible to draw precise conclusions about the answers of the questionnaire. The results can be analysed by country, or by the role played in the company, or the field of work in which they work.

The second section focused on identifying and prioritizing the main inefficiencies and points for improvement in construction processes today. In order to categorize their importance, respondents were asked to rate the importance of each of the inefficiencies identified in the literature review using a numerical scale. Respondents were also allowed to identify any other inefficiency or point of improvement that had not been included in the form if it was important.

The third section asked about the relevance of the phases of the construction process to guarantee the success of the construction, the main objectives to be achieved with the optimization of the construction processes and the importance of the characteristics of the data collection systems for quality control at the construction site. The same structure and numerical scale were used as in the previous section in order to obtain the evaluation of the importance of the different aspects that were asked about.

The fourth section focused on prioritizing the main barriers identified that hold back the implementation of the digitization of the construction process on site. In order to categorize the importance of these barriers, and to prioritize the characteristics that the DBTP should have to solve them, the respondents were asked to rate the importance of each of the barriers identified in the literature analysis using a numerical scale. Respondents were also allowed to identify any other barrier that had not been included in the form.

According to these specific objectives, the questionnaire has been structured as follows:

1. General information and professional profile

- Geographic scope of the company or organization
- Age
- Gender
- Maximum level of studies reached
- Company/ organization size
- Main company activity
- If your company's activity is a construction/subcontractor company, please indicate the specialty
- Role in your Company
- Fields where you work

2. On-site construction. Area of progress

- Assess the relevance of the points for improvement in the construction process to be successfully

3. On-site construction. Keys to ENSURE the success of the on-site works.

- Assess the relevance of the following phases in the construction process to be successfully
- Assess the relevance of the following objectives of an optimal management in the construction process to be successfully
- Assess the relevance of the feature of the data collection system to quality control in the construction process

4. Digitalisation of the construction process on site – Barriers

- Assess the relevance of the following specific barriers to the digitalisation of the construction process

Below some images of the questionnaire designed for this task are presented:

Figure 4. Images of the designed questionnaire

Although the study was intended to be focused on the constructive reality of the countries, where the pilot cases will be carried out, the questionnaire has been launched at European level, including also some of Latin America countries to cover a wide range of options.

The questionnaire has been disseminated through the BIM2TWIN project website, social networks through the Project partners. In particular, the partners leading the pilots have shared among their staff. In such a way, it has been possible to obtain responses from several roles and agents involved in the construction process. Thanks to this dissemination strategy, more than 300 responses from all over the world, but mainly from Europe, have been achieved. The results in detail are presented in chapter 5 of this document.

The following graphics represent the geographical distribution of the questionnaire respondents:

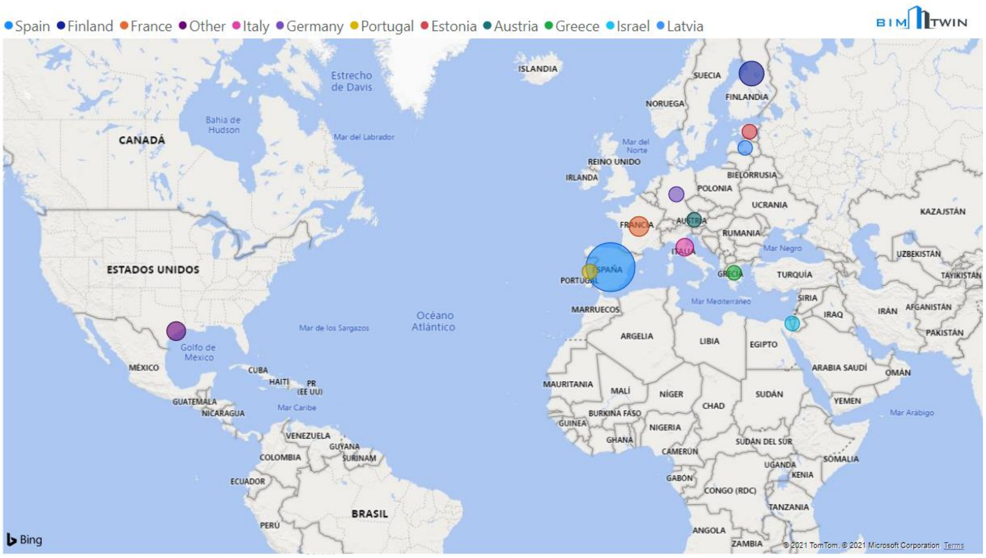


Figure 5. Questionnaire results regarding the geographical participation

As the objective of the questionnaire is to increase the knowledge of both the general construction process and the main areas on which BIM2TWIN will focus (progress monitoring and quality control, occupational health and safety, equipment optimization and production planning), the questionnaire has been designed to find out the role of the respondents and the field of the construction process in which they participate. In this way, it will be possible to draw specific conclusions for each of them and focused on the different agents involved in the construction process.

Although the main objective of the questionnaire is to collect information on current practices on the construction site in order to identify the weak points that lead to low productivity and to determine the potential of digitization of the construction site to improve inefficiencies and the definition of the needs of the users of the digital construction platform, it has also served to expand the information on other aspects of the construction site. The questionnaire has also been used to provide further information on the relevance of the phases of the construction process to ensure the success of the work or the main objectives to be achieved with the optimization of the construction processes and the importance of the characteristics of the data collection systems for quality control in the construction site.

3.4 Local workshops around the pilots and contractor companies

After finalizing the questionnaires on inefficiencies and barriers to digitization and having obtained the response of more than 300 people related to construction in the construction phase, 3 workshops were held in the countries where the BIM2TWIN pilots will be carried out, France, Finland and Spain. The objective of these workshops was to identify the current practices in the on-site construction process, and more specifically in the sub-processes (execution and quality, health and safety and planning).

These workshops have implied the participation of the site workers from the 3 construction companies' partners of the project, leading the pilot sites in Finland, France and Spain. They are aimed to identify the main inefficiencies affecting them in these areas, and how they could be solved through the use of technology and the digitization of construction processes. The main barriers in the three countries that hinder the digitization of the construction sector have also been identified.

In order to obtain the necessary information and to be able to deepen the knowledge about the current processes in construction, the workshops have been structured in 4 different blocks:

1. Overview of the construction process within the contractor companies leading the pilots
2. Main inefficiencies in the construction process affecting to the pilot sites
3. Main barriers holding back the implementation of the digitalisation in the construction process
4. Identification of relevant information to be monitored on the process

The first part has focused on knowing the construction processes carried out by the three companies where the pilot cases will be carried out. The objective of this part is to identify how construction companies carry out their day-to-day construction on site, focusing on the three areas of the project (execution and quality, planning and health and safety). For this, it has been necessary to identify the participating agents and stakeholders in each of them, the activities carried out and what information is necessary and exchanged for this purpose, etc.

The second block of the workshops focused on identifying the main inefficiencies affecting the partner construction companies, and to determine the main points for improvement in their construction processes. Thanks to this, it has been possible to relate each of the inefficiencies and points for improvement with the scope of the construction process it affects. After identifying the main inefficiencies affecting each of the 3 construction companies, it has been studied how they can be solved, identifying how technology could solve or improve these inefficiencies and identifying which agents or roles could contribute more to solve them.

The third block of the workshops focused on identifying the main barriers holding back the implementation of the digitalisation in the construction process. The barriers that most affect the partner construction companies in this project and also those that need to be solved to guarantee the implementation of digitization in the construction site have been established. The way in which these barriers could be overcome has also been identified.

Finally, in order to identify the requirements and specifications that the DBT platform should have, it has also been determined what information from the construction site would be necessary to know in real time to improve the quality of the entire construction production process and what data related to on-site work should be controlled to improve success in terms of productivity, health and safety and quality.

To ensure that the information obtained in the workshops corresponds to the day-to-day reality on the construction site of the participating construction companies, the attendees were selected to cover all the roles and areas of the construction process. The different profiles of the stakeholders involved in the construction phase, site workers, health and safety personnel, site managers, budget or planning technicians, middle managers, etc. and who work in the three main target areas of the BIM2TWIN project, have been considered.

Given the extraordinary situation generated by the Covid-19 pandemic and due to the impossibility of carrying out these workshops in face-to-face sessions, in order to achieve the objectives established, it has been necessary to carry out these workshops using a series of digital tools that allow interaction among the participants and that facilitate obtaining the information required from the participants. In the different workshops carried out, tools such as Google Jamboard [3] or Miro [4] have been used, which offer a collaborative digital whiteboard system to carry out the different dynamics designed, or tools such as Mentimeter [5] with which to make surveys and interactive questions. In some cases, these workshops have been carried out in a mixed way, with attendees virtually connected and others in a face-to-face meeting connected to the rest of the participants.

In the following pictures some screenshots of the digital tools used for the online workshops

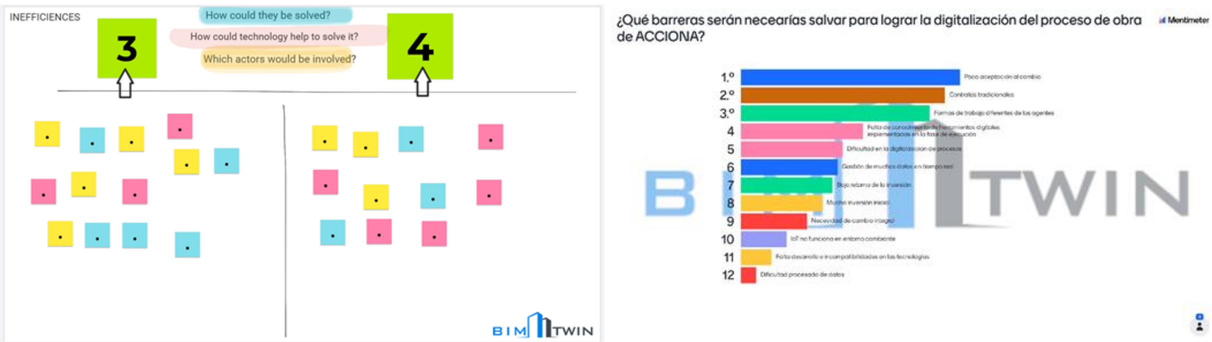


Figure 6. images of the different dynamics and digital tools used in the workshops

With this methodology, based on the experience of the participating agents in the construction phase, it has been possible to obtain the necessary information to set the current practices of the construction process, as well as the sub-processes of execution and quality, health and safety and planning. It has also been possible to define the main inefficiencies within these areas that can be overcome through digitization. Based on the results of the workshops and the analysis of the barriers that hinder the digitization of the construction process, it will be possible to define the ideal process and the user requirements that should be addressed in the DBT platform in order to meet the general and particular expectations of the agents involved in the construction site.

3.5 Technical discussions among BIM2TWIN Partners

As the last step for the definition of the preliminary definition of user requirements, the findings of the questionnaires and pilots' workshops have been shared with other BIM2TWIN partners, mainly leaders of technological WPS in technical meetings. The purpose of the meeting was to start addressing some general requirements starting from the end-user requirement detected by the pilots, from the point of views of the BIM2TWIN domains' experts.

It was suggested to identify with pilot partners some specific use cases where the requirements could be further broken down as the basis of the definition of DBT platform technical specifications. The timing of the Task T1.1 has not allowed to select properly the use cases selected by the pilots and thus it has not enabled to go into detail for the definition of the user requirements by use case.

Therefore, the prioritization of some Use Cases for the pilot sites will enable in future tasks to deepen and define the initial DBT requirements. Once agreed with pilot partners, the use cases will be worked in detail in T1.2, since they will be the basis to validate the different workflows of the project.

In the questionnaires and workshops, the information about the data relevant to know through the project has been gathered to overcome the inefficiencies. Some questions about those data will need to be answered to focus the use case and create a User story which will allow the DBT Platform respond to the end-user requirements. Some of these questions are:

- Why is important to you knowing this information?
- Why have not you collected this data so far?
- What is your starting point for this data gathering?
- What are the necessary data to monitor this RELEVANT information?
- Is it possible to obtain the data in your current flow?

The answer to these questions will help in T1.2 to focus the uses cases, from a perspective of the user stories. It will enable to define more precisely the user requirements according to the project expectations and accordingly the DBT technical specifications.

4 State of the Art of the As Is Construction Process

This section, as the first step of the research methodology applied, contains the results of the literature review with which the state of the art of the main aspects affecting the construction phase and consequently addressed in the BIM2TWIN project, as well as meaningful technologies to improve them is overviewed from the literature analysis.

As indicated in the description of the research methodology used, the state of the art has been analyzed for the main focus areas of the B2T project. The results of each of these analyses are presented in the following chapters.

4.1 Progress monitoring in the construction phase

The progress monitoring in the construction phase verifies that the work is being built in accordance with the project, both with the required qualities, execution times, as well as with the functional specifications of the installations. This activity is key for achieving quality construction, and it is usually the longest phase of the project management life cycle. Project monitoring and Control differs from all other phases in that, between phase kick-off and project acceptance, all processes and tasks occur concurrently and repeatedly, and continue almost the entire duration of the phase. This activity ensures that the project is on track and is being executed according to the established schedule and meeting the project requirements. This task is directly related to the work planning, therefore the lack of an adequate and updated planning of the work during the development and the constant changes that usually occur in the work, makes it difficult to perform effectively of this activity.

At present, all activities performed for this target area are based on visual checks and do not provide any feedback to the project manager or to the BIM models if they are used. The vast majority of construction sites lack digital tools to control and monitor the progress of the work and control the quality of what has been executed. Generally, these activities are performed by various agents, and they are responsible for checking in person the current status of the work and verifying what has actually been executed. This methodology is susceptible to errors, and manual data collection makes communication and transmission of information between the construction site and the office difficult.

Due to the changing environment of the construction site, and the large number of stakeholders involved in the work, communication between the agents in the Execution monitoring and quality control is of vital importance because the greater the number of agents, the greater the traffic of information and the greater the number of records, which increases the risk of misinformation and outdated data. This communication today is done by traditional means, using tools or documents such as the order book, minutes of work, emails, or text messages.

Currently the construction phase lacks digital tools to monitor the work progress. In some cases, digital tools are starting to be used to perform this task, but their penetration in the construction sector is residual and only 12% of organizations consider that they are carrying out an adequate digital transformation strategy for their processes [6].

Although the monitoring and control of the project is essential for the efficiency and success of the execution process and the data are used to track information related to quality, safety, efficiency and productivity, the current practices to monitor the progress and advancement of the work are manual. This task is based on visual inspections in which one or more people have to check in person the current state of the work and verify what has actually been executed. These manual collection methods are often full of errors and complicate the way data is communicated between job sites and the office. Adding to the challenge, companies use multiple systems to house project and job site data, making it difficult for main offices to turn data into actionable reports. This makes this control error-prone and time-consuming [7], making the control and monitoring of the process in the construction phase inefficient. In addition, the lack of collaboration and communication between all the agents involved in the work during the execution phase makes it difficult to successfully control the progress of the work. Being able to monitor the construction process allows identifying deviations from the schedule or budget early enough to be able to effectively implement the necessary corrective measures. These inefficiencies in control and monitoring during the construction works phase cause 75% [8] of the cost overruns in the construction process to be caused by failures in construction management.

As stated in the report written by Trackvia "*Manual processes in construction and engineering*" [9], despite the importance of data and control of the execution process for the success of the company, both managers and middle managers express the inefficiencies of the data collection process on site. Moreover, despite the existence and development of new systems and digital solutions in recent years, the custom of manual data collection and data entry is still widespread in the construction industry and even the use of handwritten notes on construction sites.

At present, the development of scanning and data capture tools that can be used to monitor the work process is very advanced and their use is widespread [10] [11]. Currently different methodologies and tools have been developed for the automated monitoring of progress through the use of scanning and data capture systems [12]. In spite of that, in the vast majority of cases the data processing is still manually done, and human interpretation is necessary to obtain the desired information. In addition, it is difficult to implement technological integration or digitization of the processes in the construction sector. This is due to the large amount of data that should be monitored and managed in real time, the technical hinders of digitizing the onsite construction often fairly reluctant to the changes and the lack of development of the suitable technology , in many cases still incipient.

There are several processing techniques that, by means of various algorithms or statistical techniques, can be carried out independently of the origin of the data (obtained by means of a capture device or generated in any other way) to obtain the objective information [13] [14]. Nevertheless, this work in most cases depends on the expert knowledge of the person to adapt them and extract the desired information. Due to a greater maturity of BIM [15] [16]and adoption of this methodology [17] [18], not only in the design phase, but throughout the life cycle of the building, there are a number of systems and tools on the market that allow or facilitate the monitoring of work progress in the onsite construction phase, such as the "Scan-vs-BIM" [19] [20] systems that allow tracking state changes by comparing reality capture data with existing BIM models.

The automate tracking progress is still a key challenge to be addressed by the technology to leverage the efficiency of the on-site process. The BIM methodology, enriched with other technologies to monitor the progress in real time, can provide the basis for this automation. In this sense some current BIM management platforms, based on CDE (Common Data Environment), lead to an optimal managing BIM data which is the starting point for the automation of the tracking progress.

Almost all of the BIM management plan are designed for the design phase and the information management for the communication between the agents in the different phases of the construction process.

Some of the most used platforms and systems to optimize the control of the construction progress on site are described below:

- Autodesk BIM 360 [21]

  Autodesk BIM 360 is a software suite that offers solutions for all phases of the lifecycle of the built element, from design to operation and maintenance, through execution and delivery to the client. Among the various tools included is BIM 360 Field [22]. This web-based application allows contractors and project managers to track the execution of any type of work. It incorporates programs that help improve quality, safety, and delivery to the client. It allows tracking of task lists and checklists.

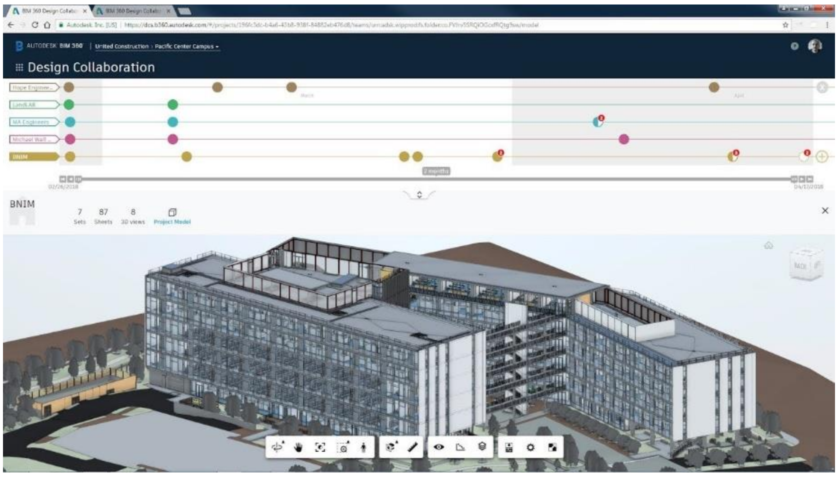


Figure 7. Example screenshot of BIM 360

- Synchro Pro [23]

  Synchro Pro, developed by Synchro Software, is a planning and execution control software for any type of construction element. This software allows working in real time, with 4D functionality, in addition to offering teams the ability to plan, communicate and manage tasks in an agile and efficient way. Synchro Pro's main functions are: discovering, understanding and reducing risks; tracking live progress and conflicts throughout the project; integrating and coordinating professionals from different disciplines to work on a unified project; improving environmental, health and safety conditions; increasing productivity; identifying points of conflict in space and time; and, finally, ensuring delivery deadlines for major projects. This tool allows the integration of planning capabilities into the BIM model of the built element, so that any planning changes are visualized in the model and any changes in the model are reflected in the planning.

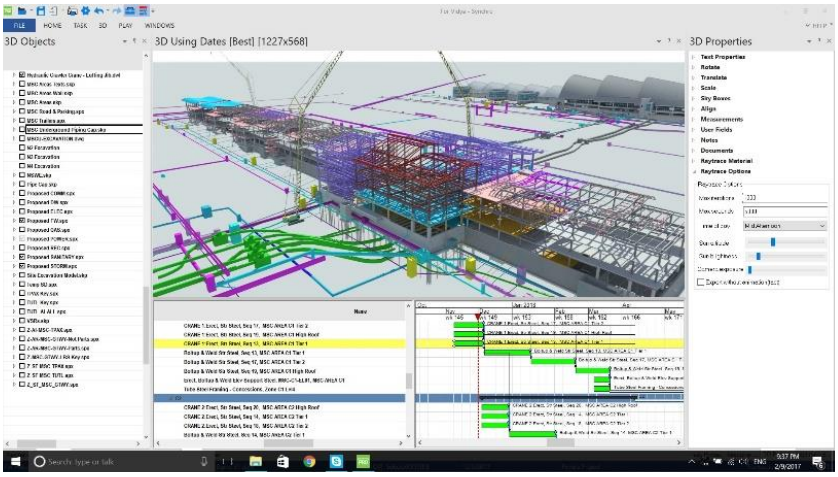


Figure 8. Example screenshot of Synchro

Due to the inefficiencies of the procedures and methodology currently used in the construction sector to carry out the control and monitoring of the construction process on site, it will be necessary to have systems or tools to automate the capture of the geometry and current status of the construction process, and that allow the collection of data in situ of the state of construction of a work, have automated methods for the comparison of construction data with the planned data to detect the state of progress of the work, the interpretation of the data and decision making based on the information.

It is necessary to point out that most of the software devoted to the progress monitoring are also valuable for planning and several of them are described in the corresponding chapter (3.2.5)

4.2 Quality Monitoring

Quality Control on site could be defined as the technical verification (both of the materials and their execution) that the work has the specific technical characteristics necessary to avoid future failures, bad methods and deficient construction practices, and thus ensure the quality of the final product.

As far as construction is concerned, it is a generalized opinion that its quality is, on average, below what would correspond to an industry of its importance and what the users would wish. The main problems associated with the quality of the construction are related to poor productivity, budget overruns, quality related issues, and schedule overruns. As a result, the quality control currently exercised in construction is generally unsatisfactory. [24] [25]

The requirement for quality control should be implemented as a general rule, to avoid not only user dissatisfaction, but also risks and losses due to poor or non-existent quality control in construction works. Quality management currently follows the ISO 9000 series [26], with which practically all quality systems are developed. This ISO series has evolved by changing many of the aspects such as approach, structure, requirements, or documentation system. In 2015, the latest revision of the standard has been published and has substantially transformed the quality management that has been performed until today. This management focuses on the entire process, not only on the execution, which will be the subject of analysis in this project.

Despite the importance of this task to achieve an optimal construction process, as is the case with the progress control in the construction phase, the quality control of the executed elements is a process carried out by visual inspection. This activity, besides not being very accurate, is not proactive and does not provide any feedback to the model.

Currently, systems or digital tools for pattern recognition based on non-intrusive techniques (images, ultrasonic devices, 3D scanning, thermography, etc.) are beginning to appear on the market, but their use in the construction industry is hardly existent. In addition, these systems lack high-level reasoning that does not provide or interpret the information obtained and therefore does not support decision making. It should also be noted that the few cases in which digital systems are utilized to control the quality of execution are used at the end of the construction, when, if any failure or error is detected, the costs of repair or correction are high.

One of these systems is scan-to-BIM, also called reverse engineering. It consists of scanning existing objects which allows to establish a non-existent element or missing components or geometrical deviations. This system is also commonly used in quality control to assess the conformity of an item built with information from a given CAD -BIM model or to detect any manufacturing defects, in the industrial sector.

The most commonly used acquisition technology for scan-to-BIM is LiDAR, which provides a sub-millimeter accuracy. Currently it is more focused on industry due to this high accuracy, although it is becoming more and more widespread in the construction industry.

In the construction industry, data acquisition systems are mainly used to analyze existing sites, structures, or infrastructures in different phases of construction. The use of these built reality acquisition techniques is mainly focused on minimizing the number of earthworks required. These types of technologies are also starting to be used to monitor construction sites, allowing the early identification of deviations from planning and, therefore, reducing the cost of corrections. This is done by comparing the current state of the construction with the initial projected state and going from a planned model to a construction model. All these uses are focused on the monitoring and supervision of the execution, and not on the control of the quality of the execution.

The application of infrared thermography can be used to achieve reliable and accurate assessment of buildings under construction and structures [27]. The principle of the infrared thermography technique is the detection of energy using an infrared scanner and the mapping of temperature contours on the surface of an object in order to detect whether an element or structure is damaged. Considering the applicability of infrared thermography, the analysis of exterior wall finishes and the study of the condition of roofing systems can be performed.

Other studies such as the one carried out by B. Tejedor [28] have explored the applicability of non-destructive techniques such as the heat flow meter (HFM) and quantitative infrared thermography (QIRT) to evaluate the difference between the predicted and actual thermal transmittance in the execution phase, allowing to quantify the gap between the design and the actual U-value of the facades of a new passive house before its operational phase.

There are also other non-destructive systems to verify the quality of the execution, such as Ultrasonic testing for air leakages detection in installation of doors or Windows. As indicated in the study by K.Stanforth [29], by using an ultrasonic sound generator that emits sound waves, a sound pressure is created and a calibrated instrument on the side of the door or window to be examined registers the leaks through the assembly.

In addition, some research about the use of AR systems based on BIM models to optimize the construction process and quality control of the construction site are being strongly deployed, such as the one developed in the research project INSITER [30]. By integrating the data obtained from laser/thermal/acoustic scanning into BIM models, the aim is to transfer the knowledge offered by AR for self-inspection systems used in the industry to the construction sector and improve the quality of the construction site.

It has been found that some of the technologies are available, but not integrated into the construction industry for use in the on-site quality control process. Furthermore, the cost of these systems is high and requires specialized knowledge on the part of site workers, which implies the need for a high investment in training and licensing. Unfortunately, the construction sector is very traditional and reluctant to change and there is a significative lack of knowledge about the use and benefits of this type of digital tools, which are the two major barriers to its implementation.

The lack of systems and tools to perform quality control in the construction sector in an optimal and simple way makes it necessary to define measurement and diagnostic instruments that, supported by self-inspection methods and analytical techniques, allow quality control during the construction phase. To achieve this objective, existing methodologies oriented to distinguish surface defects must be developed to provide real-time information on the integrity and possible problems of the execution process through integration with machine learning and deep learning.

4.3 Safety and risk detection and prevention

An inherent feature of the construction sector is the complexity of the on-site process, in which a large number of actors are involved, so the purpose of carrying out a correct health and safety prevention on site becomes more complex. In addition, the construction site is a constantly changing work environment. Due to its peculiar characteristics, the construction sector leads the indicators of incidents and accidents rates, which implies a significant increase in the cost for companies, workers and society. This high incidence due to the lack of safety and risk prevention produces at least 60,000 deaths in the construction workplace worldwide [31] in addition to a high number of serious injuries. As noted by the European Construction Sector Observatory (ECSO [32]), 75% of construction companies strive to meet OHS requirements, but 40% of construction employees do not work safely. To address this issue, OHS training for construction needs to be increased by 60% [33]. As an example, the following table shows the occupational accident rate in Spain [34]

Periodo: diciembre 2019 - noviembre 2020

Sector	Índice de incidencia total	Variación porcentual (*)
Agrario	4.295	-13,9
Industria	4.317	-17,2
Construcción	5.497	-15,3
Servicios	1.675	-24
Total	2.359	-20,5

(*) La variación se calcula respecto al periodo de doce meses inmediatamente anterior (diciembre 2018 - noviembre 2019)

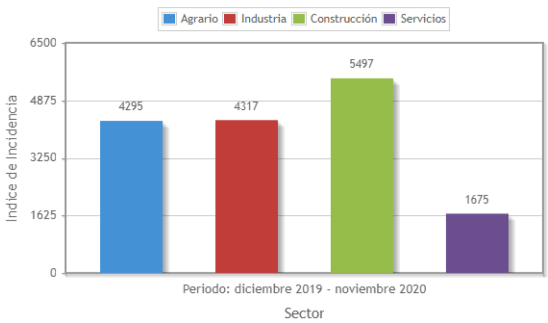


Figure 9. Occupational accident rate statistics in Spain [34]

These data demonstrate the need for a change in health and safety control during the construction phase.

Different studies indicate that accidents in the construction sector are not originated from a single cause and, as a general rule, each accident is the result of the concurrence of several primary causes, such as the permanence of the worker in a dangerous area, the absence/deficiency of collective protections, the non-compliance with work procedures and instructions, as well as the lack of control of compliance with the safety plan, among other reasons.

In the vast majority of cases, health and safety in construction is carried out in a reactive rather than proactive manner. This area is often limited to monitor the risks at an exact moment in the construction process, without foreseeing the possible risks that may arise. Health and safety risks in any sector of activity, and even more so in the construction sector, do not remain stable, but are constantly changing and evolving, as is the case with the construction site itself during its development. In the vast majority of cases, measures and actions focused on safety and health control are taken too late, when the risk has already occurred, so that safety control is not effective. Therefore, reactive actions to control or minimize a risk can only, at best, prevent the risk from recurring but they do not prevent the occurrence of new risks that may arise.

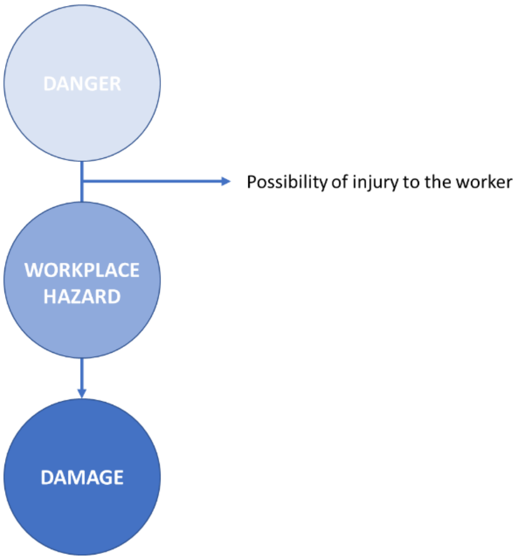


Figure 10. Hazard-risk relationship

Recent research has shown that a large proportion of safety hazards go unrecognized and unmanaged in complex and dynamic construction environments and that construction workers often fail to recognize a significant proportion of the hazards in their work environments, this makes it difficult to control the safety conditions at the construction site. The main reasons for worker failure to identify and recognize hazards are lack of attention to certain types of hazards, lack of awareness of the full range of potential hazards, and the perception that certain hazards impose low levels of safety risk. [35] [36].

Not knowing where the personnel on site is at all times makes it difficult to take safety measures in time, or to warn of possible dangers. Falls, collisions with equipment or loads, entrapment and electrocution represent more than 50% of all fatal accidents that occur on site. [37]

There are methods such as prevention through design (PtD) [38] and safety planning and training that provide effective means and tools to achieve safety and health prevention. However, in the vast majority of occasions, technologies focused on safety and health control are used too late, when the risk has already occurred, so that safety control is not effective. [39].

Studies have shown that a good implementation of Health and Safety in BIM, allows to mitigate the risks of a building from its origin, from the design phase. Moreover, by performing a virtual construction of the building, the detection elimination and mitigation of the risks generated in the life cycle of the building, especially during the execution phase, are enhanced. On the other hand, the creation of a single model where all the integrated disciplines come together, including health and safety as another discipline, encourages collaborative communication between all the agents involved in the process, such as contractors, construction managers, management and safety coordinator from the very beginning. By also allowing the real-time integration of the Health and Safety Coordinator in the project phase with the design team, the compliance with legal obligations in the field of safety is enabled.

In 2015, BIM-based fall hazard identification and prevention in construction safety planning [40] was published. The authors investigated the potential of automating hazard identification through BIM, for which they developed algorithms for checking safety rules. The contribution of this work is the development of an effective automated checking rules framework that integrates safety in BIM and provides professionals with a method for the detection and prevention of fall-related risks. Along these lines, different researches have been developed showing the potential of BIM in occupational health and safety [41] and a number of methodologies [42], systems and tools have been developed to implement safety and risk detection and prevention in BIM models.

Some of the most relevant systems are described below:

- CerTus [43]

  Certus is a software from ACCA Software to develop safety plans from a BIM IFC model. Certus allows the study and analysis of the 3D/4D model for the development of the safety study, the integration of safety with the project through the IFC standard, the contextualization of safety plans, document management and supervision and control of the safety study during the execution phase. The elaboration of a safety plan with CerTus is a simple and fast operation which allow to start from a standard plan, intervene in a guided way to configure and customize it with the data related to the actual location of the project and the work and quickly obtain a safety plan perfectly contextualized in the BIM project.

  By using the CerTus software and its various plug-ins, the following documents can be created during the development of a construction site:

  - Safety and Coordination Plan
  - Operational Safety Plan
  - Single Document for Interference Risk Assessment
  - Planning of the works (GANTT Diagram).
  - Estimated safety costs
  - Reports for the assessment of regulated risks.
  - Safety data sheets
  - Technical table on excavations.
  - Emergency and evacuation plan.
  - Technical regulations for road works signage.
  - Forms for safety coordinators.
  - Forms for companies

  CerTus has specific plug-ins for various tasks in the development of the work, such as CerTus-HSBIM (Safety) and Certus-PN (Scaffolding). CerTus-HSBIM is the tool for BIM environment to eliminate or reduce occupational hazards. With BIM technology, the design coordinator can nowadays either assist or help to

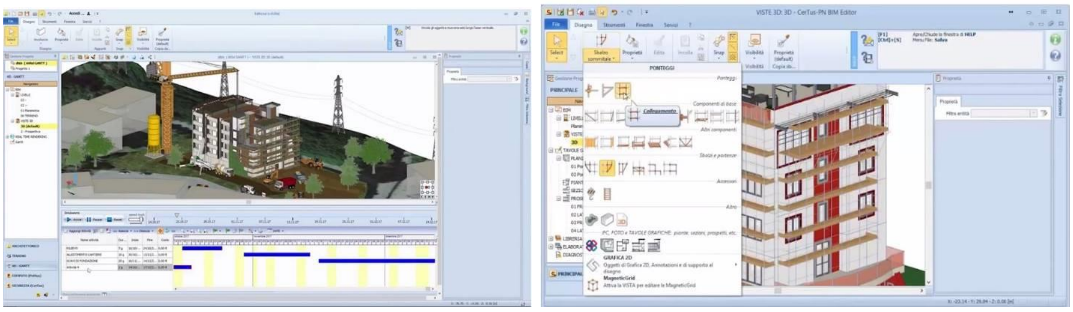


Figure 11. Example screenshot of CerTus HSBIM and CerTus PN

- Synchro Pro [23]

  Synchro Pro, the software described in section 3.2.1, in addition to having functions for execution control and planning, has functions for control and security, the functions of which are as follows: discovering, understanding and reducing risks on site; following live progress and conflicts throughout the project; integrating and coordinating professionals from different disciplines to work on a unified project; improving health and safety conditions. The simulation of alternative scenarios allows project planning taking into account risk analysis and occupational safety practices.

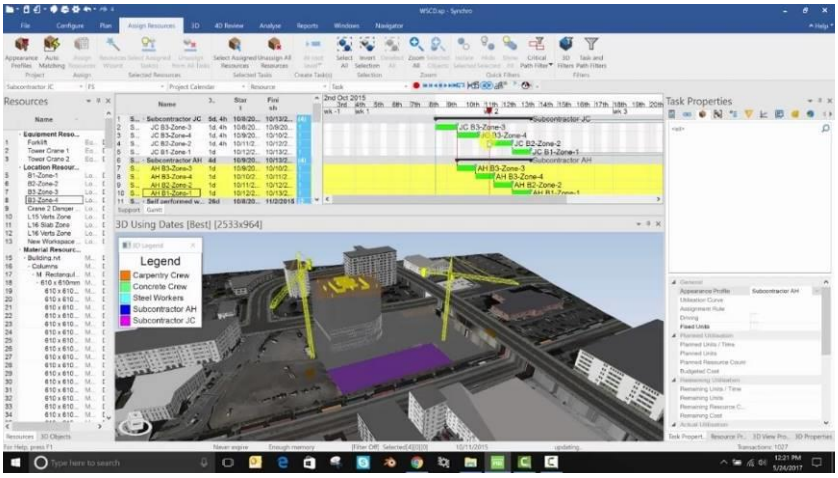


Figure 12. Example screenshot of synchro Pro

In the construction industry, PPE (personal protective equipment) is beginning to be developed to facilitate the acquisition of information from operators for safe site management. Because PPE is the personal protective equipment that workers must wear at all times while inside the worksite space, it can be used to collect important information that, when properly handled, can help to control safety and detect and prevent risks. Examples of PPE being developed include the following:

- SmartHelmet [44]

  SmartHelmet is a smart safety helmet for construction and mining created by the Chilean company Geniot Tecnología, which ensures the safety of workers. By incorporating sensors in the helmet, it provides real-time information on exposure (UV rays, temperature, noise and pressure). In addition, it allows to know if the worker is wearing the helmet and the route and location of the workers allowing in real time to send this data to a platform in the cloud, where it is processed and converted into information to manage the safety conditions of workers. The different sensors installed in the SmartHelmet case allow to know in real time the following information:

  - Knowing location and movement by Geolocation

- Detect possible blows and falls

- Monitor worker environmental exposure conditions (UV rays and environmental noise, temperature and altitude).

- Define virtual work zones

- Create and define rules and conditions in specific zones

- Analyze operational deficiencies

- Analyze opportunities for improvement

- Worker's activity resume

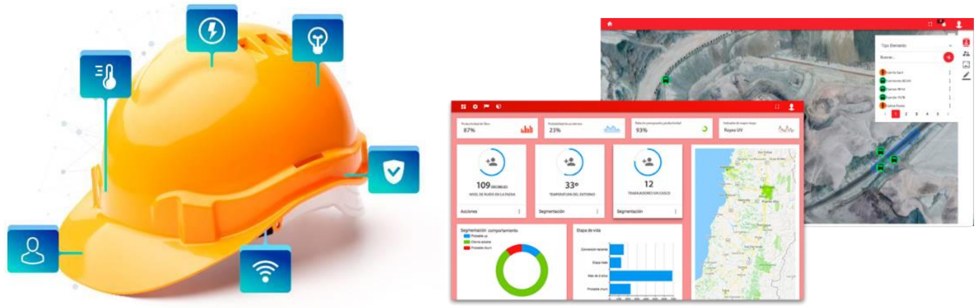


Figure 13. Example screenshot of SmarHelmet

- Daqri Smart Helmet [45]

Daqri Smart Helmet is a safety helmet created by the company DAQRI, which has an intelligent assistant AR (augmented reality) and VR (virtual reality), connecting workers with the surrounding work environment giving useful information in real time to speed up and simplify the work. A key objective of the Daqri Smart Helmet is to give workers visual instructions or signals to carry out tasks and alert them to hazards. By means of different sensors the Daqri Smart Helmet is able to record and interact in 360 degrees with what is happening outside and a "thermal" vision that simplifies the performance of some specific tasks. The worker is thus able to evaluate, as if equipped with X-ray view, pipes and machinery verifying the correct functioning. In addition, the helmet creates a complete map of the entire environment: from the structures being completed to those that have just been sketched, being able to transfer the information to a digital model, and immediately share the data recorded with the video camera and microphone provided. A key objective of the Daqri Smart Helmet is to give workers visual instructions or signals to carry out tasks and alert them to hazards.

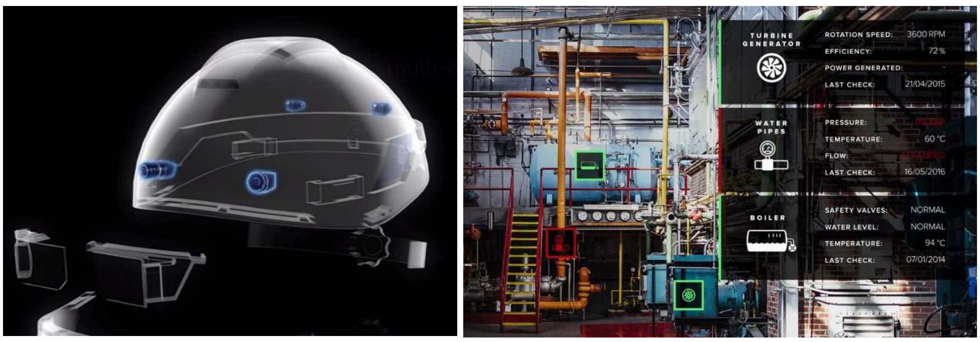


Figure 14. Example of Daqri Smart Helmet

- Asp- 030 Babaali [46]

The helmet manufacturer China Babaali has created an intelligent construction helmet, which, through technology, bluetooth, wifi, or 4G/5G and various sensors and cameras, allows to know in real time various information about the worker who wears the helmet and its environment. The Asp-030 helmet has the following equipment and sensors:

- Bluetooth / Wi-Fi / 4G / 5G technology.
- Built-in front camera for video data collection and SD card for storage.
- Real-time audio and video data delivery to cloud server.
- Real-time communication between worker and control center.
- Harmful gas warning sensor.
- Emergency reporting system transfers SOS to the back-end server for help.
- Location function based on Wi-Fi, AHRS and GPS.
- Micro USB charging and data transmission.

Figure 15. Example of Asp-030 of Babaali

- WakeCap [47]

WakeCap, launched in 2017, is an Autodesk Technology Center resident project. WakeCap is a smart helmet-shaped monitoring device that tracks proximity between workers to improve efficiency and safety. This helmet-shaped PPE is intended to detect nodding in drivers who are falling asleep. It also features non-intrusive technology that offers an innovative solution for improving worker safety and streamlining site activities, which inevitably leads to productivity gains and cost savings. It also provides valuable information on the geolocation trends of personnel on site, allowing you to tailor and optimize your on-site logistics activities.

Figure 16. Example of WakeCap

- Smart & connected Safety Shoes [48]

  French company Intellinium has created a safety boot that can protect and save workers' lives. Starting from the main idea of workers' safety, they have transformed traditional safety shoes into connected safety shoes, knowing that this device will be the hub for other smart PPE, such as smart gloves or smart watches.

  Leveraging the best integrated hardware and software technologies, within the digitalisation of construction, they have replaced "different legacy equipment" (such as emergency button or panic button) into "safety apps".

  Smart Safety Shoes have different sensors and can provide the following information:

  - Smart Man-Down. Once the shoes detect that the worker has fallen or is standing still for too long, the shoes vibrate so that the wearer can cancel the alert. If the wearer does not respond to the warning, the alert is automatically sent to safety control.

  - Intelligent panic button. End user can send "SOS" to alert his to the company and other workers.

  - Mass alert emergency notification with real-time recognition and position of the worker.

  - Remote equipment status check.

  - Battery level alert.

  - Two-way communication channel workers / workers and workers / organization.

Figure 17. Example of Smart & connected Safety Shoes de Intellinium

- Smart safety vest [49]

  Virgina Tech has developed a smart safety vest that warns workers for several seconds in the event of a risk of impact or collision with a moving object. The vest, along with the creation of the InZone Alert system, can alert workers through different types of alarms such as flashing light, audible or physical alarms, or vibrations of their clothing if a car is approaching too fast or too close to their position. Through the use of short-range radio signals, communication between the vest and the vehicles can be integrated, otherwise it can also warn and alert the driver of the vehicle that he is in immediate danger of causing an accident. In addition, the GPS-like positioning of the vest can monitor in real time the location of workers in relation to vehicles and other site equipment and keep them out of danger zones.

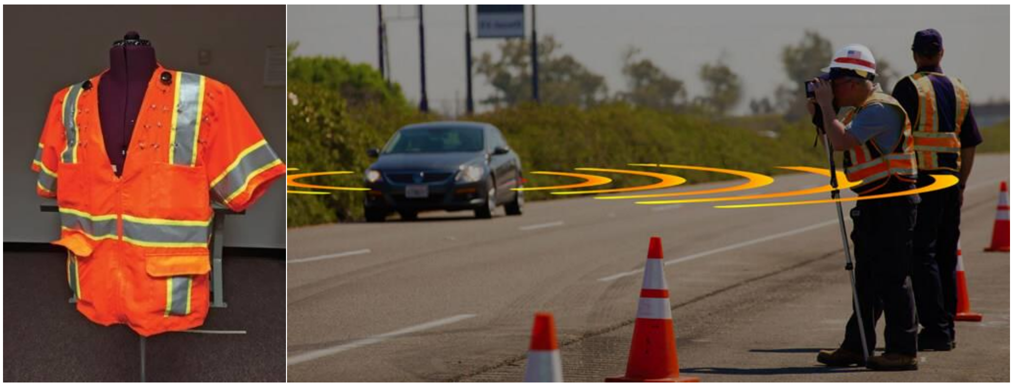


Figure 18. Example of Smart Safety Vest de Virginia Tech

Although it has been detected that in the market there are several construction site equipment with sensors, focused on improving the safety and health of the construction site, at present, there are few processes and methods to support predictive risk analysis at the construction site that allow the correct control of health and safety at the construction site [50].

Any preventive action aimed at minimizing risk in the work environment must begin with knowledge of the problem to be solved, which is why it is vitally important to have data and information on what is happening at the site, the activities being carried out, the people who are working, etc. A large part of the risks that arise with construction work are the result of poor planning. That is why it can be said that a well-planned construction site is, in general, a safe construction site.

Therefore, it will be necessary to develop a digital twin environment of the construction site that allows safety management by quickly defining safe work activities based on production planning and safety standards as indicated by S. Zhang [51]. To achieve this, a network of sensors will be needed to identify changes on site and update the digital twin model. It could be done by using machine learning technologies to predict and anticipate potential hazards that might arise on the site, alerting workers and machine operators through portable devices and actuators.

4.4 Scheduling and control of the use of equipment

Construction resource management and time scheduling require optimization, which is focused on evaluating the best possible utilization of the equipment and materials needed to achieve a predetermined objective. At present, in the vast majority of cases, the mistakes come from focusing the planning only on the execution activities themselves, without taking into account that these activities are constrained by other activities, agents and resources.

A determining aspect for the correct development and workflow within construction sites is the management of the use of the equipment and materials needed on site. In many occasions, due to a lack of planning of the work and the management of equipment, machinery and materials, some work has to be stopped because some of the materials and machinery are missed, unavailable, or in an unknown location.

The management of activities and processes allows structuring the production operation through the study of its nature, evaluating the necessary conditions for its execution: procedures, tools, raw materials, personnel skills, process continuity. Thus, it is key to detect the aspects where it is difficult to reach the quality, to obtain the expected cost or to finish on time.

The timely supply and adequate location of materials on site has a direct impact on the proper execution and development of the work. This has influence on the productivity and correct development of the work, allowing the worker to have the necessary materials to carry out his activities at the required time.

The timely and adequate supply of materials has a direct impact on the good work execution, having influence on the productivity to the extent that it provides the worker with the necessary elements to carry out his activities. Having the right material in sufficient quantity ensures the continuity of the work in accordance with the established program. On the contrary, the lack of material supply causes the discontinuity of the works, the decrease of the workers' performance, the disorder in the execution, the presence of incomplete tasks, causing quality problems since the works cannot be finished due to the existence, previously, of other incomplete works. The correct supply and availability of material during the development of the work is directly related to the quality of the construction process [52]. Appropriate scheduling facilitates construction with a minimum of problems, since by anticipating the activities, it is also possible to anticipate the purchase of materials in the quantities calculated in the schedule at the best prices obtained. With the information resulting from this process, the materials management tasks are simplified, although it is when they have a greater relevance [53].

Currently in the construction industry, the scheduling and control of equipment and material usage is set by site managers, based exclusively on previous knowledge and experience. However, this is done with limited knowledge of current and future site conditions and under great uncertainty.

According to several investigations, the greatest inefficiencies in the control of equipment on the construction site are caused by the lack of control and planning in the use of large equipment and machinery, especially cranes or in equipment to perform large earthworks.

The level of congestion on construction sites is increasing due to the effort to make better use of available construction space and reduce project lead times. The tower crane is a critical element for the efficiency of construction site processes from both an operational and economic standpoint [54], as crane operators have to work in very complex three-dimensional spaces with numerous areas of potential collision and in many cases many of the operations involved depend on moving material from one site to another within the construction site. The proper location of tower cranes within the site environment is a problem that has a direct impact on the optimization of the site process and difficult to overcome [55]. The availability of a schedule of activities for this type of equipment and a plan for lifting heavy loads facilitates the overall management of the work. Thus, it will reduce the movements necessary for the transport of materials, limiting the transfers of this equipment, which is a great cost in time and money [56].

Therefore, it is key to optimize the processes regarding the tower crane since they have a relevant role. This will require real-time planning and replanning of crane operations based on the information provided by the virtual models and the real-time information recorded by the crane itself. In this aspect, several solutions are being developed to optimize the use of this equipment, achieving an efficient use of the cranes, and allowing a continuous flow of all the work processes. Some of the commercial crane control and monitoring systems are described below:

- Vico Office [57]

Software from Trimble, Vico Office, offers an integrated BIM workflow for construction projects, extending the basic 3D model with constructability analysis and coordination, quantity takeoff, 4D location-based scheduling and production control, 5D estimating and design.

The BIM model is examined in Vico Office and quantities are generated for each type of building element in the project. For instance, it is possible to estimate the quantities of reinforcement, formwork, concrete and surface coating in a particular column. With those quantities known, it is a simple operation to arrive at the cost and time required to build it, as well as determine the material, labor and equipment needed for that area.

Vico Office allows the tight integration between the geometry of the model and the quantities, cost and schedule of the construction project. This means that whenever the design changes, and in construction it often does, the schedule and estimate are immediately updated. Vico Office helps organize material supply, delivery and equipment site management with analysis and reporting. This real-time data feeds the schedule and shows where potential problems will arise in the coming weeks.

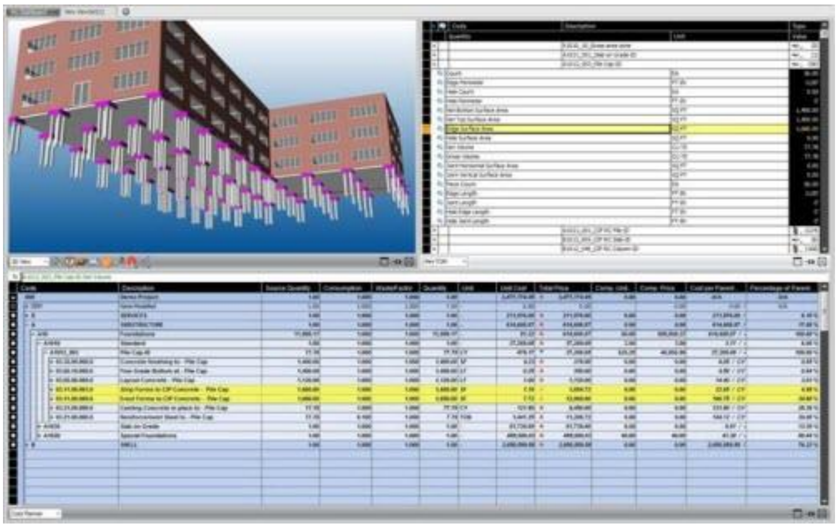


Figure 19. Example screenshot of Vico Software

- TruConnect [58]

  TRUCONNECT is a suite of products and applications created by Konecranes, an industrial lifting products company, designed for remote management and service to support maintenance tasks and promote improvements in crane safety and productivity. TRUCONNECT remote monitoring uses sensors to collect data on operating time, motor starts, duty cycles and emergency stops, providing visualization and information on crane usage. The data is transmitted to the Remote Data Center, where it is compiled and made available to the user.

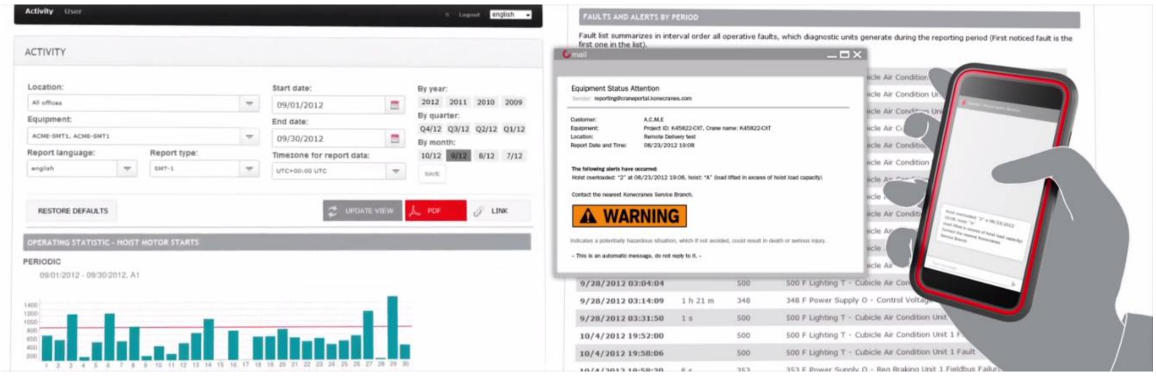


Figure 20. Example screenshot of TruConnect

- CoreBox [59]

  CoreBOx is a data logger that collects crane operation data created by overhead crane and hoist company GH Cranes. The cloud-based software makes it possible to obtain all incidents and tasks performed by the crane, improving the waiting time for fastening or material requirements that will be needed.

Figure 21. Example of CoreBox

As mentioned, in addition to the cranes, another cause that hinder the continuity of the work is the unavailability of the necessary machinery. The daily transport of the construction machinery to the work sites is very time consuming [60], and the lack of control and scheduling of the construction machinery use leads to unknow its location or status on site. Having real-time data on the use of machinery, real-time location, history of incidents, fuel level, alerts of out-of-hours use, etc., will improve the management of some operations carried out on site in the field of health and safety and productivity. In the market there are several companies that are beginning to offer services and products that allow this machinery to be smartized, as the ones presented below:

- JCB LiveLink [61]

  LiveLink is a software of the machinery manufacturer JCB that allows to manage the machinery remotely, being able to access in real time and remotely to different information about the status of the machine. This information allows to manage the machinery fleet in a more effective way and to plan the works. With this tool it is possible to control and obtain the following information from each of the machines available on site:

  - Location of all machinery in real time
  - Hours of use of the machine and current fleet
  - Alerts of position outside the security perimeter in real time.
  - Real-time after-hours usage alerts
  - Event history
  - Customized reports sent via e-mail on a daily, weekly or monthly basis
  - Fuel level
  - Utilization report (engine on and off)
  - Critical machine alerts
  - Fuel consumption report

Figure 22. Example of LiveLink

- ServiceLink [62]

  ServiceLink is a digital machine management system created by the industrial and construction machinery company AMMANN for simple and efficient machine management. This tool allows remote access to relevant information on machine maintenance, battery status and warranty duration through an online application. With this tool you can control and obtain the following information for each of the machines on site:

- Controlling the batteries and fuel of the machines. Reducing downtime and eliminating the need for expensive battery exchanges.

- Provides an online, real-time overview of machine status and maintenance records.

- Helps schedule maintenance for an entire fleet

- Data collection includes the time and times a machine is used. This helps supervisors remotely monitor job site activity.

- Accurately tracks the machine, allowing rental companies to accurately charge usage time.

Figure 23. Example of ServiceLink

- On!track [63]

  On!track is a resource and equipment management system for tracking and managing tools and equipment on a construction site created by Hilti, a company specializing in professional tools. It provides real-time information about the location of the equipment and who is using it. In this way, the tools and equipment of the work can be managed efficiently and be available at the place and time of the work necessary, ensuring that the work follows the planned scheme and reducing wasted time.

  This system works by attaching tags to the equipment and machinery, which turns them into smart assets and connects them to the cloud-based program, being able to track in real time the location and status of their assets.

Figure 24. Example of On!Track

Finally, as mentioned in this section, another of the main inefficiencies that affect the correct development of the work and the flow of the work is the lack of planning of the use and management of materials. Due to this, a series of tools and systems have been developed in the market that allow a better management and logistics of the material within the construction works. Some of these solutions are the following:

- Mobile Order Management [64]

  Mobile Order Management is an application of the Transporeon Group, specialized in logistics for the industrial and commercial sector. It allows obtaining immediate information on the current status of the material, expected time of the truck arrival transport order. It allows to perform a planning management thanks to immediate information and rapid response to unplanned actions and greater efficiency in the workflow through the planning of the day, as the response to changes in arrival times can be more flexible and agile.

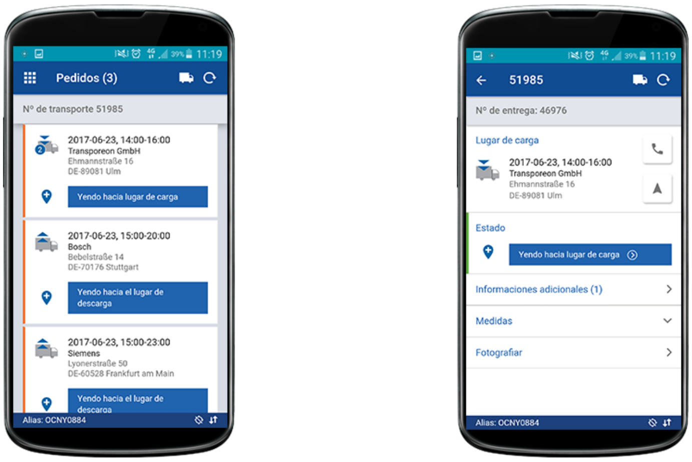


Figure 25. Example of Mobile Order Management

- SGM [65]

  Proton SGM is a software from Proton Engineer, a provider of engineering services for industrial plant projects and construction management that enables materials management through strict verification of entry into the construction warehouse. This tool also allows for proper reporting of available material and possible production at all times. In this way, storage time is reduced, optimizing the necessary space and having the material "just in time" for its use on site.

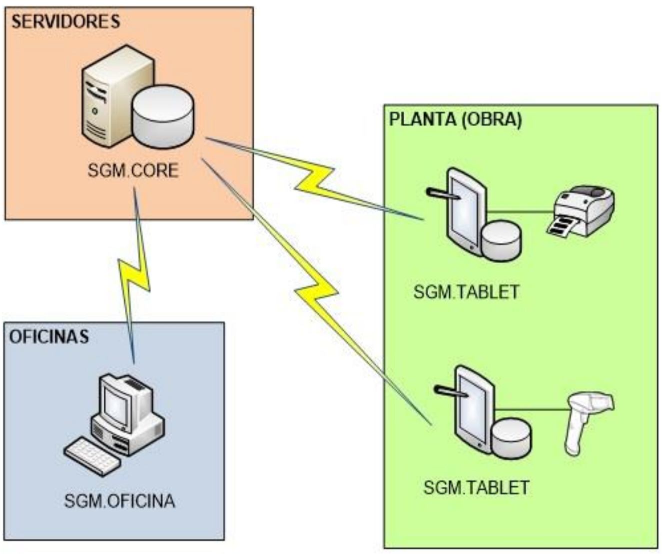


Figure 26. SGM operating scheme

Therefore, the improvement of the scheduling and control processes for the use of equipment and the management of materials on site for the building construction, through intelligent logistics solutions, will make it possible to establish a constant optimization of the flow of the work. It leads to have available the necessary equipment and machinery and the supply of the necessary material in the right place, at the right time and in the desired conditions. Being able to carry out an updated programming and control of the work will allow an optimization of execution times and consequently the reduction of deadlines, which translates into greater profitability in the work.

For all of the above, in order to optimize the scheduling and control of the use of equipment and material, it will be necessary to relate the large amounts of information from the BIM construction models with data from different sensor and camera systems installed on the equipment and machinery and the construction site to feed AI optimization algorithms based on convolutional neural networks or reinforcement learning methods to achieve automation in the use of equipment and the optimization of their scheduling and control. Technology and sensors currently exist for the control and monitoring of construction equipment, but it will be necessary to develop them and make them work together to achieve the defined objective.

4.5 Planning of resources and tasks

"*Long range planning does not deal with future decisions, but with the future of present decisions*." said Peter Drucker. Despite the importance of construction planning to achieve the objectives set, both in terms of time and cost, the construction industry has major shortcomings related to the planning and optimal management of construction projects, especially in the construction phase. An investigation by Kuenzel et al. (2016) [66] indicated that about 90 % of the construction projects analyzed suffered from coordination problems and failed project planning and project deadlines were exceeded. Other studies have shown that planning problems in construction projects in the construction phase are a root cause of project failure [67], and that planning problems, complications in project organization, and stakeholder disagreements cause projects to fail to meet their established schedules and budgets.

As in the case of health and safety management on site, changes and updates in planning are made reactively and not proactively, and these changes are made manually when a problem affecting the planning of work on site is detected.

The increased complexity of today's projects, the constant changes in the same derived from customer requests and the great variety of regulations make the planning and execution efforts even greater, in addition, the sophisticated technical requirements of the projects and the large number of participants and agents involved in them greatly affect the proper planning of the work. Other studies have identified that changes in site scheduling resulting from project changes, shifting personnel resources and inefficient use of labor or unforeseen events are primarily responsible for efficiency losses or decreased productivity on construction projects [68].

The planning of a construction project is understood as the set of activities related to the simulation of the work execution, anticipating all the tasks and activities necessary for its execution and establishing the appropriate order of them to carry out the work in the most optimal way in time and cost. This field is closely linked to Progress monitoring.

In the planning of the work execution, it is key to define the schedule of the set of activities to be performed, but thinking only in those productive work activities, which directly affect the company responsible for the execution, that is to say, the constructor. However, his activities are definitely constrained by other agents involved in the work, such as the promoter, the project drafting team, the construction management team, subcontractors and suppliers of materials and machinery, the administration, service companies, etc. Thus, the planning must take into account the expectations of all the agents involved in the construction site an

The construction phase requires planning and control by different stakeholders, in different roles of the organization and at different times in the life of a project. Planning generally tends to focus on the overall objectives and constraints of the project. But it is necessary to count on the collaboration and participation of all the agents to carry out a correct planning, and that the same one serves to reach the established objectives. Therefore, in order to ensure that the programming is the basic element of coordination between the participants in the work, the preparation, review and modification of the planning must be carried out in a coordinated manner, and the participation of all the agents involved will be necessary. This means having very specific objectives from the outset, a perfectly defined product (project), and the presence of all the agents in each and every phase of the building process.

The objective of the planning of a construction work is the definition of the activities sequence, the resources necessary for each activity, the estimated duration and deadlines of the tasks and the probability of finishing all of them within the established deadlines and budget.

In general, most construction companies use critical path method (CPM) scheduling tools to perform job planning. This method requires specialized and experienced personnel who can establish the parameters of the duration of the tasks and the relationships between them [69]. In addition, they do not have any decision-making tools that can learn from previous projects and use this experience to facilitate and improve the work of site planning. Despite the fact that construction companies usually apply these CPM tools at all levels, from general project planning to production control, through phase planning, the CPM tools do not adjust the work planning in an effective way [70]. This results in reactive rather than proactive changes and updates to activity schedules, which means that information can be visualized, but not automatically updated, requiring manual data entry.

In view of the lack of effectiveness of the traditional methods used so far, some companies have introduced the Last Planner® System (LPS) for production planning and control, which applies the principles of Lean Construction [71]. The most advanced construction companies that have opted for the digitization of their processes use software systems that integrate BIM models with LPS [72] . These systems and specific planning software allow the temporal scheduling of tasks, the detection of interferences and inconsistencies, the estimation and control of execution deadlines, construction logistics, dynamic coordination for the resolution of spatial conflicts and workspaces, and the simulation of construction execution (virtual construction). The following are some of the BIM systems used for the planning of construction projects although the vast majority are based on a combination of scheduling software (MS Project, Primavera, etc.) with a BIM model:

- Autodesk BIM 360 [21]

  Autodesk BIM 360 is a software suite that provides solutions for all phases of the built element lifecycle, including site planning. BIM 360 Plan [73] is a cloud-based web application that supports lean construction practices. The application can be used on site to facilitate the creation of work plans, inventory requirements and task re-planning. Applying lean planning principles, the application implements a reporting engine to track project performance to identify trends and opportunities for improvement.

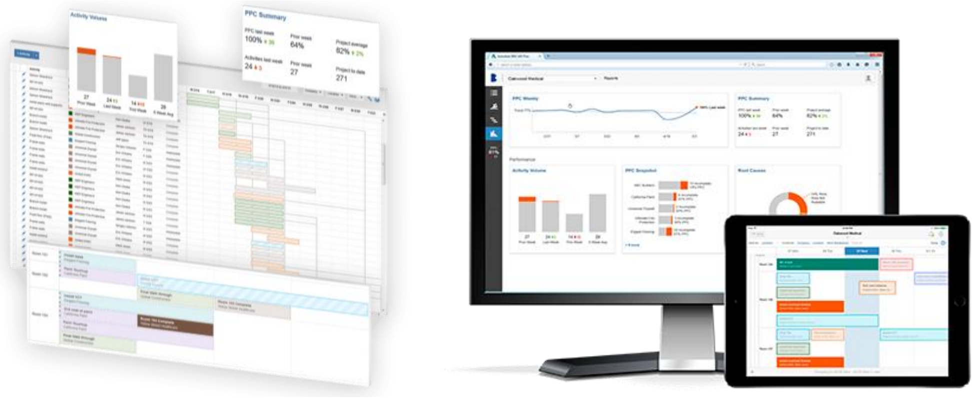


Figure 27. Example of BIM 360 Plan

- Navisworks [74]

  Navisworks is an Autodesk program that enables construction project control. Navisworks is an Autodesk program that enables construction project control. Navisworks project review software makes it easy for on-site stakeholders to review integrated models and data during construction to better control project planning.

  Navisworks® Simulate and Manage tools enable greater coordination, construction simulation and analysis of the entire project for an integrated project review. It features the TimeLiner tool, which links the BIM model to the schedule and performs construction simulations over time. It also links to project scheduling software (such as Microsoft Project or Primavera products) to import task data. In this way a record can be made of the eventualities between the planning and the executed work.

Figure 28. Navisworks example screenshots for the management and planning of the execution of a construction project.

- Bentley Navigator [75]

  Bentley Navigator V8 is a product of Bentley Systems, Incorporated designed for the review and analysis of a construction project. The program features highly versatile visualization capabilities, offering a more intuitive user experience and enhanced interactive quality of information. Users can analyze projects virtually to detect and resolve conflicts and simulate project schedules. Bentley Navigator enables the different teams involved in the project to perform optimal planning of the different activities and tasks, to improve the project, to know and make more reliable decisions, to reduce risk, to improve planning by avoiding costly errors, by simulating and resolving conflicts, simulating schedules and planning to eliminate the need for guesswork during the work execution. To improve the quality of decision making and improve the planning process, the program performs simulations of the construction process through animation to and overcome scheduling risks.

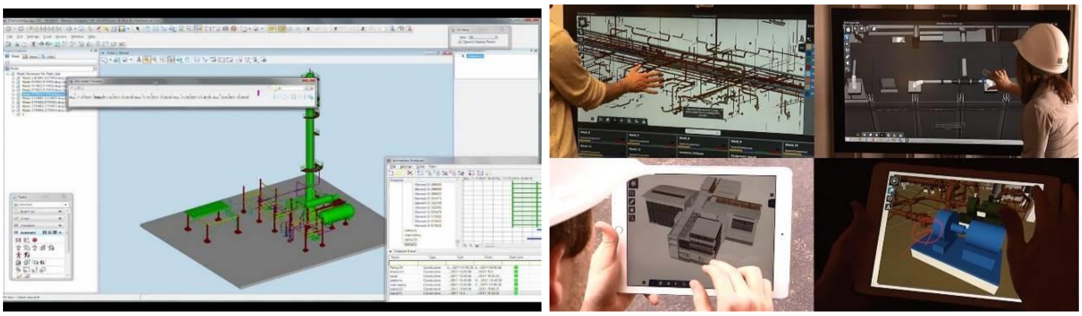


Figure 29. Example of Bentley Navigator

- VISILEAN [76]

VisiLean is a cloud-based construction management software that facilitates and supports lean production planning and execution through BIM integration. Visilean enables construction project management and allows teams to collaborate on planning decisions and provide real-time updates. VisiLean offers direct integration of collaborative planning workflow with BIM. VisiLean aims to support this workflow by providing specifically designed modules that support all phases of extraction production planning, including phasing, anticipation (including constraint management) and weekly planning. VisiLean enables real-time tracking of these plans through mobile applications and execution views, where teams can report progress and attach photos and notes.

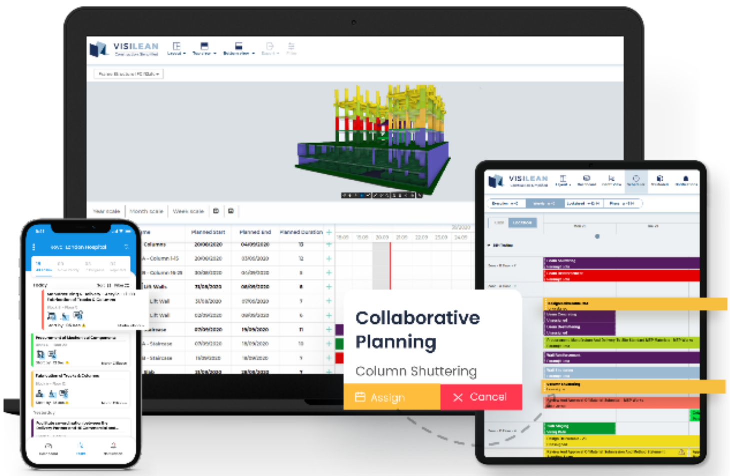


Figure 30. Example of VisiLean

From all of the above, it can be concluded that the planning processes for the construction of buildings have major inefficiencies that lead to delays in execution times and cost overruns to the construction site. The construction planning could be improved if instead of using the current methods, location-based planning and control methods (LBMS) were applied, as if they were used in some linear infrastructure projects [77]. Being able to predict through simulations the probable results of the design and planning alternatives, taking into account all the agents involved in the work (designers, suppliers, manufacturers, workers, equipment, spaces and work contents in a construction project) could facilitate decision making for the modification and adequacy of the work planning. This consideration will definitely lead to improve the final quality of the work, making the project meet the agreed budget and deadline.

Data-driven decision making provides added value in reducing uncertainties and minimizing planning deviations in the different construction phases. There is also a risk of confusing technology with technique. The added value provided must be based on a correct technique, and supported, complemented or based on reliable and contrasted data, provided by technology, generating reliability and confidence in the proposed solutions.

4.6 Methodologies and technologies for the digitalisation of the construction process

In this section the different technologies that can be used in the construction phase of the site will be analyzed in order to optimize the construction process and solve the problems derived from a low productivity and that can be useful for its application in the DBT platform.

4.6.1 *BIM*

To elaborate on one further digital tool Building Information Modelling (BIM) is providing solutions to create a platform for central integrated design, modelling, planning, and collaboration. BIM provides all stakeholders with a digital representation of a building's characteristics – not just in the design phase but throughout its life cycle.

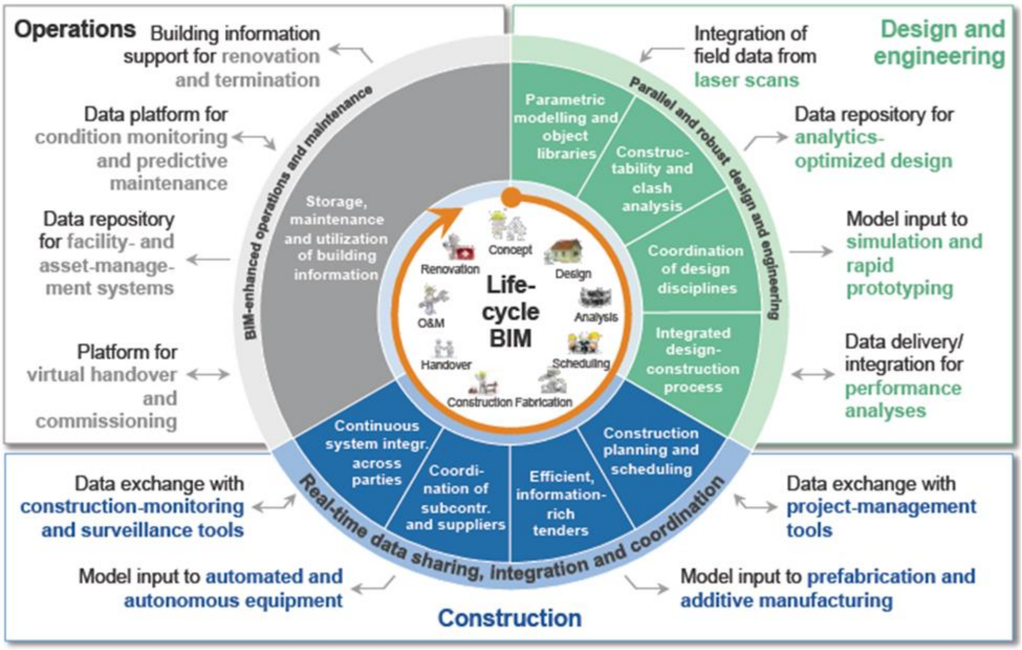


Figure 31. Applications of BIM along the E&C Value Chain. Source: The Boston Consulting Group

Although BIM uses have extended to include lifecycle management of built assets, the current state of BIM is not compatible with IoT integration, specifically because of its legacy formats and standards which limits BIM usability and extensibility with a semantic web paradigm.

Industry requirements for model interoperability have been partly fulfilled by commercial vendors, which try to facilitate seamless integration via import/export capabilities from one BIM tool to another. However, this can quickly become overwhelming as the number of tools and platforms shared amongst project actors increases over time. The IFC standard was specifically designed to deal with the industry's interoperability problem, including concepts across several well-defined application domains. Although the IFC schema has evolved significantly in the last decades, it still has not fully solved the interoperability problem for all application domains, with the creation of Model View Definitions (MVDs) being an arduous process. Additionally, the IFC format was designed for transferring model data from one tool to the next, and not to be modified or used dynamically.

The inclusion of Linked Data (LD) and Web Ontology Language (OWL) models has more recently tried to address these old challenges. A pilot study investigated the capabilities of semantic web, applied to acoustic building design closely tied to IFC concepts. Such an approach enables rule checking process to go beyond the schema scope, thus allowing for more flexible MVDs, which are crucial in including non-traditional application domains under the BIM umbrella. Many recent developments rely on IFC, which is seen as an underlying schema for structuring data, while its ontology representation – IfcOwl provides better interoperability and reasoning capabilities on top. As developments around this topic grew, it became apparent that ontology representations of the IFC schema allow for a flexible and more robust backbone for interoperability requirements. Due to being computer-interpretable, OWL models allow the inclusion of Description Logics (DL) rules, enriched semantic representations with a higher degree of 'meaning', while being part of The Semantic Web Stack for sharing resources over the web. [78]

4.6.2 *IoT*

Many studies consider the inclusion of IoT for a DT, as its increased adoption rate has made devices more affordable and their applications wider. Once again, interoperability is cited as the main challenge, due to the laborious efforts required to connect DT sensor data to simulations. Some authors propose a DT framework for manufacturing implementation, which relies heavily on IoT, and outline a comprehensive view of available technologies and their interactions within this field. On the construction side, a conceptual framework for integrating BIM models with IoT devices to monitor the real assets on site, but do not address technological issues has been proposed. In contrast to this some argumentations say that BIM is not ready to be integrated with IoT devices, due to its legacy formats, which are not aligned with the view of the semantic web. The status of distributed energy systems, for example, has been reviewed by other scientists who argue the need for a semantic web approach to ensure interoperability between all systems and agents exchanging information across grids. The IoT is considered here to fill the gap between the physical and virtual worlds, where IoT has the primary role in health monitoring by bridging physical component's sensors and actuators with its digital part. Additionally, IoT can be used to survey the way physical products are used by customers – and deliver further value to cost benefits for the multiple parties involved. [78]

4.6.3 *Integrated Project Delivery (IPD)*

Integrated Project Delivery (IPD) – an approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. (American Institute of Architects). [79]

The Key Components of IPD are:

- Multi Party Contract -
  - At least the Owner, Primary Designer and Primary Builder
  - Single Contract Amount Including Contingency
  - Profit at Risk for Partners to the Agreement
  - Guaranteed Costs for Partners Based on Audits
  - Shared Savings if Project Delivered Under Budget
- Implementation of Lean Concepts, Practices and Tools
- Intentional Creation of a Collaborative Culture

The Key Elements of Integrated Project Delivery Contracts consist of at least three parties:

- Owner
- Lead Designer / Architect
- Lead Builder / General Contractor

They may also consist of more parties in a Poly Party agreement. Example of other parties:

- Structural Engineer
- Mechanical Engineer
- Electrical Engineer
- Mechanical Contractor
- Electrical Contractor
- Concrete Contractor

4.6.4 *Machine learning*

Machine learning can improve designs overall to make spaces better for its ultimate human end users. Machine learning can also help workers figure out mistakes and omissions that might be present in the design before going forward with building. Instead, a construction company can leave that to machine learning which ultimately saves teams critical times that can be used for more productive tasks. With machine learning, the designers can even test various environmental conditions and situations in the model. The technology can help to determine if a particular element of the design is optimal or can predict if it could create an issue down the road. [80]

Machine learning has the potential to change the way that problems are addressed on the construction site, as long as contractors keep their data digitized, organized, and all in one place. Instead of reacting to problems that suddenly appear, contractors will be able to stay on top of potential risks, before they become major problems, thanks to tools like Construction IQ in Autodesk's BIM 360 environment for example.

The application of machine learning technology in the construction field is already actively underway. As a result of analyzing articles published in major journals up to 2016, it has been established that the machine learning technologies used mostly in the construction field include artificial neural networks (50.8%), genetic algorithms (21.8%), composite models (16.3%), fuzzy theory (8.2%), and support vector machines (SVMs) (2.9%). [81]

4.6.5 *Digital Twin*

A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity. The foundational elements of the definition are captured in the first sentence: the virtual representation, the real-world entities and processes it represents, and the mechanism by which the virtual and real-world entities are synchronized.

But this technology is not entirely new, as early as the 1980s, NASA was conducting simulations on digital twins. But in recent times , the technological leap has rediscovered the great potential of digital twins thanks to Artificial Intelligence (AI), Big Data and the Internet of Things (IoT), which allow industry 4.0 in general to make a breakthrough, and the Construction 4.0 transformation in particular

There are some documents where the Digital Twin concept was developed, for example ARUP [82]. This report presents the current state of digital twin in the built environment and explore ideas on what might become possible in the future. They set a framework to articulate what a digital twin is, and how to use a common language. The framework moves through five levels, from a simple digital model to act autonomously.

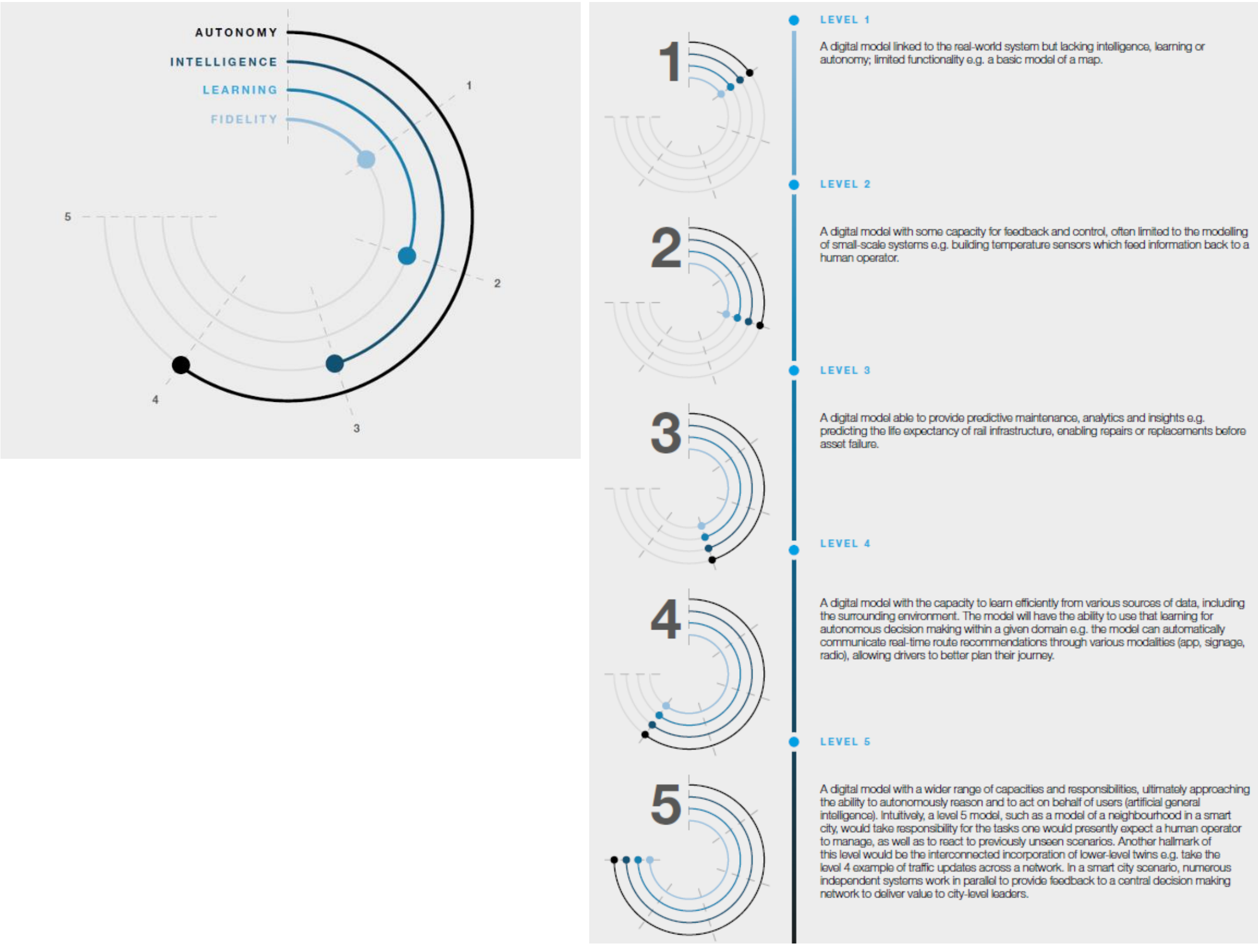


Figure 32. Digital Twin Concept by Arup

On the other hand, it talks about metrics in the digital twin development framework, these are autonomy, intelligence, learning and fidelity. Although these metrics are correlated, they should be treated differently as the development and understanding of digital twins grows. The concept of maturity means the development stage of the "Digital Twin" and no its level of complexity. The stages of development maturity run from the initial concept, through demonstration and development, and finally to commercialization. Digital twins can be highly intelligent and highly autonomous, but nevertheless, these are far from maturity.

The University of Cambridge, in particular the Centre for Digital Built Britain [83], published the "Gemini Principles" report in December 2018. This document shows the approach to information management throughout the built environment. All digital twins must have a clear purpose, must be reliable and must work effectively. For that reason, the "Gemini Principles" are simple, but their implications are long-range and challenging. They are descriptive, but agnostic in solutions, to foment the innovation and development over time. These will continue to evolve as long as they contribute to their development. The figure summarizes the "Gemini Principles". In addition, in the last months, this Centre publish different publications [83] about the integration architecture Pattern and Principles, A framework for Composition: A step towards a Foundation for Assembly, an integrated approach to information management: identifying decisions and the information required for them using activity, process model, etc.

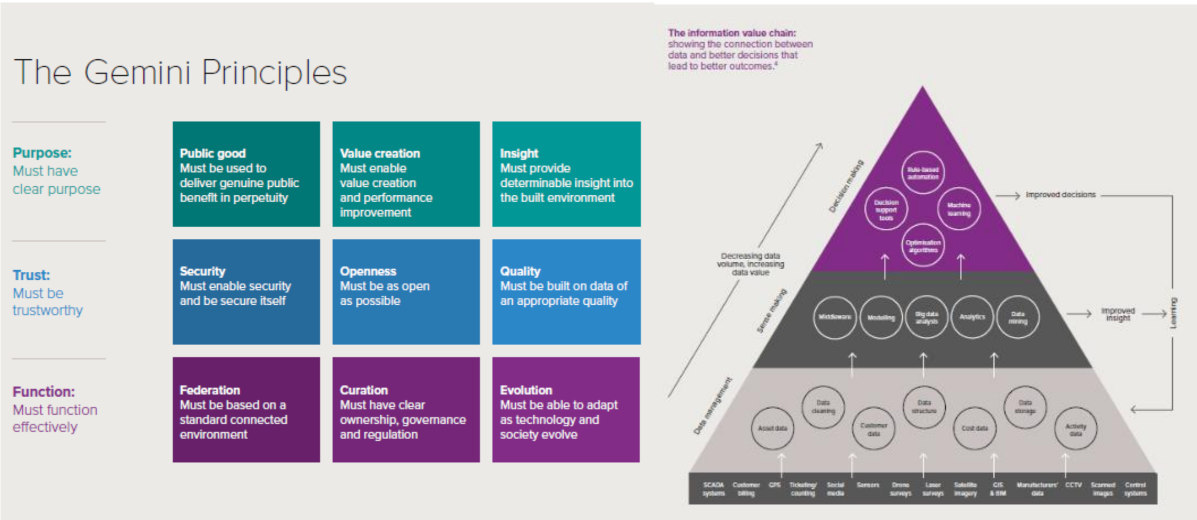


Figure 33. "Gemini-Principles" Cambridge University

Australia is leading the development of Digital Twin technology in the field of construction, to become a world leader through the Spatial Twin initiative. The government want to reduce construction project inefficiencies by 3-4% and those responsible of this initiative aim to reduce them 20%, relative to current processes.

In the field of Safety and Health, there are scientific publications [84] where reference models are proposed for the implementation of Digital Twin in order to improve the level of safety of employees in the construction site. The reference model proposed in this document consists of four main layers, the Process industry physical space, Communication system, Digital Twin, and User space.

In terms of Digital Twin and IoT integration, scientific articles [85] say that BIM integration with real-time Internet of Things (IoT) data from devices, presents a powerful paradigm for applications focused on improving operational inefficiencies. However, BIM and IoT integration research are still in preliminary stages. Emerging areas have been identified to address the integration of BIM-IoT devices, such as Construction Operation and Monitoring, Health and Safety Management, Logistics and Construction Management and Facility Management. The authors summarized 5 integration methods that are, using APIs and relational database, transforming BIM data into a relational database using a new data schema, and creating a new query language, using hybrid technologies and approach.

Furthermore, in terms of research projects it is remarkable the SPHERES project. It aims to create a platform oriented to the improvement and optimization of energy design, construction, building performance, and management, reducing construction costs and their environmental impact, while reducing overall energy performance. As it said before, this virtual information model joint with the reality, helps significantly in decision-making during each phase of the whole life cycle of the building (manufacturing, design, construction, maintenance, operation, adaptation and even demolition).

In the project framework is remarkable the report "The White Book of Digital Twin. Definitions for building", which aims to be a starting point for the creation of a standardized work environment.

Finally, it must be pointed out that there are three associations, two in Europe, Building Digital Twin Association [86] and buildingSMART International Digital Twins Working Group, [87]. The first one aims to develop an open technical-economic ecosystem space to advance the complete implementation of digital twins across all actors and all phases of the life cycle. The second one, which has published a comprehensive white paper, is focused on defining the mean of digital twin and form a strategic alignment to better unlock environmental and societal value for the entire built asset industry through the implementation of digital twins. Finally, the third one in the United States, Digital Twin consortium [88], is a global ecosystem of users who are accelerating the digital twin market and demonstrating the value of this technology. Members establish technical guidelines and taxonomies, publish reference frameworks, develop requirements for new standards, and share use cases to maximize the benefits of digital twins.

On the whole, it is important to enhance that a high scientific production has been identified in the field of the creation of the Digital Twin, as it is a revolutionary technology capable of improving processes from the moment of design to the maintenance phase. In 2017, research company Gartner already put Digital Twin technology, as part of the top 10 strategic trends and predicted that by 2020 there would already be billions of processes in relation to this technology. On the other hand, according to Markets and Markets [89], a company specializing in statistical research, it estimates that the market related to the generation of digital twins will grow to 35.8 billion in 2025.

4.7 Insight about the main inefficiencies and barriers of the process from the literature review

Based on the study for the analysis of the current construction process and the review of the literature, it has been found that the construction process on site has major deficiencies that affect the main areas of the entire construction process. These inefficiencies are considered as one of the most recurrent problems in the construction sector, causing deviations both in the budget and in the duration of the work. As a result, the works execution does not reach the expected quality.

As it has been analyzed, technological advances are making a great effort to solve or mitigate the consequences of these problems, but at present no appropriate solutions have been found to solve them. This is largely due to the complexity of some of these problems and inefficiencies, and the large number of processes and agents involved in the construction site, as well as the changes that occur at the construction site during the construction process.

Following the proposed research methodology, and based on everything analyzed and described above, the main inefficiencies and points for improvement in the current construction process have been identified. This information will serve as a basis for the conceptualization and definition of the requirements of the Digital Building Twin (DBT) platform to improve efficiency in the management of building construction processes.

The following list summarizes the main inefficiencies and points for improvement in the current processes in the construction phase that hinder the efficient construction, from the analysis of the literature review.

Regarding the Staff

- Difficulty to hire skilled workers and subcontractors
- Difficulties in controlling safety conditions
- Difficulties to know where the staff is located on-site
- Lack of collaboration between agents involved in the work phase

Regarding the Planning

- Inadequate planning of the work
- Lack of communication in task assignment
- Continuous changes and modifications
- Lack of execution control

Regarding the Material and equipment

- Tools, equipment's and machinery, loss or not knowing their location

- Material shortage or late supply

Regarding the External conditions

- Environmental factors (weather conditions, temperature, rain, wind, pollution, noise, workspace, etc.)
- Project size
- Permission management (Authorization, restriction on work hours, etc.)

The analysis of the state of the art of on-site construction processes and their digitization has also been used to identify the main barriers that limit the implementation of technology integration or digitization of construction processes in the construction sector.

The barriers to the implementation of digitization of the construction site can be summarized in these major groups: technical or technological barriers, functional barriers, economic barriers, and legal, social and/or environmental barriers, and the most relevant are the following ones:

Technical or technological barriers

- Large amount of collected data to be managed in real time and statically (data gathering, saved, analyzed)
- Technical difficulty in digitalizing the construction processes
- Difficulty in processing large data files in an agile and operational way
- Lack of development of the necessary technology and incompatibility between tools

Functional barriers

- Many different teams and companies participate, with different working procedures, (protocols, used programs, etc.)
- Lack of Iot (Internet of things) systems that work properly in the context of the changing on-site work.

Legal barriers

- Traditional contract no aligned with the actual needs
- Difficult to define the property of the information and the assignment of responsibilities.

Social barriers

- Low acceptance of change in the construction sector
- Lack of skills about the Digital tools in the activities of the construction phase.
- Need for complete integral change in the way of working on site

Economic barriers

- A significant initial investment of resources, time, and money
- High training costs and too slow learning curve
- Need for high investment in software and licensing

- Return on investment too low (or not proven)

5 Outcomes of the questionnaires

The objective of this chapter is to collect the results of the questionnaire designed within the BIM2TWIN project to gather the knowledge of the main inefficiencies that occur and affect the construction phase and that prevent the optimization of the construction process and to identify the main barriers that hinder the implementation of digitization in the construction process. All this with the objective of obtaining the necessary information for the definition of the user requirements of the DBT platform.

In this section the results of the questionnaire by category of questions are presented. Firstly, some overall data about the respondent categorization are shown in order to be able to draw the profile of the respondent and relate it with the answer to some questions in case they are relevant. Then, the following chapters point out the answers to relevant questions about the as is construction process and the outcomes are assessed to gain insight into the hinders of the overall process.

The results have been analyzed globally, and also by discretizing the responses by country, age, level of education, company size, role, and work field, in order to identify meaningful differences in the responses. It has allowed to fit the specifications of the DBT platform to different profiles, depending on these aspects. Nevertheless, in some countries, for some respondent profiles, there is not enough number of samples to consider that the data obtained are sufficiently representative. Therefore, in these cases the particular analysis does not have sense.

Regarding the methodology addressed, all the issues and topics covered in the questionnaire have been approached using the same methodology. The questions have been presented in such a way that the respondent can categorize their importance, and for this purpose the respondents were asked to rate the importance of each of the aspects presented using a numerical scale. In this way, a numerical rating was obtained, ranging from 0 to 10, with 0 being not at all important and 10 being the most important.

As described in the research methodology section, the questionnaire has been created with Google Forms and translated into English, French, Finnish and Spanish.

The following sections contain the results obtained from gathering more than 300 answers encompassing a vast range of profiles. as well as the main conclusions reached in each topic. Those insights have been used as a basis for the completion of deliverable D1.1.

5.1 Results of the participation

302 questionnaires have been completed, with the participation of people involved in the construction phase from more than 15 countries. Although the questionnaire was launched at European level, as expected, the highest response was obtained in the countries where the pilot cases of the B2T project will be carried out. The highest participation was obtained in Spain, followed by Finland and France.

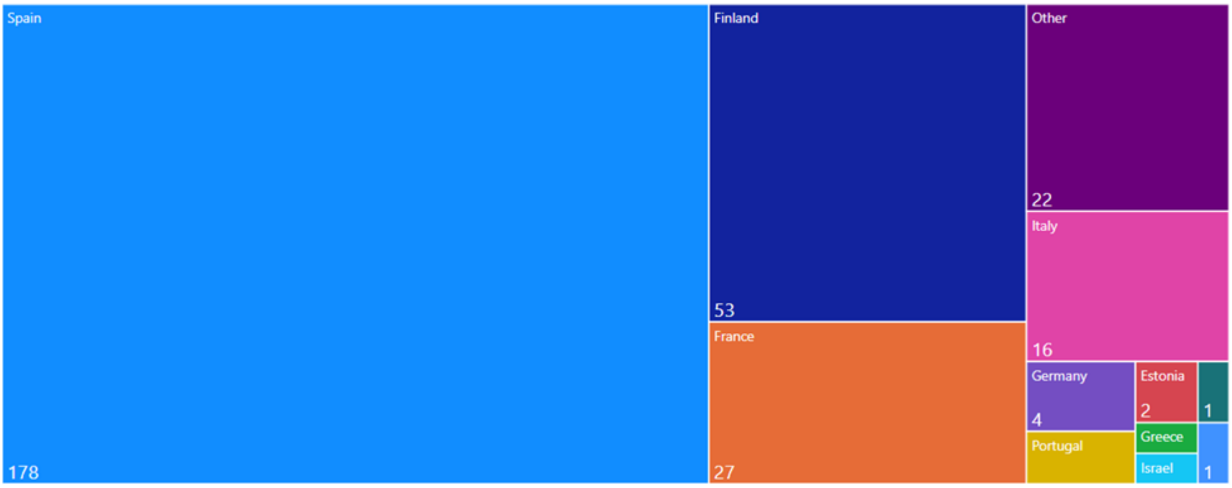


Figure 34. Results on geographic participation

In the drawings below the categorization of the respondents with regard to different fields considered relevant to make the analysis, such as studies, age, gender, role, and information about their company. Those graphics are achieved from the analysis of the questionnaire findings.

Regarding the profiles of the participants, more than 50% have a university degree and work in a large company with more than 250 employees (69.9%). Regarding age, the main age ranges are between 30 and 40 years old (25.24%) and between 40 and 50 years old (38.19%). As for the gender of the respondents, there were significant differences in the answers, with more than 75% of the respondents (78.32%) being male.

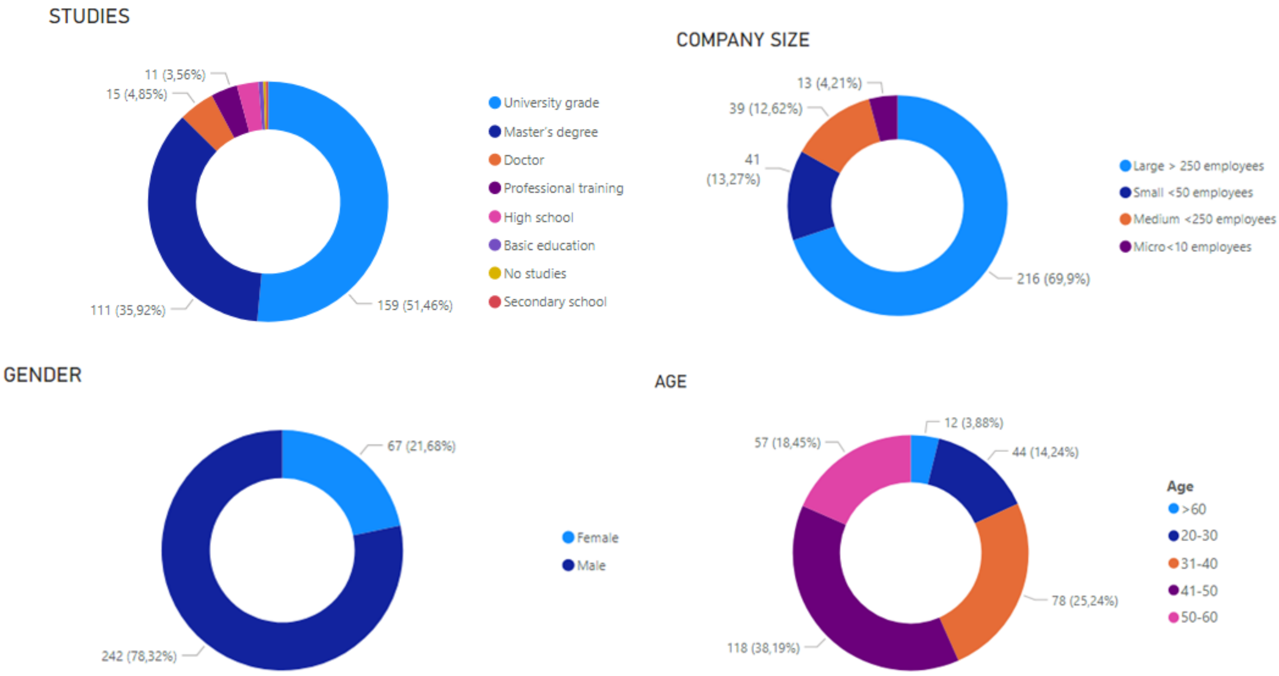


Figure 35. Participant profiles

Regarding the professional profile of the respondents, as expected, almost 75% of the respondents work in a construction company. Due to the need to increase knowledge of what happens in the construction phase, the dissemination of information was intensified among the project's partner construction companies and among the companies with which they usually work. Regarding the role they play, almost

50% of the respondents (48.22%) are technical staff, followed by the middle manager with 35%.The objective of this questionnaire was to reach people working in all fields of the construction process, having obtained the highest representation in people related to the tasks of execution and control of the executed.

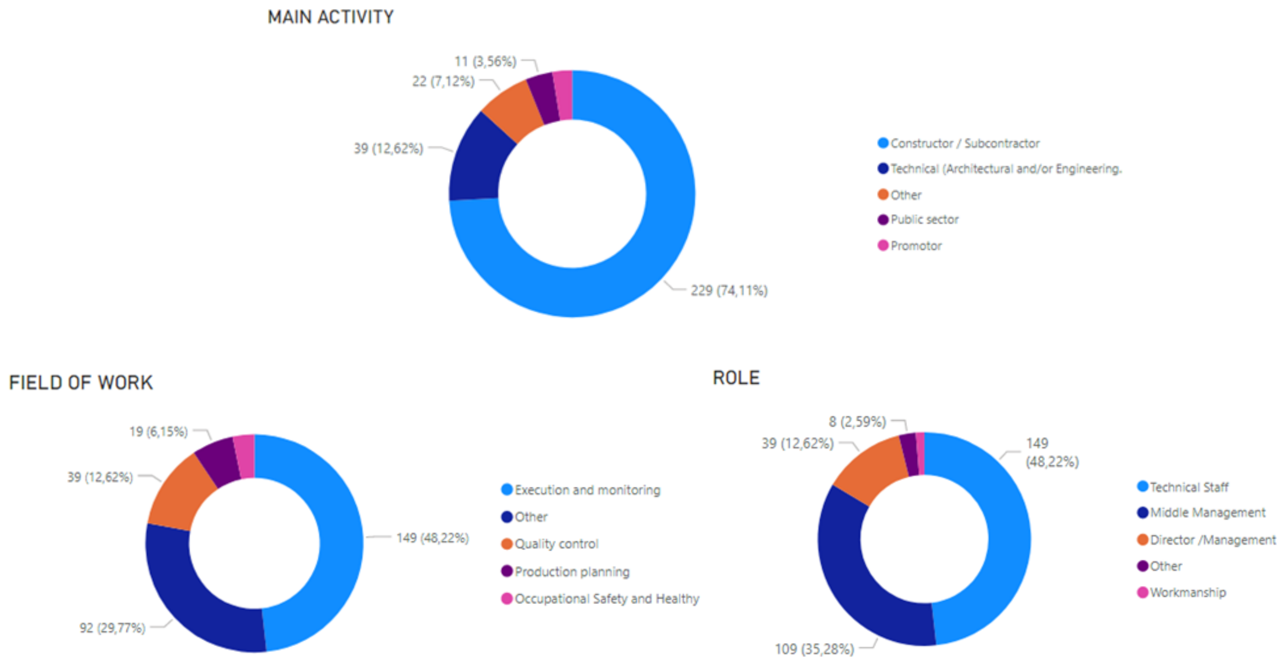


Figure 36. Technical profiles of the participants

5.2 Relevance of the keys to the success of the construction process

This section has determined the relevance of the main phases of the construction process and the keys to guarantee the success of the work. In this way, it will be possible to prioritize the phases where it is necessary to have an impact in order to complete the construction process in an efficient way. The aspects analyzed were: Design, Planning, Execution, Quality and execution control, Costs, Safety and Healthy, Deadlines/Schedule/Milestones and Sustainability.

For the respondents, the most important on-site construction process is Planning, with a score of 9.16, followed by the Execution and Design phases of the project, with scores of 9.10 and 8.85 respectively. The least important aspect was Sustainability with a rating of 7.22.

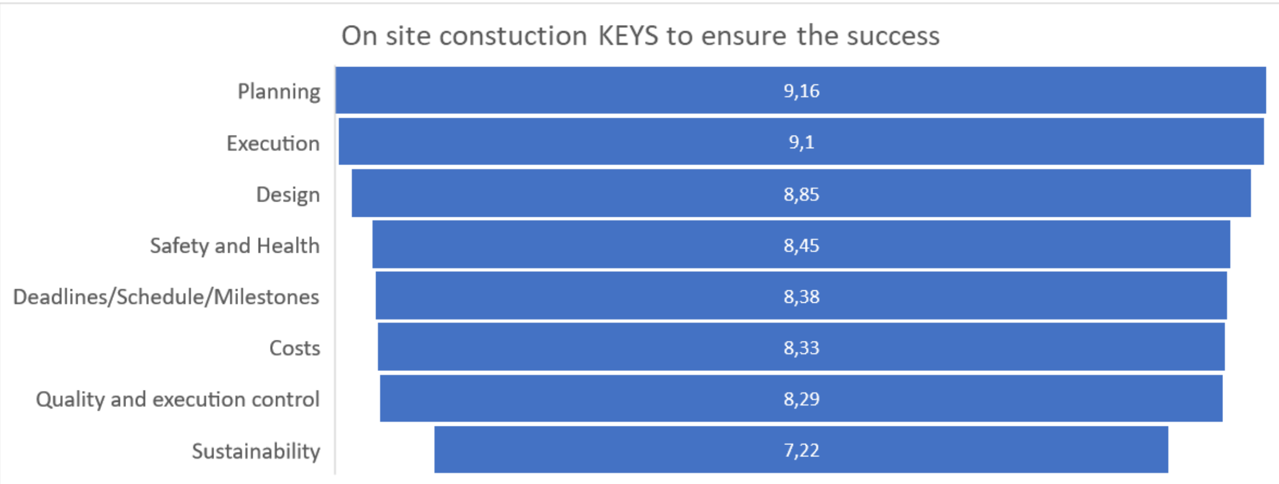


Figure 37. keys to the success of the construction process

If the results are analyzed by country, the prioritization of the importance of the phases to ensure the success of the project varies. In the case of France, the most important phase is the Design phase with a rating of 9.11, followed by the Execution phase and the Execution Quality Control phase with a rating of 9.00 and 8.07 respectively. The Planning phase would move to the sixth position, behind Health and Safety and Costs. In the case of Finland, the most important phases are the same as the overall results, but the order changes. In this case, the most important phase is Design, with a rating of 9.49, followed by Planning with 9.29 and Execution with a rating of 9.01. In the case of Finland, Costs would be the least important aspect of the construction process with a rating of 6.85. If looking at the case of Spain, Planning and Execution are the main keys to the success of the construction process, however in the case of Spain the third key factor is Project Costs with a score of 8.85.

If the answers to the questionnaire are analyzed according to the area in which the respondents carry out their work on the construction site, the results correspond to the profile of the respondents. The people who have related their work to execution and control, have indicated that the most important aspect to guarantee the success of the work is the Execution. The people related to the planning area indicated that the most important aspect of the construction process is Planning, and the respondents who related their work to the safety and healthy area of the construction site considered Health and Safety as the main aspect to be taken into account.

If the analysis of the results is done by the role of the respondents, there are notable differences in the answers. In the case of the Director/Management, the key to the success of the project is the Design, however Health and Safety and Quality of execution are relegated to the last positions only above Sustainability. In the case of the Workmanship surveyed, the main keys are Execution and Quality control and execution control. For both Technical Staff and Middle Management, the results are similar to those obtained globally, with the prioritization of the key phases and aspects of the construction process coinciding.

The results do not vary significantly if the responses are compared with the size of the respondent's company, and in all cases the three main keys are Planning, Execution and Design. Only in the case of micro-companies with less than 10 employees are there changes in the results. In this case Quality and Execution Control is more important than Design.

If the results are analyzed by age, only in the over-60 age group are there changes in the results. In this case, Safety and Health and Cost are positioned as the main keys to the success of the construction process (9,75).

No significant changes are detected in the results if they are analyzed by the level of study of the respondent, and in all cases the three most important keys are the same, although in some cases the order of these keys is changed.

5.3 Relevance of optimal management objectives

In this section, it has been established the importance of the main objectives to be achieved by means of an optimal management of the construction process. The aspects analyzed were: Increase profitability, Improve customer service, Reduce the generated documentation and guarantee the traceability of the information, Improve the quality of the construction, Reduce the unforeseen events during construction, Reduce environmental impacts and Enhance safety on site.

The results of the questionnaire show that the main objectives of effective construction are Reduce the unforeseen events during construction with a rating of 8.54, followed by Improve the quality of the construction (8.36) and Enhance safety on site (8.10), while Increase profitability is the least important objective with a rating of 7.49.

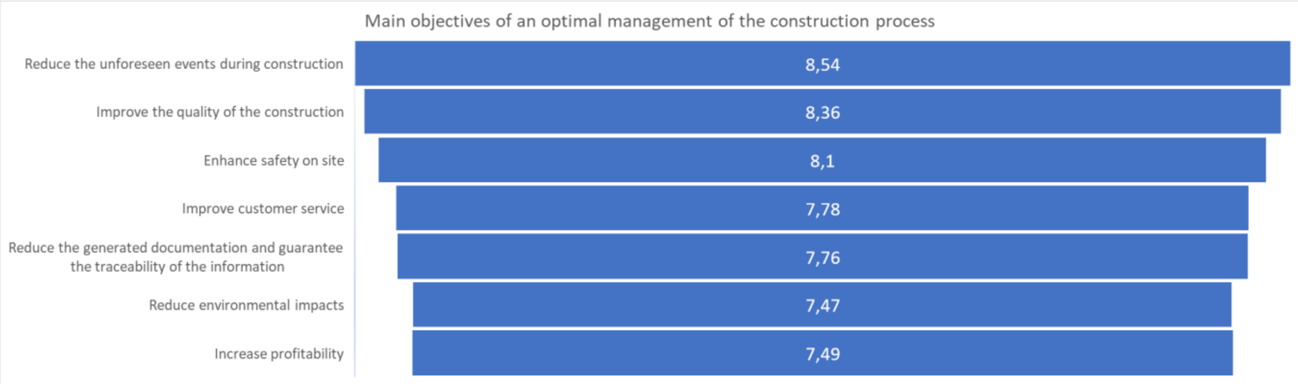


Figure 38. optimal management objectives

When studying the results by country, it is possible to draw the following conclusions: In the case of France the main objective is Reduce environmental impacts (8.04), however in the case of Finland and Spain, the main objective is Reduce the unforeseen events during construction. The least important objective in France and Finland is Increase profitability, with a rating of 6.44 and 5.98 respectively. However, in Spain, this objective is the fourth most important, with a rating of 8.11.

Analyzing these data by field of work, there are no major differences in the results. The only major variations are observed in the responses of the staff related to Occupational Safety and Health, where the objective of Enhance safety on site is by far the most important objective, with a rating of 9.70.

Regarding the role of the respondent, the biggest differences are observed between those responding to a Director/Management profile and those responding to a Workmanship role. In the first case, the Improvement of the customer service is the second most important objective, while for the Workmanship role this objective is in last place. In both cases they agree that Reduce the unforeseen events during construction is the most important objective.

In the case of company size, the results show similar responses for all sizes except in the case of micro companies <10 workers. In this case "Reduce environmental impact" is more important than Enhance safety on site.

When analyzing the results by age of the respondents, the main change is observed in the 20 to 30 years age group. In this case, Reduce the generated documentation and guarantee the traceability of the information is the second most important objective.

Regarding the level of education, the main change with respect to the most important objectives is observed when analyzing the data of people who have a PhD. In this case," Improve customer service" is placed as the main objective, with a rating of 8.60.

5.4 On-site construction. Inefficiencies and points for improvement.

In this section of the questionnaire we have analyzed the main inefficiencies of the current construction processes at the site and the points for improvement based on the results of the state-of-the-art study described in chapter 4.7.

The results of the questionnaire indicate that the main inefficiencies occurring in the work phase are the Inadequate planning of the work, the Continuous changes and modifications and the Lack of execution control, with a valuation of 8.32, 8.15 and 8.15 respectively. The inefficiencies related to Tools, equipment's and machinery, loss or not knowing their location and Difficulties to know where the staff is located on-site, were the least valued (5.76 and 5.39 respectively).

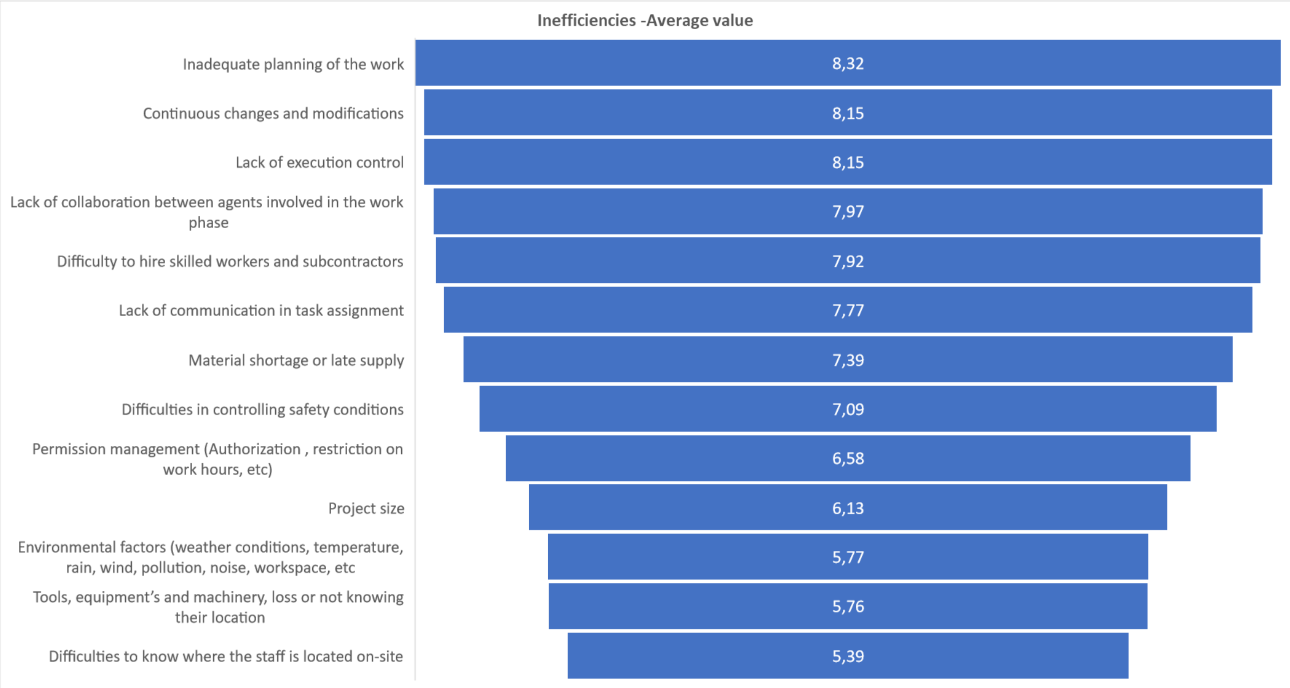
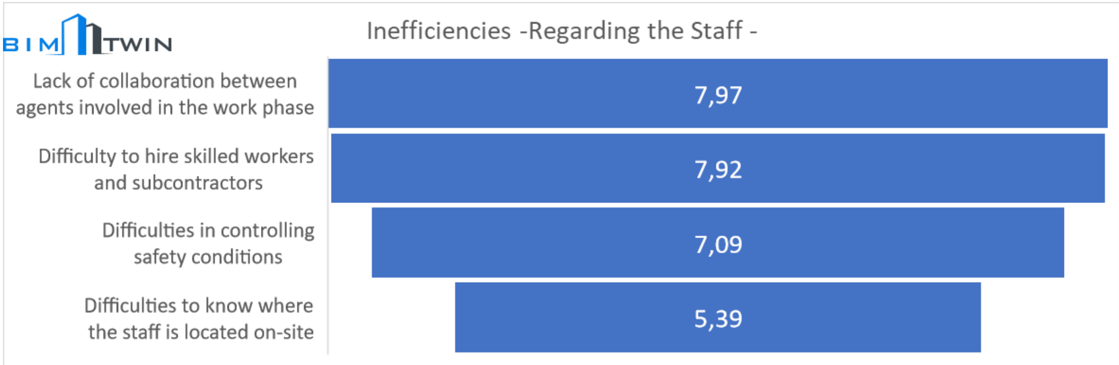
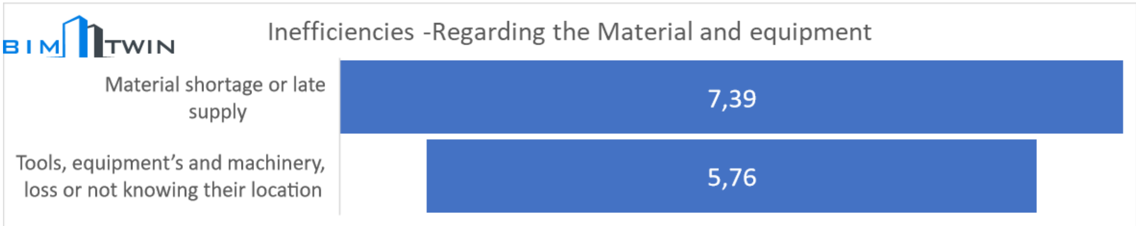


Figure 39. Prioritization of inefficiencies

It can be seen that the main inefficiencies are related to the Planning of the work on site and the less important inefficiencies are related to the external conditions of the site.





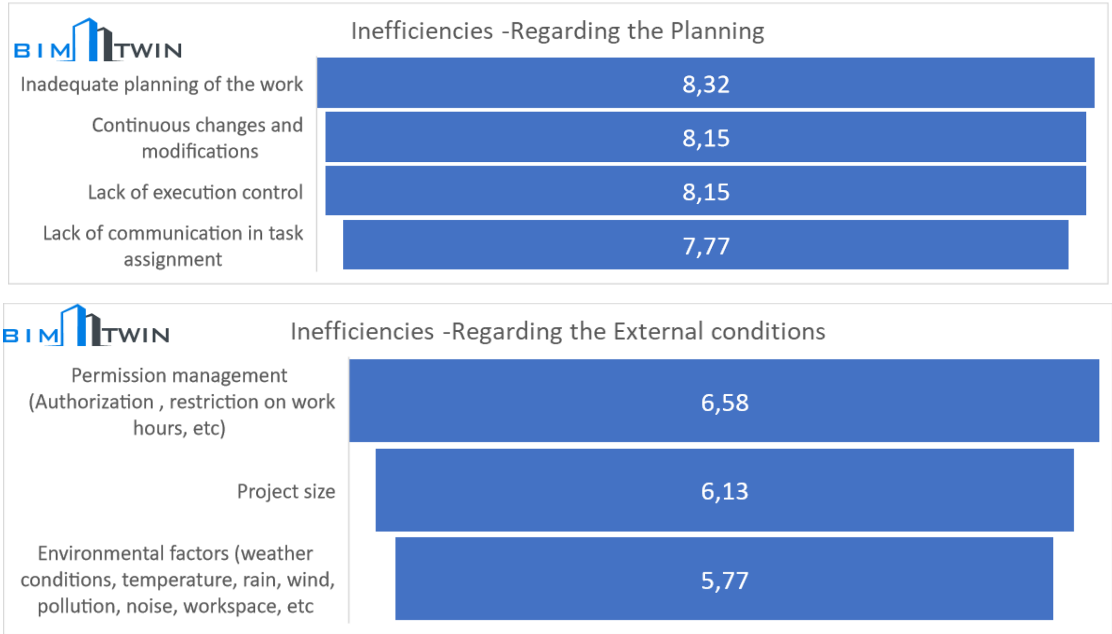


Figure 40. Inefficiencies by category

If these results are analyzed by country, there are considerable differences. In the case of France, Difficulty to hire skilled workers and subcontractors goes from being the fifth most important inefficiency to being the first, with a score of 8.48. In the case of Finland, it is the inefficiency Lack of collaboration between agents involved in the work phase, which moves from fourth place in the general questionnaire to first place with a score of 8.85. In the case of Spain, slight differences are observed in the intermediate positions, but the three main inefficiencies continue to be those represented by the overall results.

If the data from the questionnaire are crossed with the respondent's field of work, the main differences are observed in the answers of the personnel related to Occupational Safety and Healthy and Production planning. In the first case, and as expected, the main inefficiency detected is Difficulties in controlling safety conditions, with a score of 9.40, and the main inefficiencies are related to on-site workers. In the case of people related to planning, and as was also expected, the main inefficiencies in the work phase are related to the Lack of collaboration between agents involved in the work pass and the Inadequate planning of the work, with a rating of 9.05 and 8.89 respectively.

If the results are studied by role, it should be noted that in the case of Workmanship, the main inefficiency is related to Difficulty to hire skilled workers and subcontractors. The rest of the roles present results very similar to those obtained globally.

The results show that for medium-sized companies (less than 250 workers) and small companies (less than 50 workers) "Difficulty to hire skilled workers and subcontractors" is the main inefficiency, with a rating of 7.90 and 7.71 respectively. For the rest of the company sizes, the results are similar to the general ones.

Difficulty to hire skilled workers and subcontractors is also the main inefficiency for respondents who are over 60 years old. In the case of respondents between 20 and 30 years old and between 30 and 40 years old, one of the main inefficiencies in the construction process is due to Lack of collaboration between agents involved in the work phase. Lack of collaboration between agents involved in the work phase is also the main inefficiency for respondents with a master’s degree.

The following sections will analyze the main inefficiencies that affect or occur in the three main domains on which the project developments will focus. Execution monitoring and quality control, Occupational Safety and Healthy and Production planning.

5.4.1 *Execution monitoring and quality control*

Regarding Execution monitoring and quality control, according to the results of the questionnaire and the workshops carried out, it can be concluded that the main inefficiencies that have been identified are the lack of a correct control of the execution, the continuous changes and modifications in the project, the lack of collaboration between the agents involved in the work execution, and the difficulty to hire qualified workers. All these aspects are the main problems that the on-site construction process currently presents.

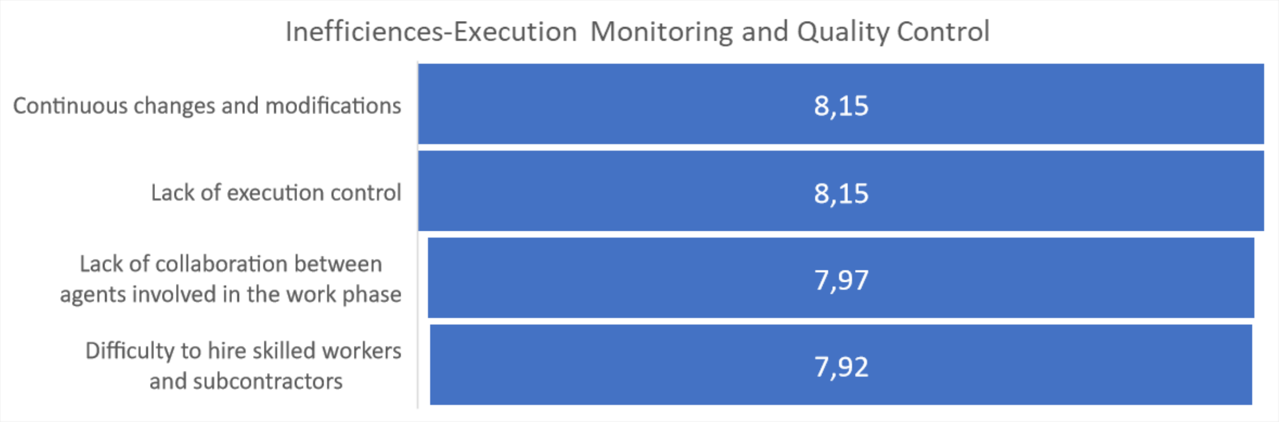


Figure 41. Main inefficiencies in the field of Execution monitoring and Quality control

It should be mentioned that the people related to this field have identified that the main inefficiency and point of improvement to be achieved in order to reach success in the construction process is an adequate planning of the works. Having an adequate planning it will be easier to perform a correct execution monitoring.

While in Finland, the main inefficiency affecting Execution monitoring and quality control is the "Lack of collaboration between agents involved in the work phase", in the case of Spain, this inefficiency is not so important. In the case of France, the main inefficiency that prevents a correct Execution monitoring and Quality control is the "Difficulty to hire skilled workers and subcontractors".

In relation to the roles, the Director/Managers also consider that "Difficulty to hire skilled workers and subcontractors" is the main inefficiency in the domain of Execution monitoring and quality control. However, for Middle Management or Technical Staff, lack of correct execution control is the main inefficiency.

5.4.2 *Occupational Safety and Healthy*

Based on the results obtained, with regard to Occupational Safety and Healthy, it can be concluded that the main inefficiencies that occur at the site are due to the lack of control of the execution at the site, the lack or difficulty in hiring qualified workers, the lack of communication in the assignment of tasks, and the difficulty in controlling the safety conditions at the site. All these aspects are the main problems that occupational health and safety currently presents.

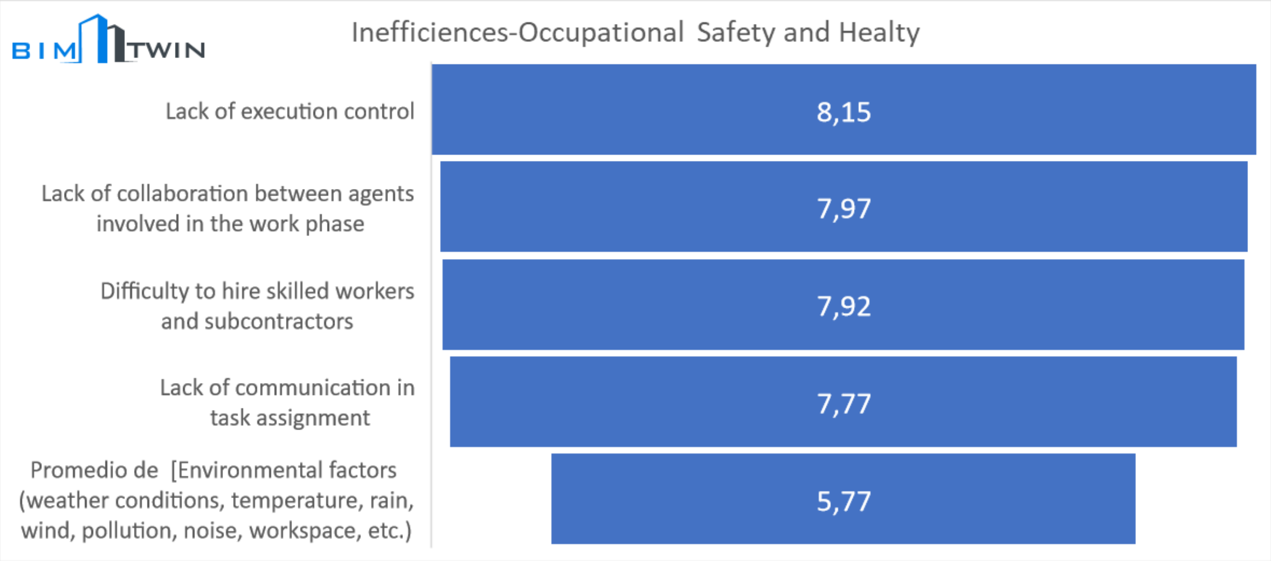


Figure 42. Main inefficiencies in the field of Occupational Safety and Healthy

As expected, when analyzing the responses of the staff related to Occupational Safety and Health at the construction site, it can be observed that the main inefficiency identified is "Difficulties in controlling safety conditions" with a score of 9.40.

While, in the case of Finland and Spain, the main problem and point for improvement of Occupational Safety and Healthy on site is the Lack of execution control on site, for France the main problem is caused by the lack of qualified workers on site.

If analyze the main inefficiencies that affect or occur in the fields of Occupational Safety and Healthy based on the roles of the workers, it is observed that only in the case of Directors/Managers the main problem is produced by the lack of qualified workers. For the rest of the roles and profiles the main problem affecting the safety and health of the work is the lack of control of the execution.

5.4.3 *Production planning*

Finally, regarding the Production planning, according to the results of the questionnaire and the workshops conducted, it can be concluded that the main inefficiencies that have been identified are; Inadequate planning of the work, the Continuous changes and modifications, the Lack of collaboration between agents involved in the work phase. All these aspects are the main problems that make it difficult for the Production planning of the work to be effective.

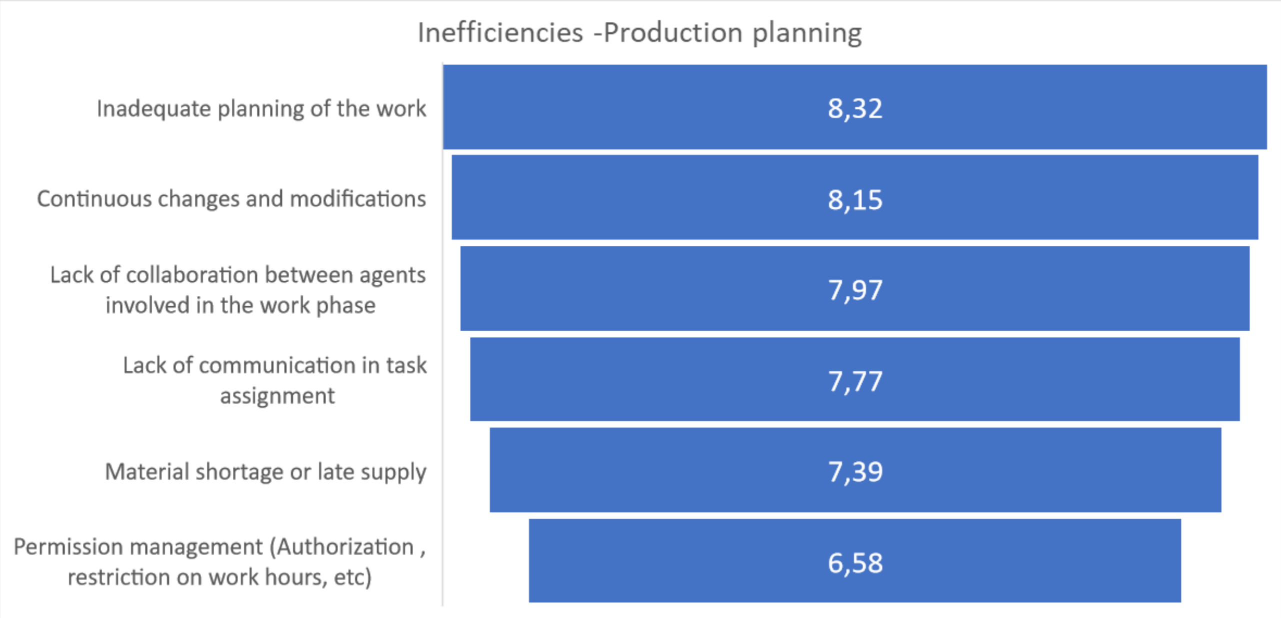


Figure 43. Main inefficiencies in the field of Production Planning

It is worth mentioning that the people related to the work planning tasks have identified as the main inefficiency and point of improvement to achieve success in the construction process is the lack of collaboration between the agents involved. If the communication and relationship between all the people and companies involved in the work were more fluid and effective, it would be easier to carry out a correct Production planning of the work.

The lack of collaboration between the agents involved in the project is also the main inefficiency that occurs in the field of production planning in Finland. However, in the case of France and Spain, the main problem that occurs in the field of production planning is the inadequate planning of work on the site.

Regardless of the worker's role or professional profile, in all cases the main inefficiency and point of improvement that occurs in the area of planning is the Inadequate planning of the work on site.

5.5 Digitalisation of the construction process on site – Barriers

Another of the main objectives of the questionnaire was to identify the main barriers that hinder the integration of the use of technology or the digitization of construction processes. Based on the results of the study of the state of the art and the review of the existing literature on the main specific barriers to the digitization of construction processes in the construction site collected in chapter 4.7, this section has determined the main barriers that must be overcome to ensure the successful implementation of this type of digital tools in the construction phase. Technical or technological barriers.

The main barriers that will have to be overcome to achieve the digitalisation of construction processes on site are; the Need for complete integral change in the way of working on site, the existence of Many different teams and companies participate, with different working procedures, (protocols, used programs, etc.) and the Lack of development of the necessary technology and incompatibility between tools. The importance of these barriers to achieve the digitization of the work on-site has been rated with 8.06, 7.99 and 7.97 respectively.

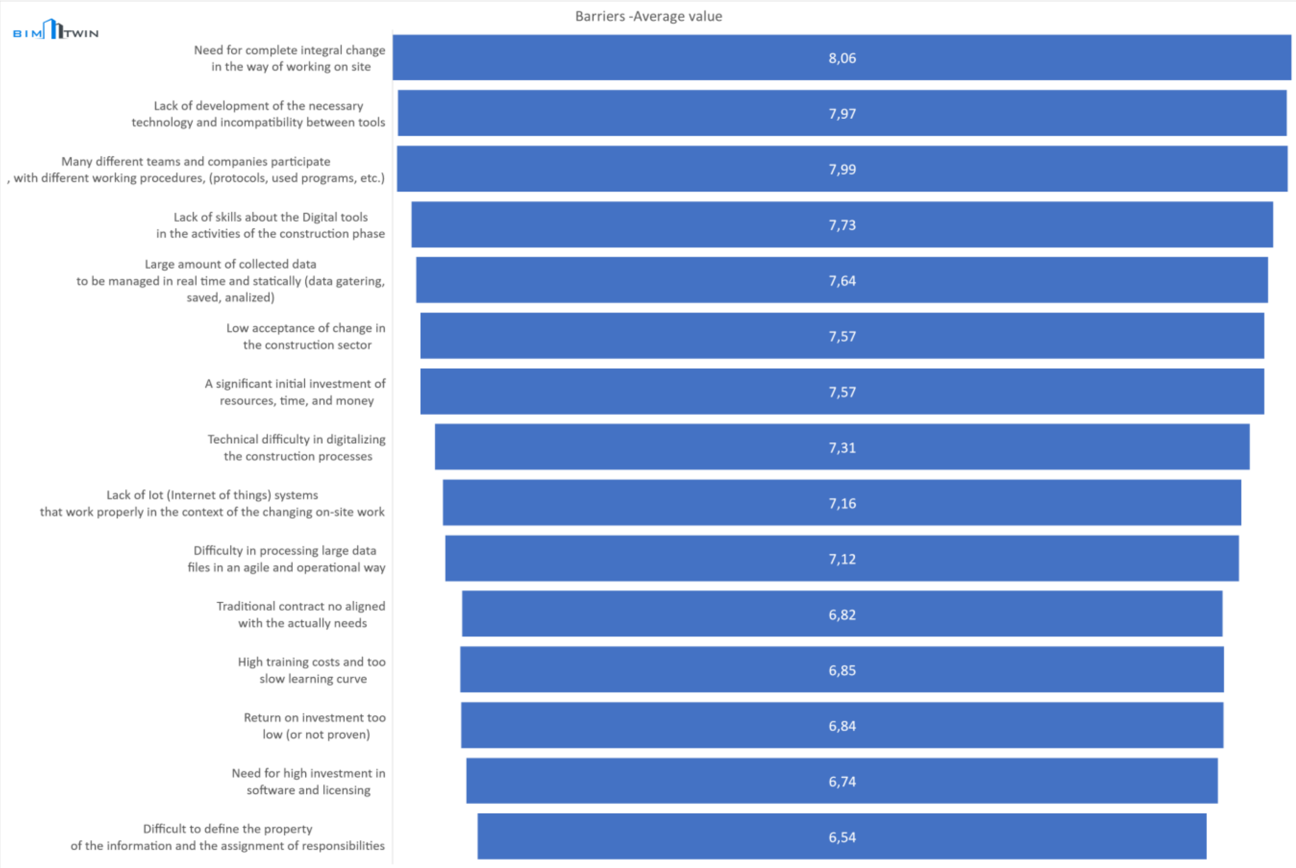


Figure 44. Prioritization of Barriers

Analyzing the results by country, in the case of Finland and Spain there are no major differences with respect to the overall results, and the order of the main barriers is similar in both countries. In the case of France, this result does differ from the global results. In France the main barriers continue to be related to social barriers, but economic barriers become more relevant, as well as the barrier Many different teams and companies participate, with different working procedures, which is the most important according to the results.

There are no major variations in the overall results of the main barriers if the results are analyzed according to the field of work of the surveyor.

If the results are analyzed according to the respondent's role, there are only notable differences in the workmanship responses. In this case the main barrier that hinders the digitization of the work processes is the Lack of development of the necessary technology and incompatibility between tools with a rating of 9.25, and in second place of importance is the barrier related to the Large amount of collected data to be managed in real time and statically (data gathering, saved, analyzed) with a rating of 8.25.

When analyzing the main barriers by company size, it was observed that for medium-sized companies (less than 250 workers) and micro companies (less than 10 workers) "A significant initial investment of resources, time, and money" was one of the main barriers.

Regarding the age of the respondents, the main differences with respect to the general results are observed in the responses of the group >60 and in the group between 30 and 40 years old. in the first case, "Large amount of collected data to be managed in real time and statically (data gathering, saved, etc.)" is ranked as one of the main barriers. In the 30-40 age group, "Low acceptance of change in the construction sector" is one of the main barriers to achieving digitalisation in the construction sector.

If the results are analyzed by the level of the respondent, it is observed that both the respondents with a PhD degree, and those with a Professional training think that the main barrier is the Lack of skills about the Digital tools in the activities of the construction phase.

5.6 Feature of the data collection system

The questionnaire was also used to ask about the most relevant features that the data collection systems and equipment within the site should have, in order to use these features for the definition of the DBT platform specifications. The characteristics analyzed were: Accuracy, User-friendless, Portability, Time efficiency, Remote access to information, no advanced knowledge required and Continuity in the registration and information monitoring.

The results indicate that the most valued characteristics that the data collection equipment should have are: User-friendless with a rating of 8.26 and Time efficiency. It is interesting that being "User-friendless" the most important characteristic, the least valued was that it should be Usable by low skills workers with a rating of only 6,83.

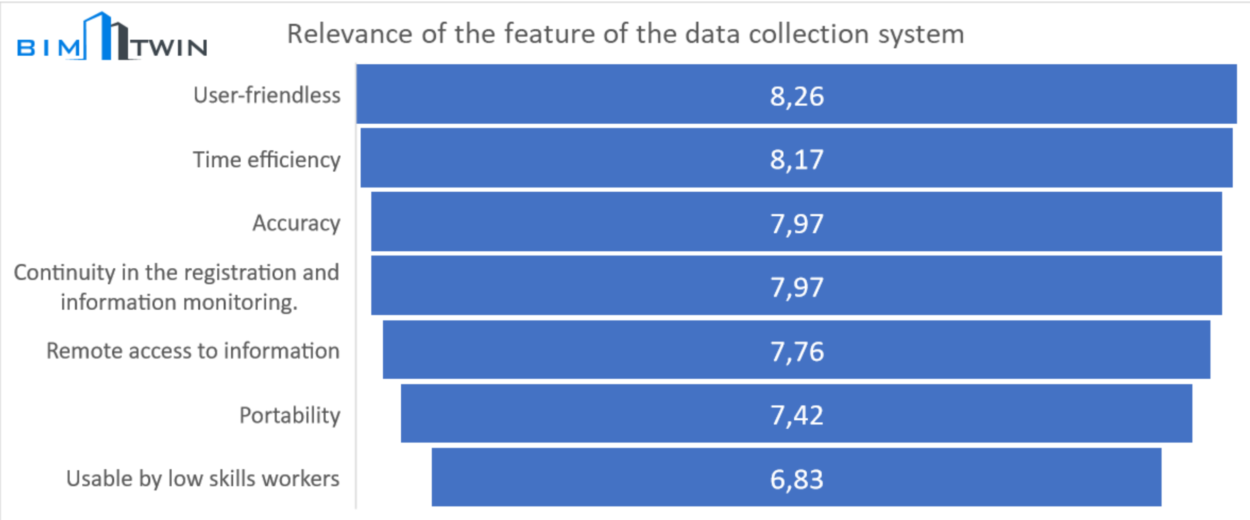


Figure 45. Feature of the data collection system

If analyzed by country, it can be concluded that in the case of Finland and Spain there are no relevant changes, however, in the case of France, User-friendless is the least important characteristic with a rating of 6.70 and Usable by low skills workers is the third most important characteristic with a rating of 7.52, and Accuracy of the equipment is the most important characteristic in the case of France with a rating of 8.11.

When analyzing these data by respondent's field of work, no notable changes are observed in the cases of personnel related to Execution and Monitoring and Quality Control. However, if this data is analyzed by Occupational Safety and Healthy, the most important characteristic is Accuracy (8.80) followed by Time efficiency (8.50).

If the responses of people related to Planning are analyzed, the most important characteristic is Remote Access to information with a rating of 9.21.

As expected, if the results of the main characteristics that data collection equipment and tools should have on site are analyzed by the role of the survey respondent, it can be seen that in the case of the Workmanship, the most important characteristics are User-friendless and Usable by low Skills workers. The data for the rest of the roles do not show any significant changes with respect to the overall results of the questionnaire.

When analyzing the characteristics that data collection systems should have by company size, it is observed that for micro-sized companies (less than 10 workers) "Remote access to information" is the most important characteristic. This feature is also the most important for respondents aged between 20 and 30 years. However, for respondents between 30 and 40 years of age, the most important characteristic is the Time efficiency. The rest of the age groups show similar results to the overall results.

Regarding the level of education of the respondents, it is worth mentioning that for the respondents with a PhD degree, the most important characteristic is "Usable by low skills workers".

5.7 Result by gender

Finally, an analysis of the results of the questionnaire by gender was carried out to check if there are significant changes in the results depending on the gender of the respondents. These results analyzed by gender will not be used to define the specifications and requirements of the DTB platform, however, having this information available, it has been considered appropriate to carry out this study to see the differences by gender in the construction sector.

However, in the case of the main objectives of optimal management, Reduce the generated documentation and guarantee the traceability of the information and Reduce environmental impacts gain importance, although the three main objectives continue to be: Reduce the unforeseen events during construction with a score of 9.00, followed by Enhance safety on site (8.69) and Improve the quality of the construction (8.66).

Regarding the inefficiencies and points for improvement, if analyzing the results by gender, slight changes can be detected that change the order of relevance and impact of the inefficiencies. However, although in a different order, the three main inefficiencies continue to be the same: Lack of execution control, the Continuous changes and modifications and the Inadequate planning of the work, with a valuation of 8.58, 8.43 and 8.33.

As in the previous case, if the importance of the barriers is analyzed according to gender, it can be seen that the main barriers are the same, but in a different order. In this case the most important barrier that will need to be resolved to ensure the success of the digitization of the work is the Lack of development of the necessary technology and incompatibility between tools, with a rating of 8.49, followed by Many different teams and companies participate, with different working procedures, (protocols, used programs, etc.) (8.34) and Need for complete integral change in the way of working on site (8.24).

Regarding the main characteristics of the data collection teams, no major changes were observed between the responses of male and female respondents.

6 As-is practices analysis in the BIM2TWIN construction process

In this chapter, the as-is construction practices related to the domains tackled in the BIM2Twin project, based on the findings of the questionnaires, have been assessed. Meanwhile the chapter 4 and 5 addresses the overall construction process, from the state-of-the-art analysis and the general outcomes of the questionnaire, in the current chapter the analysis has been focused on the 3 countries where the pilot sites are located.

Beyond of an overall as-is practices analysis, a more practical approach specific for the target countries (Spain, French and Finland) has been done in order to ensure that the real user needs are considered in the DBTP developed in the project. In future work, the standardization practices and exploitation perspectives ensure the replicability of the project to the European framework.

This approach targeted to the pilot countries has been reached thanks to the analysis of the questionnaire´s results focused on those countries, of the local workshops ‘conclusions and finally verified through the technical discussions among pilot partners, as it is explained in the methodology (Chapter 3) . The assessment has allowed to identify the standard construction processes in the countries, the level of digitalisation of the pilot partners, the most affecting inefficiencies of the process for them and finally how can they overcome the barriers toward the digitalisation. This approach intends to ensure the future developments of the projects will meet the user's expectation starting from real cases.

Therefore, based on all the work done in Task 1.1 and described in the previous chapters, this section presents the analysis of current practices in the construction process. For this purpose, the analysis scheme represented in the following image has been followed.

Figure 46. Scheme of the analysis of the current practices in the construction process

The methodology for addressing this chapter is based on an overall analysis of the main topics affecting the efficiency of the construction site, from the point of view of digitalisation. Then, a later focalization in the 3 pilot sites taking into account their construction process and the available technologies for them, is done.

The methodology responds to the following scheme, and it is described below,

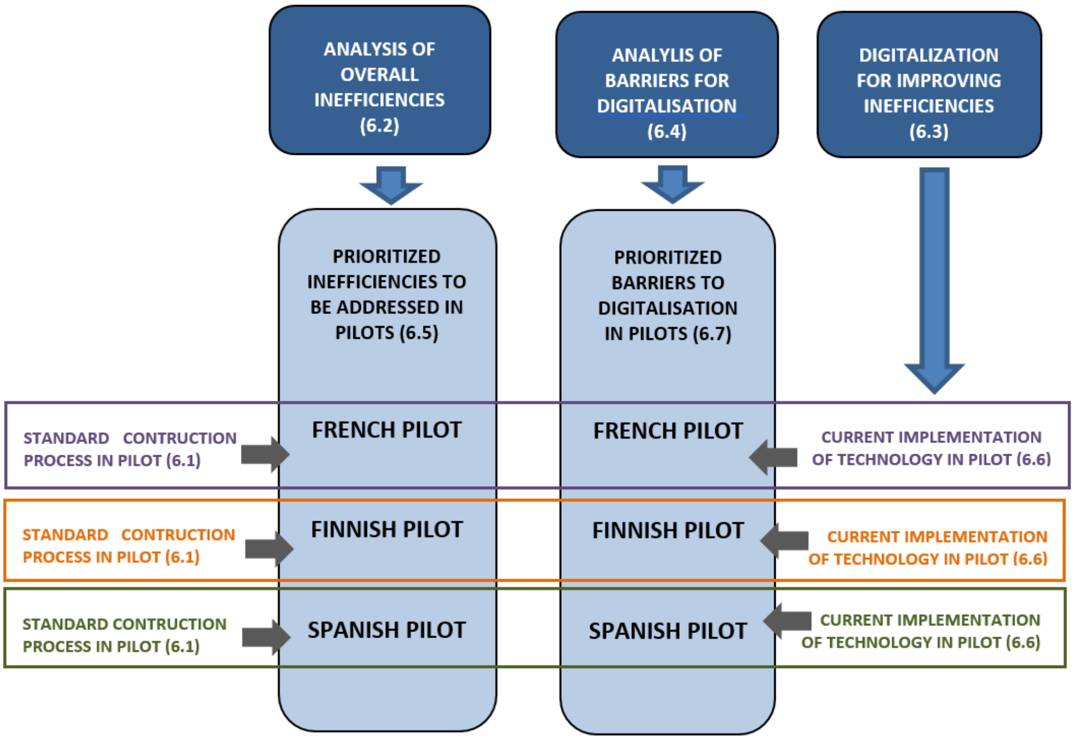


Figure 47. Scheme of the tasks completed for the analysis of current Practices

First and as a starting point, as shown in the diagram above, it has been necessary to broaden the knowledge of the construction processes in the three different countries focused on the activities of the pilots. This information has been directly extracted for the contractor companies which run the pilots who have described their own organization, construction process, and product to be considered as a reference for future developments. (6.1). This has enhanced to identify the differences existing between the construction processes in the different countries, regarding the stakeholders involved, their duties and relationship, as well as the tasks included in the process and subprocesses.

Secondly, with the results obtained from the questionnaire and the workshops, an analysis of the main inefficiencies that occur in the construction site, related to the areas and sub-processes on which the BIM2TWIN project will focus, has been carried out (6.2)

An overview of different existing technologies that can be implemented in the DBT platform has tackled in the chapter 6.3 in order to identify how the technology can overcome the main inefficiencies derived from a low productivity of the construction process.

After this, the main barriers that hinder the integration of the identified technologies and hold back the implementation of the digitization within the construction processes have been analyzed. (6.4)

Once the aforementioned points have been tackled and with the aim of facilitating the future definition of the end-user requirements, a matrix of inefficiencies for each pilot has been defined (6.5). Thus, the inefficiencies that affect the most their productivity on site have been identified.

The level of digitalisation of the process in each construction company leading the pilots has been also described as a starting point to know their improvement possibilities in terms of technology application (6.6).

Finally, the pilot partners have drawn the main barriers to be overcome in order to implement further the digitization of the on-site processes and consequently improve their productivity and success of the site (6.7).

6.1 Background: standard construction process descriptions and organization of the stakeholders in Spain, France and Finland

With the objective of understand the state-of-the-art construction process in three different countries, mapping of the current construction process in each pilot construction site is proposed. In order to be able to analyze the differences between the construction processes in the different countries, a mapping of the main characteristics of each one is going to be done, focusing on the following aspects: Organization, Process and Product

Organisation

(1) Who are the parties involved in the construction process, what are their responsibilities, contractual relationships and business models?

Process

(2) What is the general description of the construction process and its different stages? What are the key deliverables / decisions in each stage?

(3) What is the construction schedule, sequence and phasing of the works on site?

(4) What is the scheduling logic used (critical path method, flow line, takt planning etc.)?

(5) What is the degree of prefabrication / on-site works, how much is equipment used versus manual labour etc.? What is the typical method of construction?

(6) What are the current key performance indicators of each construction sites with which the site works are managed on daily basis / as part of the project portfolio of the contractor?

(7) Are these typical for this type of works in the target country or is there something exceptional?

Product

(8) What is the frame system, what are the construction technologies used? what are the key materials? Are these typical for this type of buildings in the target country or is there something exceptional?

6.1.1 *France*

Organization

According to the French Building Construction Federation (FFB), in 2019, the construction industry in France was worth 148 billion euros of turnover and weighs more than 1,1 million jobs. It is quite an important share of the French economy since it represents half the weight of the industry sector and twice the bank sector.

However, it is still a quite fragmented sector with a high number of small companies. Among the 403 000 companies of the sector, around 95% has less than 10 employees and more than 11% has no employees at all. Note: this does not include architects, engineers and consulting companies.

All together, they produced more than 61 billion square meter of building in 2019 with a majority of housings (around 55%). [90]

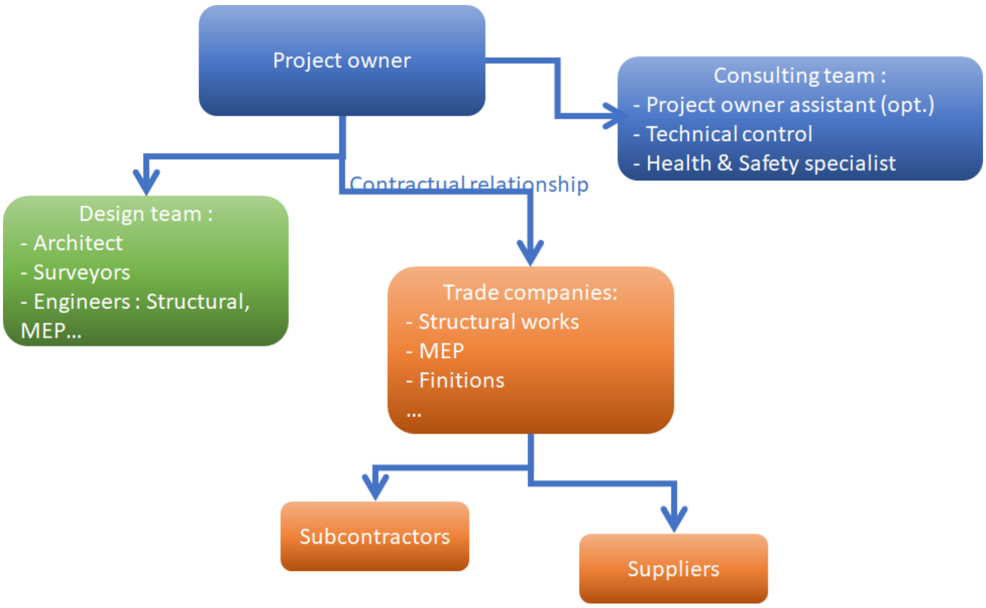


Figure 48. Construction management system for building construction in France

Every contracting type exists in France such as separate trades contracting, General contracting, Design & Build contracting. However, the bulk of the market is the model of the separate trades contracting. In the public sector, it is the default type of contracting and if other types are possible, it has to be based on an objective reason such a technical specify for example. The project owner in private sector also contracts usually with separate trades companies since it is perceived to be more cost effective than the general contracting model.

Probably, as a result, the make or buy strategies of the general contractors' companies seems to be very specific to this French context. Pure player is not a common model and usually, the companies that can manage a general contracting project are the Structural compagnies.

Process

The French Law precisely defines the relationships between a public project owner and the private design teams lead by the architect through the missions the first has to entrust to the last (See below). Although it does not apply so strictly in the private sector, all projects are usually structured the same way.

Each step of the design phase gives more details to the project and aims to obtain the building permits and redact the tender documents. The construction phase goes from the contracting of the works all through the final reception of the building.

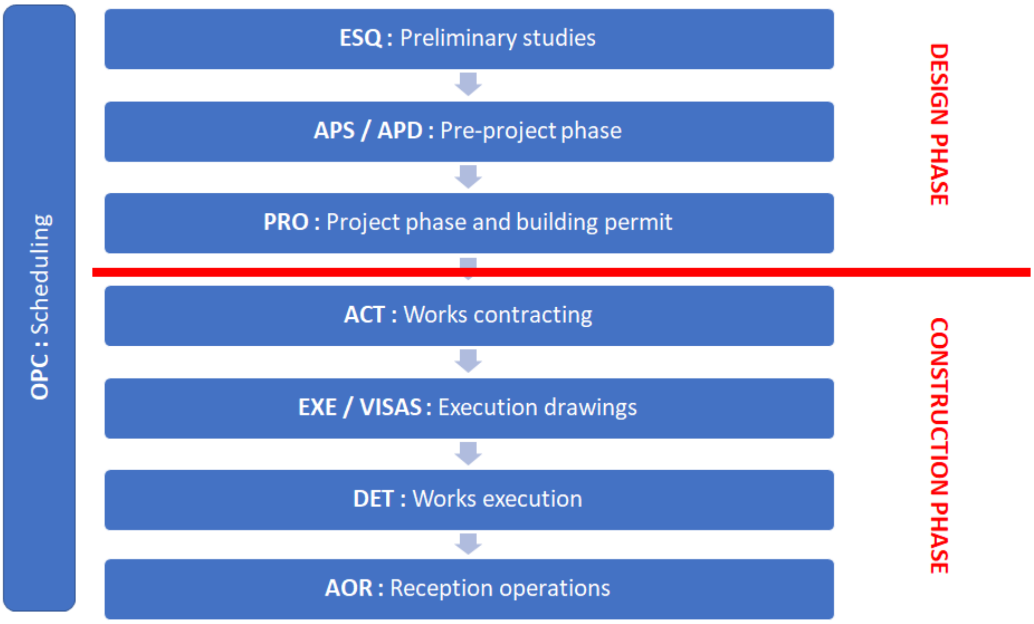


Figure 49. Standard French construction project stages

The general conditions of the contractual terms between the project owner and the different contractors are normalized in the following documents:

- Public sector : Cahier des Clauses Administratives Générales (CCAG) applicables aux marchés publics de travaux
- Private sector : NF P03-001 / Cahier des clauses administratives générales applicable aux travaux de bâtiment faisant l'objet de marchés privés

The French industry is also organized around a set of norms called the “*document technique unifié (DTU)*” that precisely defines the technical standard of construction. The CSTB is a major actor in the redaction of those documents.

Product:

Typical construction principles used in France:

The most commonly used structural frame system in France is the cast-on-site concrete frame with load bearing walls stabilized with staircases and standard slabs. Pre-cast concrete exists and is widely used but not as extensively as cast-on-site concrete.

Metal is also quite common in structural frame either mixed with concrete (ex: collaborative metal form-slabs) or for the complete structure above foundations such as in warehouses.

Use of wood in structure is also growing widely and is a material to be accounted for.

Precast elements tend also to be developed in other trades. For examples, completely equipped bathrooms can be delivered on site in just-in-time system with the structural frame construction.

Figure 50. Typical residential building in France

Of course, energetic efficiency is a great concern in the industry at large and are the focus of a lot of public policy. The national low carbon strategy set by the government fixes a 54% reduction of greenhouse gases by 2028 and 87% by 2050. It shows up in the diversity of the environmental label used in building projects: regulatory (RT2012, BEPOS, BBC, E+C-) or international (BREEAM, LEAD) and even local (BDM in the south-east of France).

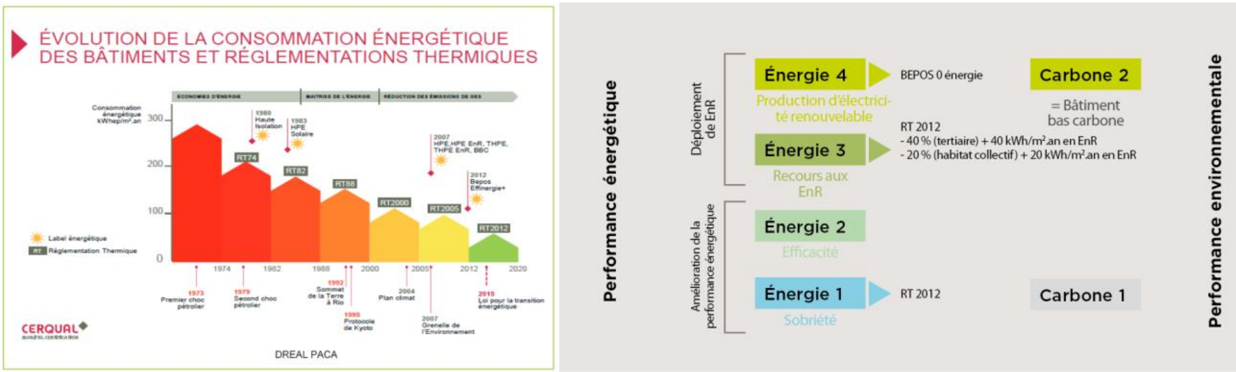


Figure 51. Evolution of building energy consumption and thermal regulations in France

As a consequence, insulation of the building has evolved over the last few years. External insulation tends to disappear for aesthetic reasons mainly. It drives to some specific treatments of thermal bridges created with internal insulation (insulating concrete or thermal breaker).

It also leads the trends in the choice of energy for heating and cooling and tends to develop the use of energy use counting down to the flat to help each occupant adapt its consumption.

The buildings also have to comply with several norms and regulation that tends to shape the project such as:

- Acoustic requirements
- Accessibility to disabled persons
- Resistance to earthquakes

6.1.2 *Finland*

Organization

The Finnish construction industry has been locally regulated and special efforts have been made to standardize project delivery models nationally. However, project delivery models, related instructions and agreements have not been implemented by law, but by mutual agreements with the help of industry associations. The most influential and widely used national agreement is the General terms and conditions for construction project (Yleiset sopimusehdot 1998, YSE1998) which dates to 1998. In 1998 YSE conditions are not law, but the contractor aggregation and subscriber side jointly negotiate contract terms, which can be applied in addition to the individual agreement of project. The YSE 1998 conditions are intended to apply throughout the entire contract chain, including subcontracting, and the implementation of construction project organization is defined there.

The figure below describes the typical Finnish organization of the design-bid-build parties. Green arrows are describing the contractual relationships.

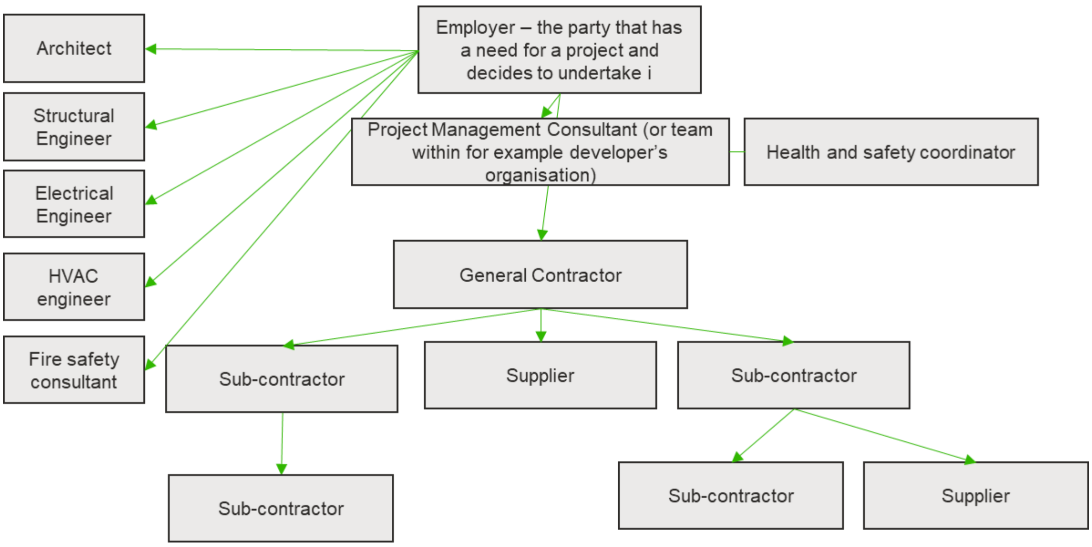


Figure 52. Construction project process in Finland

In case the employer is a party that does not have internal team of executing projects or they have a very small team, they usually hire a Project management consultant to manage the project and to support in hiring the different project parties. The contractual relationships are still formed between the employer and all the different parties. Sometimes, the employer might even have some specified subcontractors directly in contractual relationship with themselves. In this case the general contracting contract usually obliges the general contractor to coordinate and manage the daily work execution on site even with those sub-contractors that are hired by the employer.

Additionally, in Finnish residential construction sector there are many general contractors who have also taken the role of the residential developer to themselves and are selling apartments directly to customers. In this case, there is usually no external project management consultant, but instead there is the general contractor's development team who does the project management and coordination between customers, design team and general contractor. It is noteworthy that architects in Finland, even though they have overall legal responsibilities of the principal designer and coordination of different designers and engineers, do not generally lead the site execution of the projects like in many other countries. Architects do have a say, but they for example do not usually certify works completed etc. This is usually task of the Project Management Consultant which may well have personnel with engineer or architect background.

Process

The below figure describes the standard Finnish construction project stages as they are defined in the industry standards.

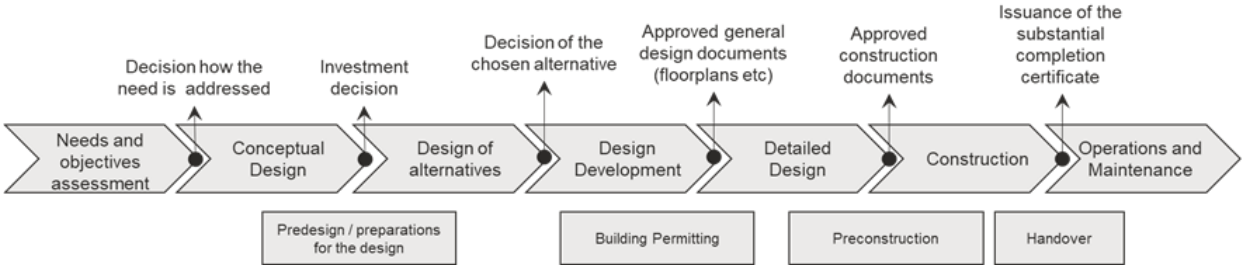


Figure 53. Standard Finnish construction project stages

The standard construction production planning is based often on location-based scheduling (=flow line scheduling), where the target is to optimize the different trade crews' flow through different sections and floors of the building. Master schedule looks like in the figure below (can also be presented in traditional Gantt-format).

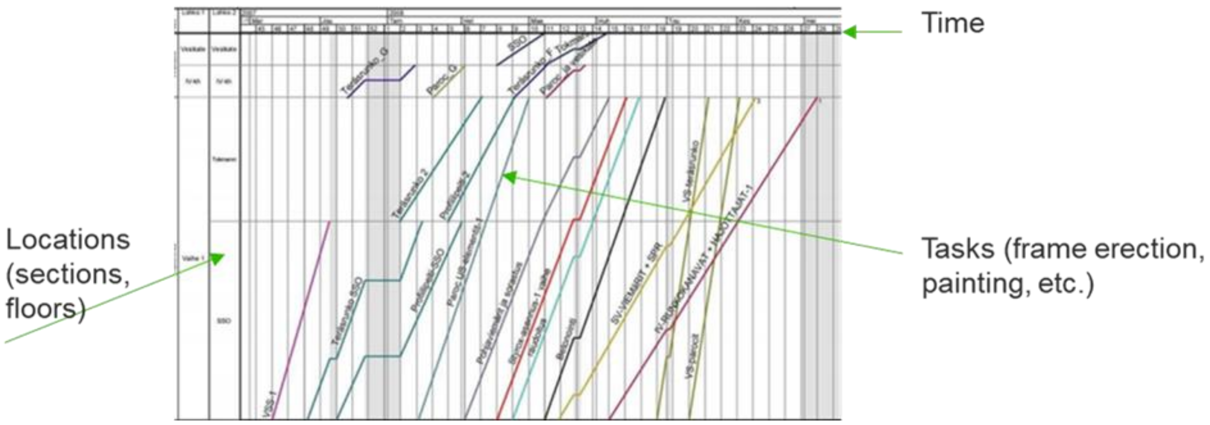


Figure 54. Example of master schedule for a project in Finland

The daily site management utilizes often either Last Planner System (developed by Lean Construction community, by Glenn Ballard & Greg Howell in US 1990-2000s) [91] or more traditional weekly planning with standard meeting routines with weekly or bi-weekly meetings with contractors and the project management team + bi-weekly or monthly meetings between general contractor, project management and employer. The quality of works is generally managed with quality matrix which defines the works for which a separate mock-up will be installed and verified.

Product: Residential Apartment Building

Typical residential building in Finland:

Structural frame system: precast concrete with load bearing walls (external walls and internal walls (between apartments), stabilized with elevator, shaft or staircases, beams and hollow core slabs. External walls are usually made of precast concrete called precast sandwich walls that include inner shell, insulation and outer shell altogether forming the façade. Sometimes the outer shell may be left out from the precast assembly and the façade layer is instead made of bricks on site. The roof and foundation structures vary from project to project.

Figure 55. Typical residential building in Finland

6.1.3 *Spain*

Organization

The contracting and construction management system for building construction in Spain can be divided into two main models, the public and the private. The public model traditionally carries out a tender for the design of the building, the winner of which will oversee the design of the entire project. Once the design project is ready (basic or execution), another tender is carried out for the construction of the project, being favored the contractor that meets all the technical and economic requirements. On the other hand, the control and compliance processes are carried out by the public entities assigned for this purpose and the topics related with the design/quality by the "Project Site Management" (traditionally the project designer).

Traditionally, the project designer (architect) is responsible for all structural and installation calculations, geotechnical studies, etc., processes that are not always, but are usually subcontracted to specialized engineering firms.

The following graphic shows this process:

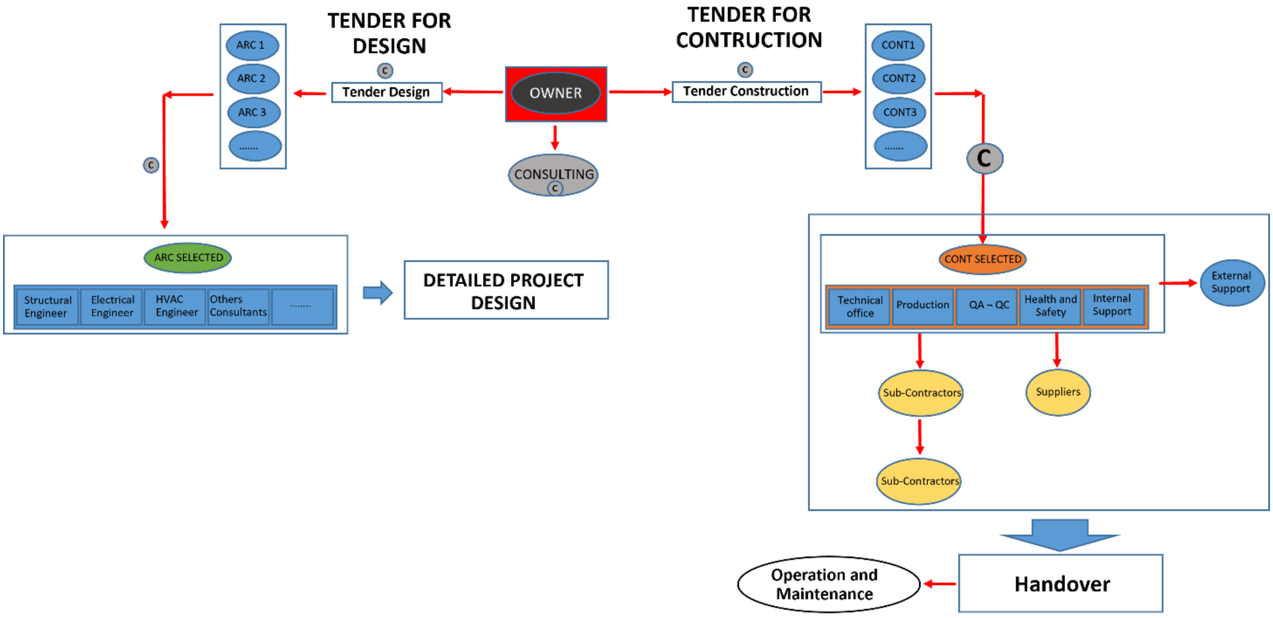


Figure 56. Traditional contracting and construction management system for building construction in Spain

On the other hand, contracting with the private sector can be done in different ways, all of them involving a consultant specialized in the technical and economic management of construction projects, who represents the property in dealings with the main contractors (designer and builder). For any of the types of contracting with the private sector and as well as in contracting with the public sector, the designer usually subcontracts all the calculations and the construction companies subcontract most of the work execution items, as well as any necessary technical support. It is also increasingly common for construction to be split into several phases, with each phase being put out to tender.

The first type of contracting is the same as the one with the public sector, but with the figure of the consultant, who is in charge of carrying out the tenders and controlling and managing the entire project.

The second type of contracting with the private sector consists of contracting the design and construction to the same subcontractor. In this case, a builder is usually contracted either directly or through a tender, who in this case is responsible for managing the project design and all related calculations (structural, geotechnical installations, etc.) and subsequently executing the construction works. The following graphic shows this process.

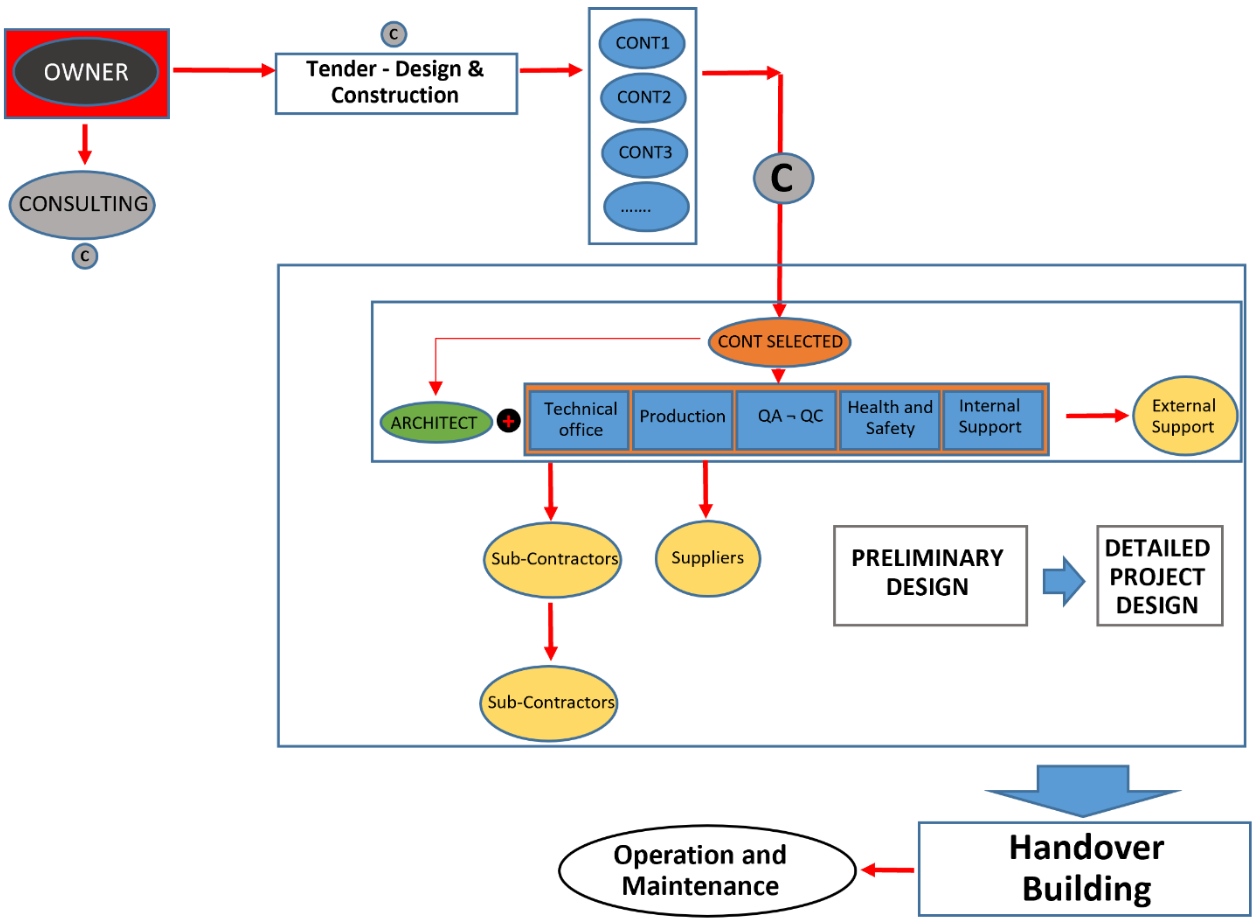


Figure 57. Second type of contracting and construction management system for building construction in Spain

The third case of contracting with the private sector, which is becoming more and more frequent, tends more towards an Integrated Project Delivery or open book model in which the property, represented by a consultant, as previously explained, hires either through a tender or directly a builder, architect and in some cases also the future maintainer of the building. The target is to work together with the consultant and the property on a common objective, in order to obtain the greatest benefit for all.

Finally, it can also be the case of contracting a designer and builder, to obtain a fairly well-defined design and in a second phase, contract the construction directly or through a tender. The following graphic shows this process.

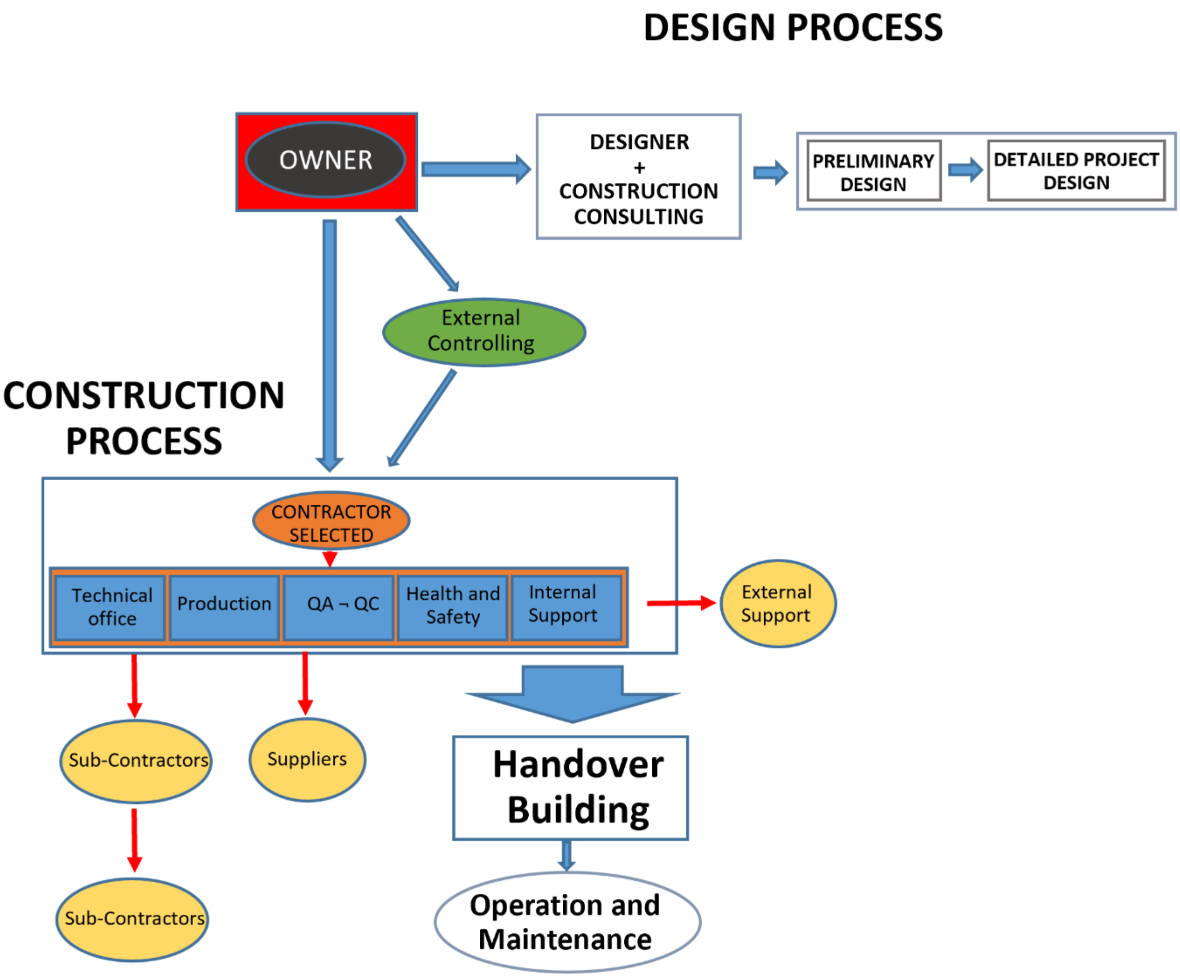


Figure 58. Third type of contracting and construction management system for building construction in Spain

Process

The following image shows the common process of the building life cycle, the main actors involved in this process and the key moments to make decisions or carry out procedures to have a correct development of the cycle. The first image fit with the public building life cycle and the first type of the private. This is the most common way in the marke

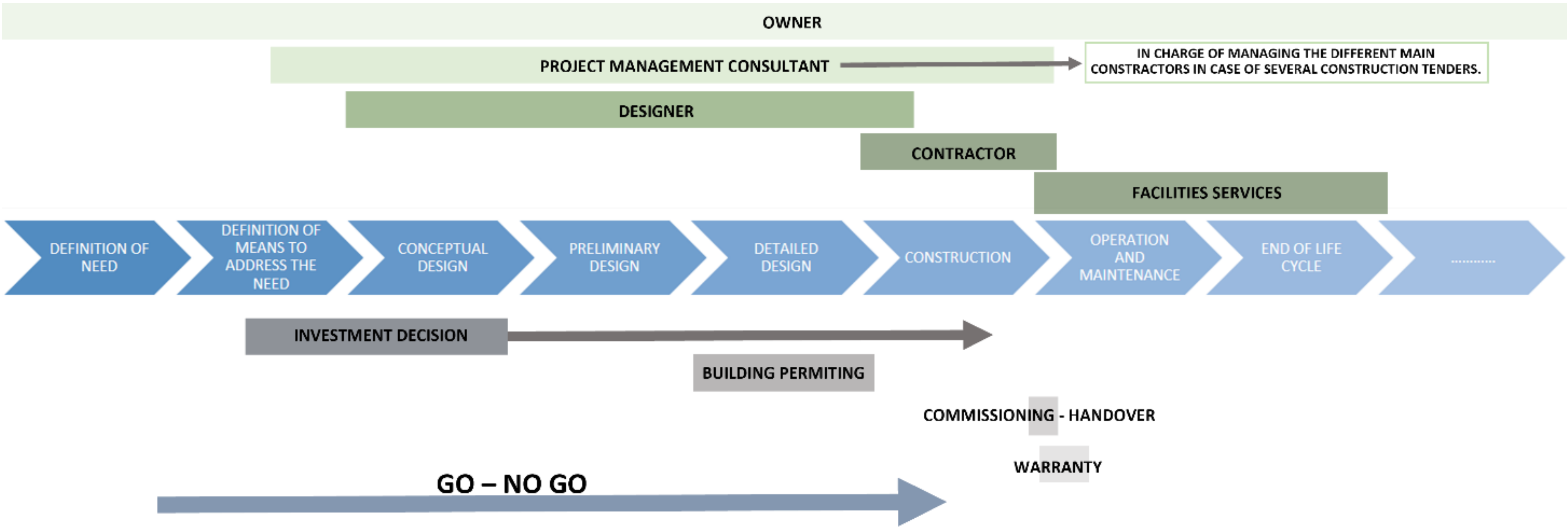


Figure 59. Standard Spanish construction project stages

The following image shows one of the ways of contracting and manage building life cycle with the private sector in the Spanish market.

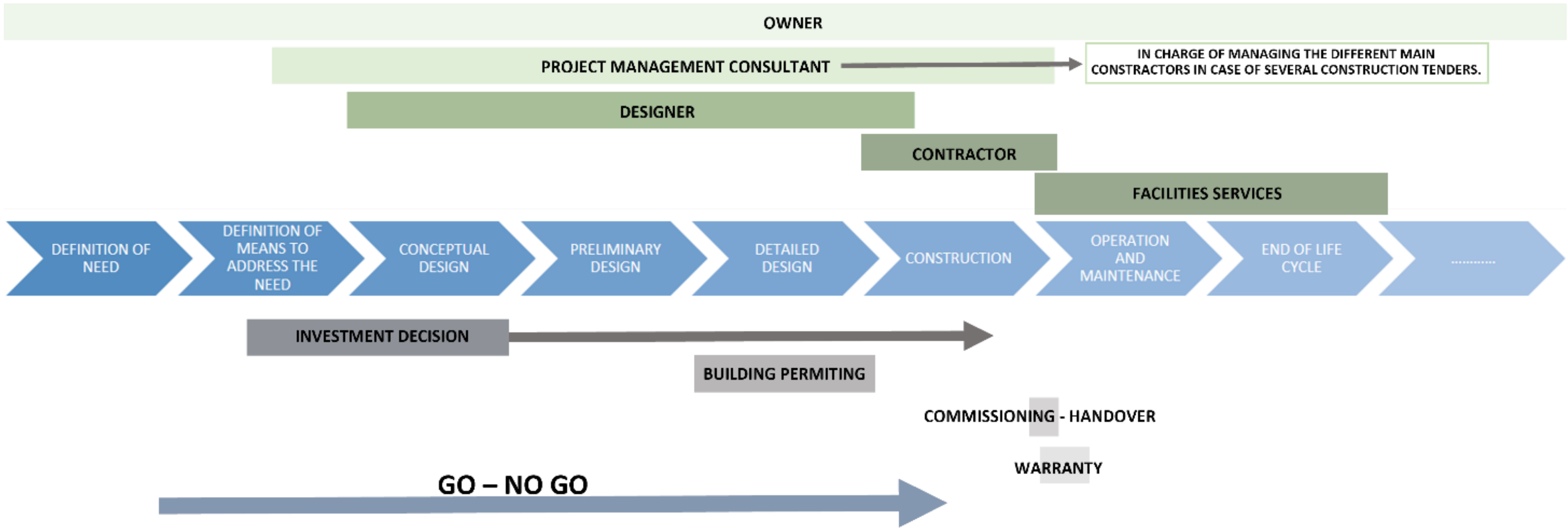


Figure 60. Standard Spanish construction project stages with the private sector

In relation with the panning procedures, the next image shows a standard construction production planning in a Gantt table, which can be linked to a Synchro for work tracking and visualization with BIM models, which could be a common practice in Spanish market.

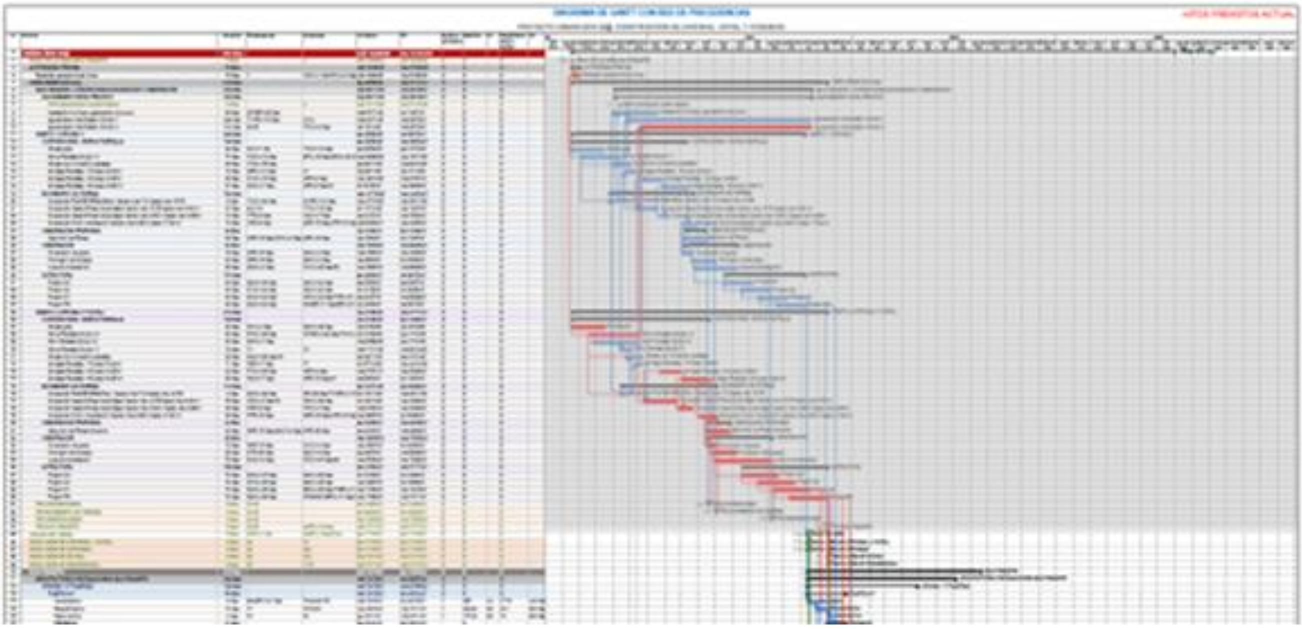


Figure 61. Example of master schedule for a project in Spain (*)

(*) The purpose of this figure is exclusively to show a general view of a common master schedule but due to confidentiality reasons of the company which has provided it , the tasks and schedule are not deliberately identified on the image

There is not a strict procedure for all projects, the planning team, adapts to the needs of each project/client. The planning can be done in different tools as Ms. Project, Presto, Primavera, etc., or even go a step further and use LPS (more common in infrastructure projects). About which tool to use is going to depend on the client's requirements, however, taking into account that the use of BIM models is becoming more and more common in projects, the use of synchro or similar tools will end up being used in all projects.

Project: OFFICES & HOTEL

The project involve on BIM2TWIN Project is located on Barcelona Spain and is Offices and Hotel buildings, the whole project cover around 35.000m2 and the construction process is 36 months.

The Facades is a structural curtain wall system, with thermal bridge break + Extruded aluminum frame +, the Roofs is a Flat walkable roof made up of slope formation with cellular concrete, mortar base layer, fiberglass felt, waterproofing with two polymeric sheets, polyester fiber felt, thermal insulation with extruded polystyrene panels, polyester fiber felt and 3 cm mortar layer. The project also has a Green roof with a gardened finish based on gravel for drainage, topsoil, and natural grass. The Structural System consist of a vertical structure of reinforced concrete portal frames working in conjunction with the stair and lift cores to ensure the overall stability of the building and its load-bearing capacity against the gravity actions considered. The floor slabs are solid reinforced concrete slabs on all floors.

6.2 Prioritization matrix of the inefficiencies to be solved according to the Pilots

In this section, each of the project's partner construction companies that will be in charge of the pilot cases will select and identify the main inefficiencies that, based on their experience and the results of the surveys and workshops carried out, most affect their on-site productivity. To this end, for each pilot case, the exercise of analyzing and prioritizing those inefficiencies that can be solved and improved through the digitization of the construction process will be carried out.

6.2.1 *French Pilot*

Altogether the French Pilot managed to gather information out of 11 professionals. It was important for us to represent the diversity of key players. SPADA and CSTB decided to organise two different workshops, thinking that people would be more willing to talk in a small group. Participants included three worksite managers, a foreman, a tender manager, a safety & health engineer, a topographic surveyor, a chief operational officer, an architect (partner of SPADA) and two team managers.

When asked about the inefficiencies most affecting their work, the participants highlighted and prioritised:

i. Continuous changes and modification

ii. Difficulty to hire skilled workers and subcontractors

iii. Lack of collaboration between stakeholders involved in the work phase

iv. Inadequate planning of the work

v. Difficulty to update the planification and work tools and methods

Most issues revolve around the planning of work, which is affected by the owner's changes and the difficulty to know about the work that has been done effectively on site. Key players struggle to keep planning updated and take the right decisions according to it and this has a strong impact on productivity and project's progress.

Regarding the first cause of inefficiency, continuous changes and modification, participants identified that the problem was rooted in the conception phase or related to project management. The digital twin could help by making the planification of work more fluid by giving real-time access to this information to everyone. They stressed the fact that they have very little time and that, to be used, a tool would have to make them save some. It should be user friendly, meaning that stakeholders would need to select or focus on data that is useful to the execution team, easily updated and accessible in a few clicks. More specifically, useful functionalities would include first, automatic update of surveyed quantities, automatic work (tasks, machines...) re-planification when a drawing is modified and second, workflow of validation of the modifications to avoid mistakes.

This relates to issues inadequate planning of the work and difficulty to update the planification and work tools and methods (iv and v), where participants pointed out the problem of control of the work "really done" and how to adapt to discrepancies with the "as-planed" work. A tool that could allow to have real time information on the progress of tasks (notifications when work is completed, zones of pouring, used quantities of concrete) linked to an update of the planification of future work accordingly would prove be very helpful. Such a tool should be adapted to every user from site manager down to the foreman and workers. It would need to take in account, not only the need of project management but also the specificities of each trade work. Per example for structural work, a functionality that propose a planification of formworks use would be necessary. Far more basically, the ability to access thanks to a 3D model to the representation of final work and go through the different phases (as in BIM 4D) interested team leaders as it could help anticipating problems.

The lack of skills of workers was identified as the second cause of inefficiency on the construction site. The identified causes are that there is a shortage in skilled workers as the difficult working conditions in construction make this type of career unattractive to students. Consequently, many workers are not trained and learn to do the job on the spot, where they may lack tutorials. New technologies could provide training or tutoring solutions: some tutorials could be accessible from the model besides work planification and solutions. Robotisation of the tasks was also noted as a countermeasure to the lack of skills.

Participants explained the lack of collaboration between stakeholders (project management team, each trade companies) involved in the work phase by the fact that each of them has different goals that might not be consistent with one another. Better worksite organisation by project owner and its management team, increased and better communication were identified as key to address this problem. Participants believe that the use of 3D Models could help improve the communication as long as everyone uses it.

Additional interviews with the two team leaders revealed a new identified issue regarding control of quality especially about control before pouring of concrete (to check quantities) and positioning of reinforcement (*ferraillage*). It appeared that processes and methodologies would differ in each company and would be very basic (paperwork + pics) and that there was no clarity about who should do it and no trackability (who did intervene, which products were used...).

6.2.2 *Finish Pilot*

Fira has been developing flow-based renovation model from 2015 and started development of takt production system for residential housing from 2018. Fira's construction production is based on conceptualized construction and the use of sub-kits to standardize an apartment building.

From the perspective of Fira’s construction philosophy, we are not just focusing on the flow process and its digitization, but we want to build feedback on design solutions. In our view, the building, its solutions and product components as well as the materials determine the process and its efficient flow. The process consists of the tasks and their order, as well as the materials connected to them. Fira has sought to take over a demanding entity by developing a data model-based design and implementation process, the core of which is structured information management. To increase labour productivity, Fira focuses on synchronous production, which makes the flow concretely visible, as the core of synchronous production is batch size reduction compared to traditional fixed-price subcontracting and the purchase of materials and labour in a black box. As a basis for the development work, Fira has used task management, which requires the main contractor to manage design information at a much more precise level than usual than in the traditional way of operating, where schedule, quality and quantity risk are outsourced to a subcontractor. As a result, Fira has separated product and process information from each other and developed its own software solutions, as there are no tools available on the market that would allow production planning and clock production to be managed with sufficient accuracy. For the same reason, Fira has also been able to be the first on the market to develop a digital and real-time awareness tools for construction sites using Fira’s Open Data Platform (ODP). Currently Fira is developing the takt production in flagship projects and plans to include Suvela for BIM2TWIN project as a pilot.

Fira has divided the construction project into four sub-series groups and the pace phases they form. Fira has been collecting data on the implementation of construction sites for three years, which in practice has arisen thanks to the introduction of digital tools in schedule management and quality control. In practice, this has meant the introduction of mobile apps at work on the construction site in addition to the applications used in the office. Fira has used this data in workshops to determine on a fact-based basis the sources and root causes of inefficiency that Fira is investigating in this project. Fira has organized workshops with two kitchen suppliers and these subcontractors and interviewed site staff on three projects to verify the deficiencies identified by the data. Based on this analysis, Fira has selected the kitchen installation process to be modelled in the project so that Fira can practically test the KPI of the process and collect data more comprehensively than would normally be possible. In kitchen installations, Fira focuses on modelling the entire supply chain from design to delivery, so that Fira can find out what the root causes of inefficiency actually are.

Based on the workshops, Fira clarified the three main reasons for the workshops (inadequate work planning, constant changes and modifications to plans, and lack of implementation control) as shown in the figure below, and fourthly added the lack of debug feedback for design, prefabrication and procurement. In practice, the fourth point means that Fira must add to the snapshot both delivery management and the delay and delivery status of repairs / post-deliveries.

From the point of view of prioritization, the most important things to correct are managing continuous change and identifying these root causes with the help of model work. Fira aims to implement a decreasing error rate in the pilot project. This takes place in practice at three levels in kitchen installations: measuring the correctness of measurement visits and prefabrication, measuring the readiness of the previous work steps (initial conditions), and managing installation work and post-delivery. This implementation makes visible the control of the implementation that is missing from the current snapshot, because then we can also see and recover data from quality management, i.e. repairs, post-deliveries and approval of repairs. Fira's data also show a clear relationship between job planning and the success of measurement visits, especially when looking at installation work for dimensionally accurate kitchens. A failed measurement visit produces incorrect input data for prefabrication, which naturally results in an increase in the expected error rate.

6.2.3 *Spanish Pilot*

The workshop on the Spanish Pilot was conducted with the presence of four ACCIONA workers that operate directly on the construction site, including the site foreman, the production manager, the quality manager, and the technical office manager. At the first activity, all participants agreed that both the inadequate planning of the construction and continuous changes in the project can be considered main overall inefficiencies in the construction site, which were the inputs brought by the organisers as a result of the previous questionnaire conducted by BIM2TWIN project.

When asked specifically which were the inefficiencies most affecting ACCIONA, the participants highlighted and prioritised other weaknesses, such as:

i. lack of qualified workers.
ii. lack of cooperation between the different parties involved in the field.
iii. lack of control of the execution.
iv. inadequate construction work planning.

According to the workers, these inefficiencies affect mainly the execution & quality control, and the planning aspects of the construction management. However, the omission of the health and safety aspects of this conclusion could be explained by the absence of the H&S coordinator at the workshop.

As the discussion moved on, conclusions were that many of these inefficiencies could be resolved by more constant and regular meetings between the different parties of the construction site for the improvement of the project planning, working collaboration, monitoring the execution of tasks, checking for possible modifications, and setting intermediate milestones.

The technology could support the construction management in solving the issues of difficulty in contracting qualified contractors and subcontractors, by adding value in the capacitation of workers by training and management of offers, where a digital management platform could support on the identification of best option (based on previous works, price, etc.). For improving the collaboration between different parties in the construction, technology could be used to facilitate the communication via portable devices.

For monitoring quality and control execution, the workers suggest having more milestones in between, and more people responsible for quality follow-up, for dividing the workload. A software could support project managers and the entire team on having quality certifications and plans at hand, besides allowing the input of immediate inspections results. The construction planning could also be enhanced by having a system in which workers could follow the schedule in real time, with the latest modifications and even different scenarios based on past experience of previous projects.

For the ACCIONA construction team, the most important information that the workers would like to know on real-time at the building site are what are the subcontractors working on in the construction, the monitoring of materials (what is going in or out of the storage, and the quantity of material being used), and the current situation of the machineries on site. Some additional ideas also arose from the discussion, as the workers reflected on the current issues happening on the site on the phase of excavation and foundation. There is the need of monitoring infiltration points on the construction, in which technology could support solving.

6.3 Current implementation of the Digitalisation on the works led by BIM2TWIN Contractors Companies

As it is explained in the chapter 4.6, some technologies for the digitalisation of the process are key to improve the productivity and the barriers to use them in each pilot must be clearly identified to adjust the future developments to the pilot partners' needs. Additionally, as starting point for knowing the barriers for digitalisation, it is necessary to identify the current level of digitalisation of the contractor s companies.

In consequence, this chapter is devoted to knowing further the current level of the digitalisation in the companies leading the pilots, as starting point to define specifically the requirements for the DBT in each pilot. In the following points, the different technologies, tools and devices that the construction companies that are partners in the project use on site to address any of the specific domains of BIM2TWIN, Planning, Health and Safety and Quality and Execution Control, are described.

6.3.1 *French Pilot*

SPADA doesn't use many technologies, tools and devices in the areas covered by BIM2TWIN.

The most used tool is Easy-KUTCH edited by Attic+. This tool is a 2D / 3D graphic calculator allowing the automatic realization of all the quantities and sub-details of a project out of PDF files or CAD / CAD plans in DWG or DXF formats. Although SPADA has been mainly used it for bidding until now, they consider using it in the construction phase to assess additional work implied by project owner's additional request or evaluate quantities to prepare invoices.

In addition, worksite managers use the viewer EveBIM and the platform Kroqi to open and visualize 3D models sent by partners or the owner, but once on the site, they get back to 2D plans. Note that SPADA gave up on Revit considering it too complicated (capacitation time proved too long) and not adapted to the specificities of structure work (no functionality relating to concrete pouring and stopping). Finally, they also use FINALCAD et KALITI after the handover phase to track the areas to be checked, whether during preventive inspections or troubleshooting.

6.3.2 *Finish Pilot*

The digitization of Fira is practically based on the use of two tools on site. Fira makes production planning pace scheduling using the scheduling software Sitedrive developed by Fira. Quality management is based on software developed by Fira's partner, Congrid, for which Fira has implemented a task-specific checklist implementation that forms Fira's quality matrix. These systems have been made compatible by structuring the ontology developed by Fira in the Diction project. One of the most important outputs of this digitization is the building spatial data model, which enables the indexing and integration of production design data and quality management data in Fira's ODP. Fira's snapshot is based on data processing in ODP and its visualization using BI. The architecture and structure are described in the figure below.

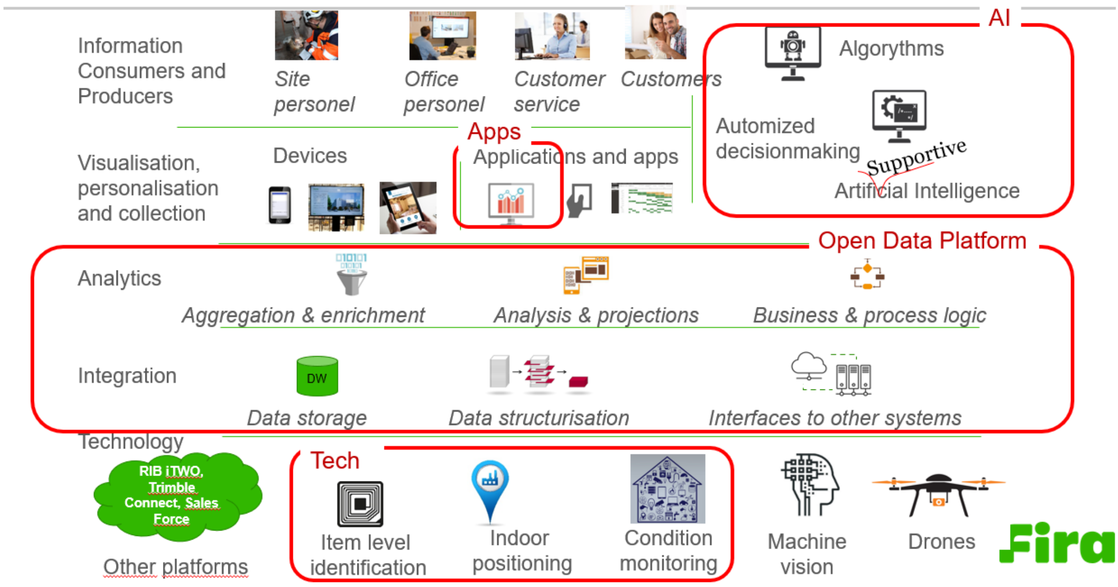


Figure 62. Current implementation of the Digitalisation on FIRA

From a process perspective, Fira's applications form a chain of use cases that allow Fira to gather an end-to-end process dual from the construction process. The use cases are shown in the figure below.

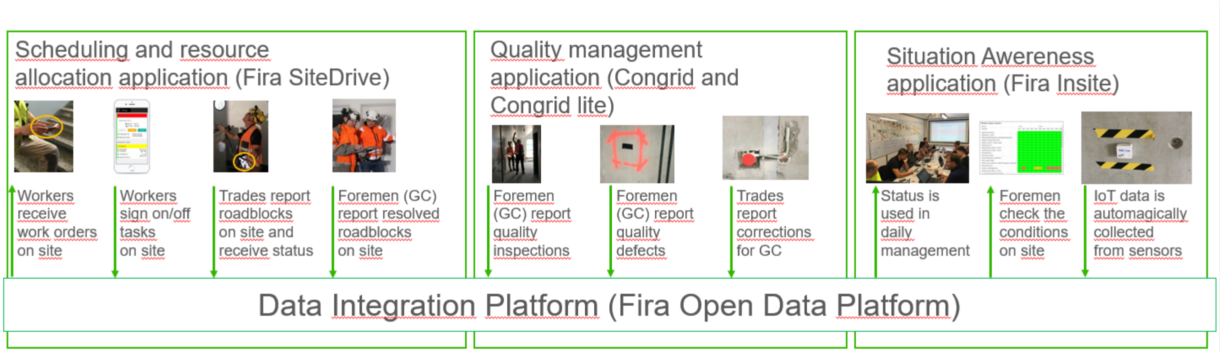


Figure 63. Fira Open Data Platform

In Finland, there is a statutory standard safety measurement carried out once a week, which provides information on site deviations and the frequency of accidents. Fira has integrated the applications it uses into a production management system, which has been supplemented with health-related management of lock-down situations due to the Covid-19 pandemic, as well as daily management information on corona measures and the snapshot.

6.3.3 *Spanish Pilot*

ACCIONA has in place a Construction Technology Centre, an innovation lab with which, among other tasks, the company designs digital solutions to optimize construction processes, combining different software platforms with the employment of IoT and monitoring devices such as sensors, drones, lasers scanners and mobile mapping. Currently, the company has been implementing and testing several software platforms to digitalise its construction processes, as a part of the company digital transformation. Within ACCIONA´s strategies for the digitalisation, the company has developed an IoT Platform for supporting the monitoring and management of the projects (e.g., project management, tracking and use of resources), which allows real-time control for optimising operations and improving productivity in projects.

Since ACCIONA has a comprehensive scope of construction typologies, the IoT platform has a modular characteristic that can be adjusted to each individual project, according to its unique requirements and conditions. The different modules correspond to the main construction typologies or main phases, for instance: foundations, tunnel construction, pavement, and structures.

There is not a strict procedure for all projects. The planning team adapts the processes to the needs of each project/client. The planning can be done with different tools, such as presto, primavera, etc. The decision about which tool to use depends on the client's requirements, however, considering that the use of BIM models is becoming more and more common in projects, the use of tools for digital project management will come to being used in all projects. One example is Synchro, which includes all the functionality to plan and control the work execution - it uses an advanced CPM (Critical Path Method) engine for project planning.

For Quality and Execution Control, ACCIONA is also implementing digital applications for replacing paper-based technical reports at the construction site, as an approach for speeding up communication between actors, saving time in data processing and reporting daily updates for faster decision-making (e.g., FINALCAD, EPCTracker, BIM 360 Field, etc.).

There are also digital technologies for enhanced Health and Safety, which consists in risk prevention by the use of different wearable devices in real time, such as bracelets, smart bands and sensors with smartphones, beacons, and tablets. This system enables early detection providing warnings about risky situations that could lead to real incidents, both to workers and supervisors.

Overall, all the platforms have as a common goal provide real time status of the field of construction, improving the efficiency at the working site, avoiding unnecessary work and predicting possible issues and risks for a more holistic decision-making process.

6.4 Barriers to overcome for the implementation of the digitalisation in the construction process

From the starting point of each contractor company state, they have prioritized the barriers for digitalisation that should overcome on their process to improve the productivity, on the basis of the results of the surveys and workshops. Those barriers will be transformed later on into user requirements for the DBT.

6.4.1 *French Pilot*

The main obstacles to digitalisation identified during workshops are mainly linked to the specificities of the construction industry in France. Construction companies in France are predominantly of a small size, meaning they have limited investment capacity in training and R&D, and ROI is not easy to assess. They also have a low digital culture, especially on the construction sites.

Participant consider resistance to change on construction sites as the main obstacle to digitalisation. Therefore, changes in methods and must be incremental and very progressive. Pedagogy work will need to be conducted to explain and demonstrate the benefits of the change for the users (ROI, health, security,

time), who will only change his habits for a simpler/safer/more efficient work routine. For the same reason, software tools require to be user friendly and take in account the specificities of each trade.

The significant amount of initial investment (financial and time resources) needed to use new technologies is a barrier to construction companies such as SPADA. Participants stressed the fact that most construction companies (except from the big ones) cannot afford to dedicate a significant budget to R&D and thus to the implementation of innovative technology and training, especially when there is no clear evidence in terms of ROI.

The lack of data management skills in companies is another difficulty and participants have recommended that most actions should be automated, especially collection of onsite data, integration of new drawings, calculation of surveyed quantities, selected work solutions/methods so that data updates require minimum intervention.

Finally training on software tools seems complicated to participants, in terms of finding time and money and some training adapted to their specific needs. They recommend putting an extra effort on ergonomics and MMI to minimize capacitation efforts of stakeholders. Training would need to include Tutoring on the job to be efficient.

6.4.2 *Finish Pilot*

In the Kontula project, Fira implemented a series of workshops and a limited PoC, which tested the ease of use of mobile tools with the help of QR codes and a user-specific language menu. The results obtained from miniature PoC using Teams platform tools and platform independent QR implementation confirmed the barriers and method for removing the barriers. Fira has previously identified the main barrier to digitization as the poor usability of mobile applications in the field:

1. there are so many differences between the different types of subcontracting tasks that it is not possible to implement quality management in one application
2. the main contractor is practically unable to compile effective generic checklists because the quality information produced by Rakennustieto Oy or similar actors is too superficial and always requires the exact information of the material supplier as additional information.
3. status information (started, stopped, suspended, continued) is not sufficient to manage job status information, and obstacle notification without two-way dialogue on solution, scheduling, resourcing and payment is not a sufficient feature

In practice, WhatsApp management has become more common and is practically a substitute in many situations due to ease of use and interactivity. Fira has analysed WhatsApp data and found that its use is widespread and effective on site. In practice, there are four management channels at the construction sites (1) the main contractor's own employees, 2) all foremen, 3) hourly workers, 4) special needs: demolition site, crane, etc.) and supply chain-specific channels (e.g. element foreman, element installer, demolition worker, Fira's goal during the project is to develop a solution that combines schedule planning, site management, quality management and the supply chain.

6.4.3 *Spanish Pilot*

In the workshop conducted in the construction site of the Spanish pilot, the most relevant barriers highlighted for ACCIONA to solve for implementing digitalised construction management were:

i. Resistance to change to the new ways of digital working.
ii. Traditional contracts might not be aligned to the new way of digital working.
iii. Each subcontracted company has a different way of working, with their own tools and internal processes.

iv. Lack of knowledge in the digital tools used on the construction.

Most of the participants agree that the way to overcome the resistance of changing is to demonstrate to the actors involved that the new way of working is more efficient. The types of contracts with subcontractors will also need to change in order to adapt to the new way of working. New models of contract, that could be different depending on the service, should be defined by goals to be reached and include more detailed assignment of responsibilities. Moreover, to facilitate the digitalisation in the construction management, the different companies involved should use a unique platform, in which should all of the end-users should receive proper training.

Moreover, the workers of ACCIONA defined that the information regarding the construction works should be monitored for improving aspects of the performance of the companies and work completed, the degree of safety of the construction site and possible risks, and mapping of staff on the site.

The participants demonstrated openness towards using new tools for digitalizing the work. For the tools, a combination of phones and tablets would be ideal, since the needs can vary in each part of the work - the phone is a preferred tool on the daily use for using the platform (usually workers carry many tools around the site), and other construction inspections could be done by tablets. The chosen digital platform for digital construction management should be practical enough for introducing data in a simple way, where each input gives an immediate output.

7 User requirements towards Digital Twin Building Platform

In this chapter, it is drawn up a first approach of the high-level user requirement which will lead to the further definition of the technical specification of the DTB platform, based on the elicitations from the stakeholder. Therefore, a preliminary list of overall requirements for each pilot has been outlined from the user´s perspective.

By requesting the insight of the partners involved in the pilots, the areas where they would like to concentrate their improvement are defined. At this time, a draft including the priorities of the pilots is terms of parts of the process and vertical BIM2TWIN Domains where they want to focus, has been outlined This approach must be still deeply discussed between pilot partners and technical partners in order to cover as much as possible the objectives of the project.

The preliminary draft of requirements and the prioritization of scenarios for each pilot will allow to further define the use cases where the DBT Platform must focus on the basis of the end-user requirement of the DBT.

7.1 Mapping of the expectations with the end-user's requirements

In this section, as described in chapter 3.5 of the research methodology followed, through several technical discussions among the BIM2TWIN partners, the mapping and definition of the end-user requirements has been carried out in order to establish the specifications of the digital twin construction platform.

In the technical meeting with the partner, after addressing the overall technical it has been suggested to identify some specific use case to define into detail the user requirements, which must respond to the needs of the end user.

First of all, the results obtained in the workshops carried out by the construction companies with the staff involved in the construction process, have been assessed. In those workshops the main inefficiencies and points of improvement of the execution process on site have been identified. In addition, the real-time data that should be monitored and known to solve them have been identified by asking the participants.

From the prioritization of the pilots´ needs, regarding their areas for improvements, their starting points in terms of digitalisation and barriers to implement this digitalisation, a first draft of overall user requirements has been drawn up. This high-level users’ requirements must deeply break down into particular requirements to define further the specifications of the DBT Platform. This approach will be helpful to design a user-centered platform starting from the real need form the point of view of different stakeholders involved in the process.

As a result, a first approach to the overall user requirements for the Digital Building Twin Platform has been outlined for each pilot country

In the following tables, drawn by each pilot, the key areas for improvement identified by each one is listed, as well as a suggestion of user requirements to overcome those inefficiencies. The domain where each point is addressed has also been included with the aim of deeply tackling in future steps of the project by the fields of study.

FRENCH PILOT :

	INEFFICIENCY AND POINT OF IMPROVEMENT	USER REQUIREMENTS	DOMAIN
GENERALITIES TO IMPROVE ON SITE	**Continuous changes and modification**	to Automatic update of quantities surveyed when a drawing is modified	Scheduling & equipment control
	Continuous changes and modification	to Automatic update of planification of works when a drawing is modified	Scheduling & equipment control
	Continuous changes and modification	to make Workflow of validation of the modification to avoid mistakes	Scheduling & equipment control
	Difficulty to hire skilled workers and subcontractors	to help improve and enhance the training and tutoring of the workers with the new technologies	Quality & execution control
	Lack of collaboration between agents	to improve the communication between agents with 3D Model by everyone	Scheduling & equipment control
	Lack of collaboration between agents	to provided Clash management meetings	Scheduling & equipment control
	Inadequate planning of the work	to have a real-time information of what work has been really executed	Quality & execution control
	Inadequate planning of the work	to update the planification of future work accordingly with the executed work	Quality & execution control
	Difficulty to update the planification	to have a software that automatically update the planification	Scheduling & equipment control
	Difficulty to update the planification	to be adapted to the use of everyone on site from site manager down to the foreman and even the workers	Scheduling & equipment control
	Difficulty to update the planification	not to perceive as time consuming	Scheduling & equipment control
MOST IMPORTANT ASPECTS	**Difficulty to maintain the data updated**	Acquisition of data on site	Quality & execution control
	Difficulty to maintain the data updated	integration of new drawings	Quality & execution control
	Difficulty to maintain the data updated	calculation of quantities surveyed	Quality & execution control
	Difficulty to maintain the data updated	tools adapters to the specific own trade	Quality & execution control
	Low acceptance of change	software tools have to be very easy-to-use by every user	All Domains
	Low acceptance of change	To demonstrate and convince the gain or the improvement brought by the change	All Domains
	Low acceptance of change	Changes has to be incremental and very progressive	All Domains
	Need of training	software tools have to be very easy-to-use by every user	All Domains
DATA AND INFORMATION REQUIREMENTS	**real time data**	orders of equipment	Scheduling & equipment control
	real time data	Deliveries of equipment	Scheduling & equipment control
	real time data	Localization and schedule of on-going concrete pouring	Scheduling & equipment control
	real time data	Presence of collective safety protection	Health &Safety
	real time data	Conformity of collective safety protection	Health &Safety
	real time data	list of personal on site	Health &Safety
	real time data	Risk detection (e.g.: fall from heights)	Health &Safety
	real time data	Quantities of work really executed (concrete volume)-Quantity of volume of concrete poured	Quality & execution control
	real time data	Quantities of steel (Relation between volume of concrete and weight of steel (in relation with drawings)	Quality & execution control
	real time data	Quantities of work really executed (weight of steel)	Quality & execution control

Table 1:. User requirements from French pilot case

FINNISH PILOT :

	USER REQUIREMENTS	DOMAIN
GENERALITIES TO IMPROVE ON SITE	Inadequate work planning	Scheduling & equipment control
	constant changes	Scheduling & equipment control
	modification to plans	Scheduling & equipment control
	lack of implementation control	Quality & execution control
	lack of debug feedback for design, prefabrication y procurement	Scheduling & equipment control
	poor usability of mobile application in the field	Scheduling & equipment control
	"so many differences between the different types of subcontracting tasks	Quality & execution control
	that it is not possible to implement quality management in one application"	Quality & execution control
	the main contractor is practically unable to compile effective generic checklists because the information is too superficial	Scheduling & equipment control
	Status information (started, stopped, suspended, continued) is not sufficient to manage job status information	Scheduling & equipment control
	notification without two-way dialogue on solution, scheduling, resourcing and payment	Scheduling & equipment control
MOST IMPORTANT ASPECTS	the snapshot of delivery management	Scheduling & equipment control
	the snapshot of delay	Scheduling & equipment control
	main contractor is practically unable to compile effective generic checklists very status of repairs / post-deliveries.	Scheduling & equipment control
	to correct the managing continuous change	Scheduling & equipment control
	to identify the root causes	Scheduling & equipment control
DATA AND INFORMATION	the kitchen installation process	All Domains
	measuring the correctness of measurement visits and prefabrication	All Domains
	measuring the correctness of measurement prefabrication	All Domains
	measuring the readiness of the previous work steps (initial conditions)	All Domains
	managing installation work and post-delivery	All Domains

Table 2:. User requirements from Finnish pilot case

SPANISH PILOT :

	INEFFICIENCY AND POINT OF IMPROVEMENT	USER REQUIREMENTS	DOMAIN
GENERALITIES TO IMPROVE ON SITE	Inadequate planning of the work	Obtain changes in the planning of tasks automatically according to the actual progress of the work.	Scheduling & equipment control
	Inadequate planning of the work	to have a real-time information of what work has been really executed	Quality & execution control
	Inadequate planning of the work	to update the planification of future work accordingly with the executed work	Scheduling & equipment control
	Continuous changes and modification	to Automatic update of quantities surveyed when a project is modified	Scheduling & equipment control
	Continuous changes and modification	to Automatic update of planification of works when a project is modified	Scheduling & equipment control
	Continuous changes and modification	to Automatic update of methodology of works when a project is modified	Scheduling & equipment control
	Continuous changes and modification	to make Workflow of validation of the modification to avoid mistakes	Scheduling & equipment control
	Difficulty to hire skilled workers and subcontractors	to value in employee empowerment through training	Quality & execution control
	Difficulty to hire skilled workers and subcontractors	to help improve and enhance the training and tutoring of the workers with the new technologies	Quality & execution control
	Difficulty to hire skilled workers and subcontractors	to manage bids received and support in the identification and selection of the best option (based on previous work, price, etc.)	Quality & execution control
	Lack of collaboration between agents	to improve collaboration between the different stakeholders of the site	Scheduling & equipment control
	Lack of collaboration between agents	to facilitate communication through portable devices	Scheduling & equipment control
	Lack of collaboration between agents	to provided constant and regular meetings between the different parties	Scheduling & equipment control
	Difficulty to update the planification	to have a software that automatically update the planification	Scheduling & equipment control
	Difficulty to update the planification	to have different planning scenarios based on the experience of previous projects	Scheduling & equipment control
	Difficulty to update the planification	to provide more intermediate milestones for control of the work executed and quality monitoring,	Scheduling & equipment control
	Difficulty to update the planification	to have software that facilitates access to certifications	Quality & execution control
	Difficulty to update the planification	to have a software to provide access to quality plans	Quality & execution control
	Difficulty to update the planification	to take into account not only the need of project management but also the specifies of each trade work.	Scheduling & equipment control
	Difficulty to update the planification	to provide the task calendar in real time	Scheduling & equipment control
	Lack of control of the execution	to have a software that facilitates the entry of immediate inspection results	Quality & execution control
	Lack of control of the execution	to have a IPP software (Inspection Point Programs) that facilitates the control of execution and quality.	Quality & execution control
MOST IMPORTANT ASPECTS	Low acceptance of change	To demonstrate and convince the gain or the improvement brought by the change	All Domains
	Low acceptance of change	software tools have to be very easy-to-use by every user	All Domains
	Low acceptance of change	tools adapters to the specific own trade	All Domains
	Low acceptance of change	digital platform must be practical to enter data in a simple way	All Domains
	Lack of collaboration between agents	the different companies involved should use a common platform	Quality & execution control
	Lack of collaboration between agents	all companies involved must receive appropriate training	Quality & execution control
	Difficulty to maintain the data updated	Acquisition of data on site	Quality & execution control

	INEFFICIENCY AND POINT OF IMPROVEMENT	USER REQUIREMENTS	DOMAIN
	Difficulty to maintain the data updated	Calculation of company performance and work performed	Scheduling & equipment control
	Difficulty to maintain the data updated	digital platform should give immediate output of information with each data entry	Scheduling & equipment control
	Difficulties to know where the staff is located on-site	mapping of on-site workers	Health &Safety
	Tools, equipment's and machinery, loss or not knowing their location	mapping of on-site workers	Health &Safety
DATA AND INFORMATION REQUIREMENTS	**real time data**	Company performance and executed work.	Quality & execution control
	real time data	what are the subcontractors working	Quality & execution control
	real time data	water loss flow rate in foundation wall analyses	Quality & execution control
	real time data	Checking movements or displacements of the retaining walls	Quality & execution control
	real time data	Quantities of work really executed (concrete volume)-Quantity of volume of concrete poured	Quality & execution control
	real time data	Quantities of steel (Relation between volume of concrete and weight of steel (in relation with drawings)	Quality & execution control
	real time data	Quantities of work really executed (weight of steel)	Quality & execution control
	real time data	Quantities of work really executed (surface of slabs)	Quality & execution control
	real time data	Quantities of work really executed (length of walls)	Quality & execution control
	real time data	monitoring of materials	Scheduling & equipment control
	real time data	material stock level	Scheduling & equipment control
	real time data	material leaving the storage	Scheduling & equipment control
	real time data	current situation of workers on site	Scheduling & equipment control
	real time data	current situation of the machineries on site	Scheduling & equipment control
	real time data	Tools and machinery needed for each task.	Scheduling & equipment control
	real time data	Schedule of subcontractors and other work entry	Scheduling & equipment control
	real time data	need to know the circulation plans within the construction site.	Scheduling & equipment control
	real time data	Risk detection (e.g.: fall from heights)	Health &Safety
	real time data	Potential risks associated with the work I perform	Health &Safety
	real time data	Presence of collective safety protection	Health &Safety
	real time data	Control of the personal protections according to on-going task	Health &Safety
	real time data	Conformity of collective safety protection	Health &Safety
	real time data	Control of collective safety protection	Health &Safety
	real time data	list of personal on site	Health &Safety

Table 3:. User requirements from Spanish pilot case

7.2 Preliminary identification of the use cases according to the pilots expcetations

Even though all the construction companies of the consortium are interested in improving most of the processes of the and different domains of the on-site works on site, it´s necessary to focus on a use case in each country. It will enhance to identify specific user requirements, which will address all the domains in different phase of the construction processes. The analysis of the workshops findings has made possible to extract the main points for improvement and the processes and activities performed in the site with the highest interest in obtaining and analyzing the information. In this way it has been possible to define the use cases for each pilot from which the developments will be made in the following WPs. These focus areas and use cases are represented in the diagram below for each pilot site.

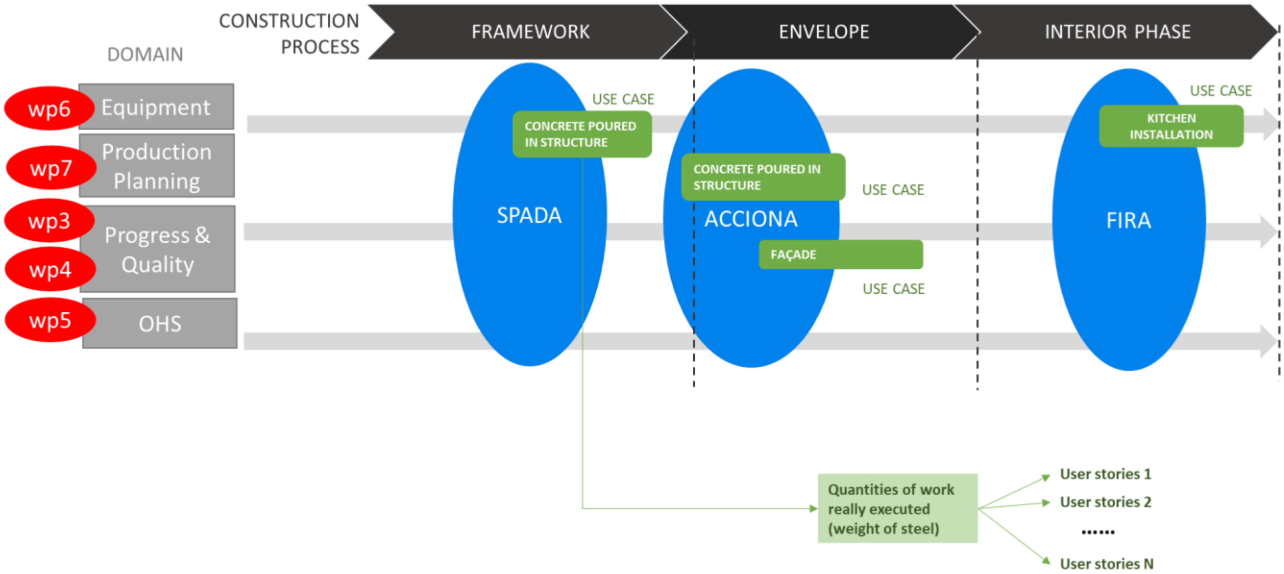


Figure 64. Diagram representing the relationship between the Use Cases selected in each pilot, and the phases and vertical domains of BIM2TWIN.

Based on the workshops´ information, the current state of digitization in the construction companies has been set. In addition, the specific elements or processes on which the developments of the project will be focused have been defined. All this has allowed to obtain an approximation to the specifications of the DTB Platform based on the demonstrator's expectations.

A first approach of the use cases selected in each pilot has been done. The use cases refer to the process phase where the pilots must focus and also the particular needs in terms of information that need to know to improve the success of the process. Nevertheless, those use cases must be deeply defined and determined in the pilot sites to cover the different topics of the BIM2TWIN that must be validated

In the following diagram an approach of the use cases definition for each pilot has been drawn up as well the key points of the selected stage where the pilot will focus on.

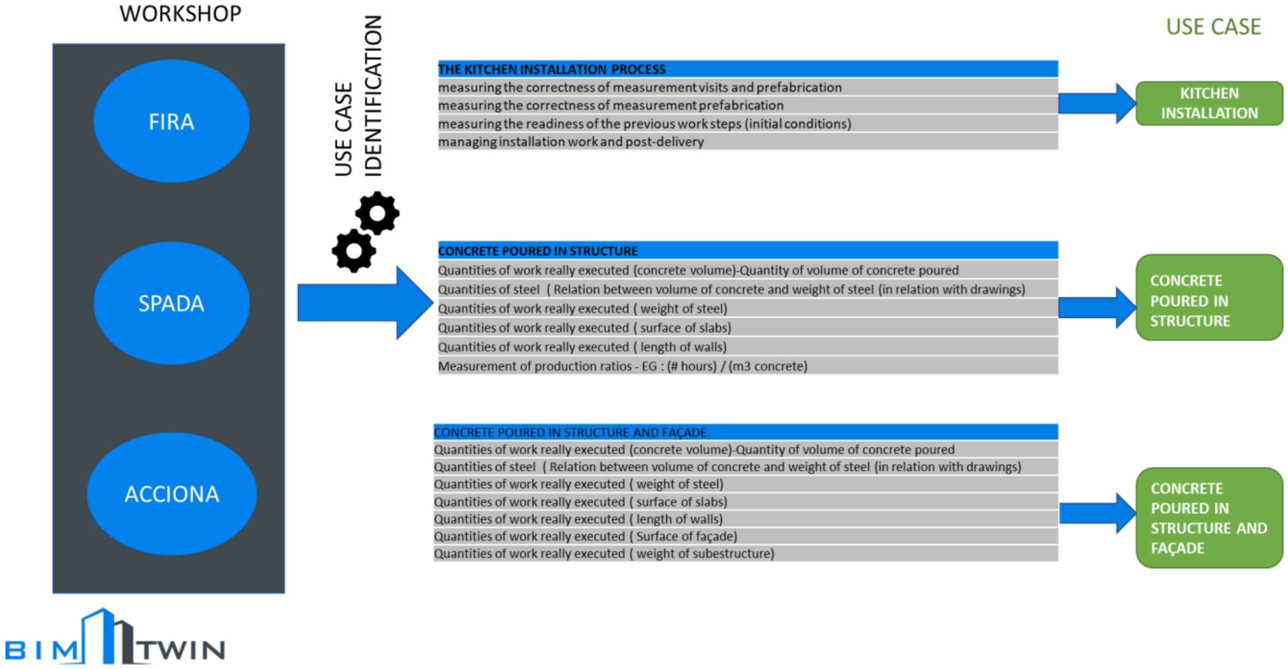


Figure 65. Relevant data to be monitored in each pilot case according to the workshops´ outcomes.

In order to provide detailed information for the project developments, an analysis of the needs of the use cases defined in each pilot and of the most important data and information of the work process to be monitored has been carried out. For this purpose, the most important specific data have been defined and the Use Cases have been defined. All the Pilot have been focused their main interest in the process and the information, which has been able to define the global requirements with a definition level according with the following work package needs.

In the case of France the defined Use Case is related to concrete poured in structure, and they suggest the following data to be monitored: Quantities of work really executed (concrete volume), Quantity of volume of concrete poured, Quantities of steel, Relation between volume of concrete and weight of steel (in relation with drawings) or Quantities of work really executed (weight of steel).

In the case of Finland, the Use Case will focus on the kitchen installation process, and in this case the information to be controlled is, among other: the measuring the correctness of measurement visits and prefabrication, managing the installation work and post-delivery.

The Spanish case is very similar to the French case, but the Use Case will be focused, either on the concrete pouring in structure, or the façade installation. For this case it should be possible to monitor among other things the following job data: Quantities of work really executed (surface of slabs), Quantities of work really executed (length of façade substructure) or Quantities of work really executed (façade surface).

Based on these use cases, for the identification of the functionalities to be implemented, through the development of some services, or alternatively, through the integration of existing services, in the next tasks of the project it will be necessary to detail this information. For this purpose, the technical discussion among the BIM2TWIN partners determined the information that will be necessary to know to detail the use cases

Starting from this global requirement, it will possible to define specific requirements using a specific tool for the agile software development, namely the User Stories methodology. Based in the global requirement, with this tool It will can define the User stories for the actual construction processes in the Pilot , using the following the pattern 'As an <end user>, I want to <action to be performed> in order to <goal>' Through these user stories the DBT Platform functionalities will be outlined in order to implement the services to integrate.

This level of detail will be tackled later on in the Task T1.2 where the workflows will be set, based on the real examples extracted from the user cases.

8 CONCLUSIONS AND FUTURE INSIGHTS

This chapter summarizes the main findings drawn from the work carried out in task T1.1 , which lead to the development of the future work of the project ,As the first task of the project, the principles which will guide in the DBT platform development are set, strongly integrating the end user perspective.

The task T1.1. *As-is practices analysis end-user requirements* which leads to this Deliverable has been performed according to a research methodology based on the stakeholders´ elicitations to gain insight about the as is practices in the on-site construction process, which leads to an overall definition of end-user requirements. In such way, it is ensured that the project developments fit to the real needs of the users, focused on the projects pilots and having into consideration the different actors' expectations.

As conclusions of the research applied in this task, the following issues about the analysis of the as-is construction process focused on the pilot countries can be highlighted:

- The **main inefficiencies** of the on-site construction process are related to the planning and monitoring of the work execution, being the most relevant ones: Inadequate planning, continuous changes and modifications and lack of execution control. In the case of France and Spain, it is remarkable the lack of collaboration between the parties and difficulty in hiring qualified workers
- The **main barriers** hindering the implementation of technology in the on-site phase a are related to social and technical barriers, being the most relevant ones: need for integral change in the culture of working on site, involvement of different teams and companies with different working procedures, poor usability of mobile applications in the field, reluctancy to change of the on-site workers and t lack of knowledge of the advantages offered by the technology , difficulty of implementing quality management in a single application due to the variety of tasks. In order to overcome these barriers, it will be necessary to demonstrate to the workers that the use of digital tools allows a new and more efficient way of working.
- The **level of digitalisation** of the contractor companies involved in the BIM2Twin project, and consequently in the pilots, is varied. Meanwhile the use of digital solutions in the Finnish pilot is broadened, the rest are starting to integrate technologies such as the IoT devices, drones or laser scanners, to optimize the on-site construction. Although BIM is beginning to be implemented and becoming more and more common, the companies misses an integrated system or platform that could centralize the monitoring, management and processing of information of the entire process, not only of specific activities. In fact, although some of the aforementioned technologies are used to digitize some standalone parts of the process, as part of the digital transformation, the digitization of the entire workflow on site does not appear to be reached. Although software development and construction companies have made, in recent years, a great effort for the deployment of digital solutions in the construction process, these are focused on specific processes of the work. However, there is no current solutions that provides the holistic management of the entire workflow, as BIM2TWIN aims to develop through the DBPT.

According to the pilot partners needs and available means, a preliminary **list of users´-requirements** has been drawn up in the Deliverable, which will be further developed together with the partners involved. The points for improvement previously detected in each pilot have given rise to specific user requirements which will be tackled in one or more BIM2Twin domains, as presented in the tables 1,2 and 3. These requirements are the **basis for the identification of the DBT Platform functionalities** to be implemented through the integration of standalone existing or developed services.

Although all the construction companies of the consortium are interested in improving all the processes of the different domains of the work, and especially Progress & Quality and Planification, each one will specifically address a particular domain. Although a first approach has been done in this Deliverable, the Use Case selected for each pilot site will be further detailed in the task *T8.1 Plan building demo cases and provide design information.*

On top of that, the need of knowing some real-time data regarding the construction site by involved stakeholders is revealed in the research. Therefore, the monitoring of some data is proposed, according to the main activities developed in each pilot. For that purpose, a preliminary use case addressed in each pilot has been identified aiming to define more precisely the data to be monitored in the linked process. As an example, in the French use case related to the poured concrete for structural elements, the main parameters to be monitored are related to the volume of concrete, steel, ratio concrete/steel etc. **Those real-time data expected to be monitored in the pilot sites are strongly related with the KPIS defined in *T1.3 KPIs for evaluating the construction process behaviour.* Furthermore, those KPIS will be considered in the DBTP dashboard defined in T1.4 and further developed.**

The first approach to the high-level user requirements defined in this deliverable has led to the identification of the final end-user requirements for the DTBP (T1.2 *Definition of digital workflows for the construction process*) which will **give rise to the subsequent definition of the technical specifications of the DBT platform** *(T1.4 Digital Twin dashboard requirements & specifications*). Additionally, in the Task T1.2 the **optimal workflows will be designed in order to overcome the aforementioned barriers and allow the implementation of the Digital Building Twin concept.**

APPENDIX A: LITERATURE

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Appendix B ANNEX

Annex 1: French Workshop

General Information:

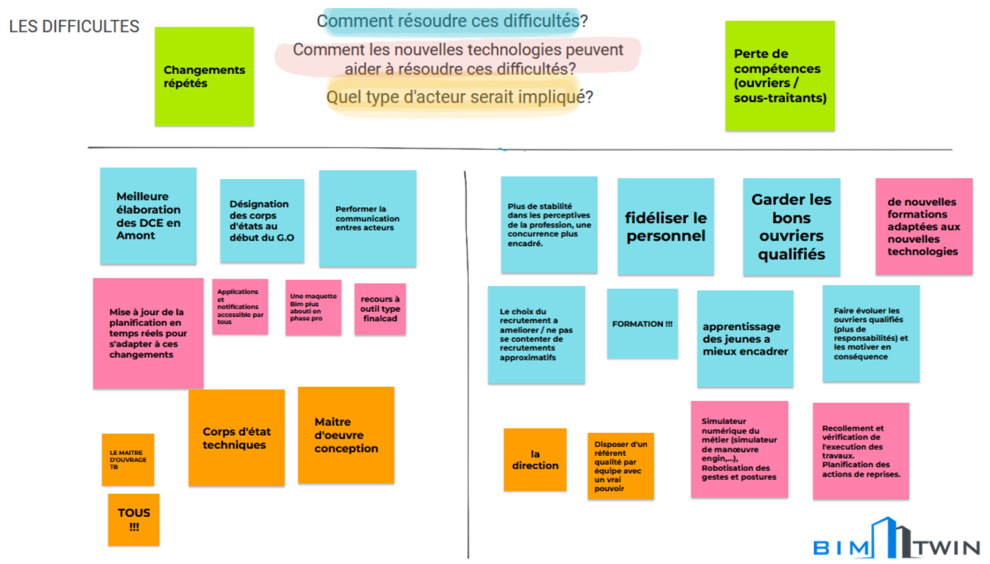
Two workshops were held on March 11th and 12th 2021. 5 professionals attended the first one and 4 the second one. Participants including 3 worksite managers, 1 Foreman, 1 Tender manager, 1 Architect, 1 Safety & Health Engineer, 1 topographic surveyor and 1 Chief Operational Officer. All of them were SPADA employees, except for the architect who was a partner. In both cases, the workshop lasted almost 2 hours and was virtual, although some coworkers from SPADA shared the same office. The workshops were animated by two facilitators, namely M. Tual (CSTB) and F. Noiray (SPADA). Tools included PowerPoint presentations, Jamboard and the Mentimeter.

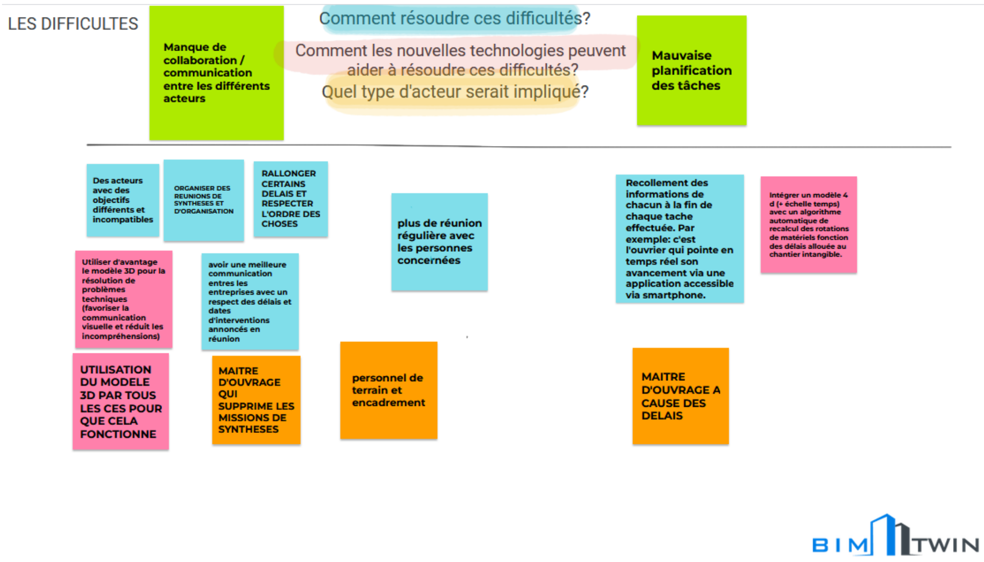
The two groups behaved differently. The first one participated more, but responses remained generic, whereas the second one had more difficulties to engage but provided more precise and technical information. Participants had no difficulties using the tools. Because we ran after time, the first workshop focused on the first part of the questions and with the second one we focused on the second part. We used the results of the questionnaire to give some background information to the participants and start the discussion.

Questions and answers

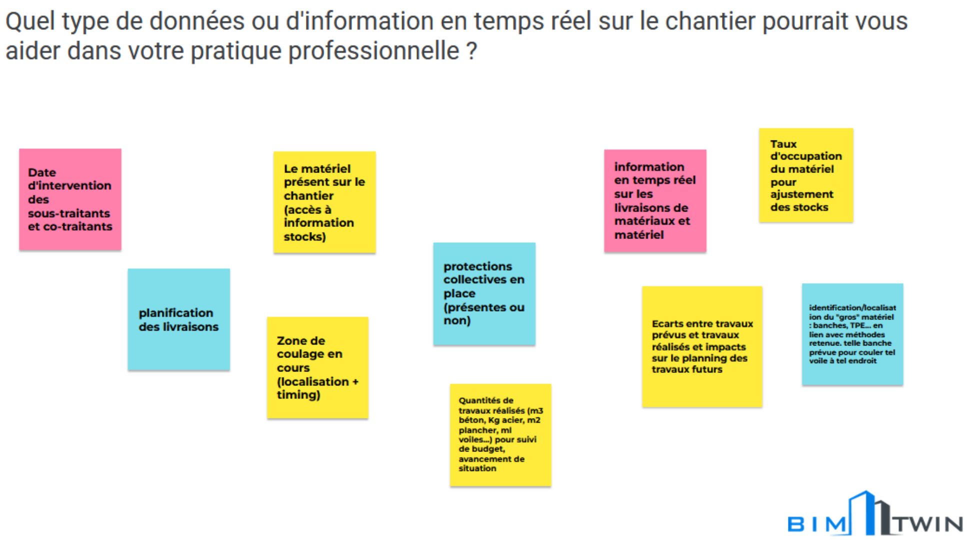
The screenshots of Jamboard results sum up questions asked to participants and their answers.

- What are the most important issues faced by stakeholders on construction sites? how to resolve them? What could bring new technologies? Who are the key players?

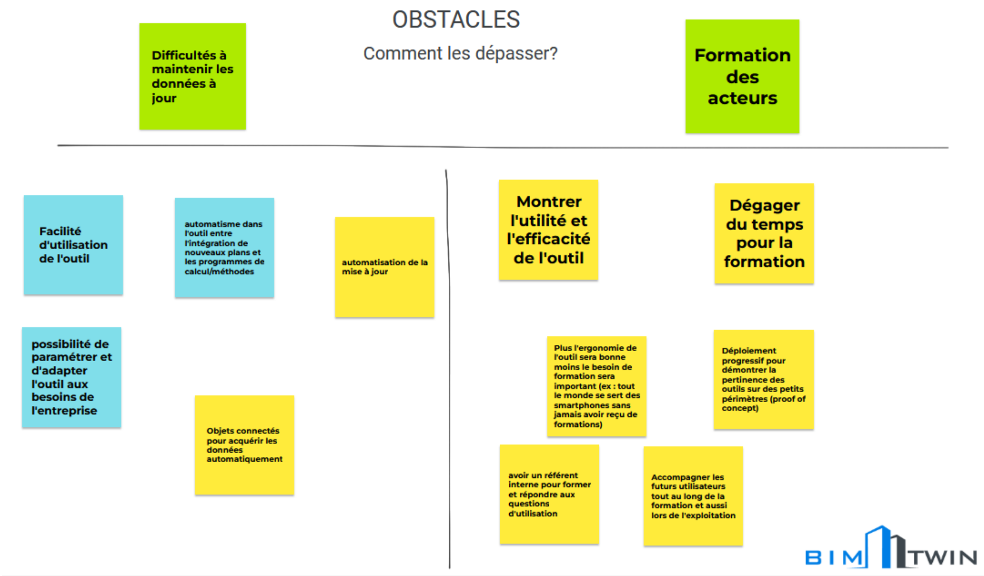




What kind of data or real time information on construction site could help you in the construction phase?



What are the obstacles to digitalisation of construction work at SPADA?



Conclusions:

One main conclusion was that participants felt like using new tools/solutions would prove difficult unless they would be based on their current practices (extensive use of smart phones to take pics, use of very simple software's) very user friendly and the benefits in terms of time saving and efficiency would appear clearly to them.

Workshops also brought into light the fact that the main issue they face regards the difficulties to have a global view on the construction phase especially regarding changes and their impacts on the next steps.

According to information gathered during workshops, execution and quality control seemed like the area where a digital twin would prove most helpful, especially regarding areas of concrete structure work (concrete pouring and reinforcement).

Annex 2: Finnish Workshop

General Information:

The Finnish workshop was held virtually on 8^{th} of April. Before the workshop the participants had site visit to Fira's Kontula site, which members participated to the workshops. Workshop was organized as a Microsoft Teams meeting and interaction between partners was facilitated in the Miro whiteboard tool. Participants did include two site foremen, site engineer, production engineer and a MEP project manager. The focus of the workshop was the management of the prerequisites and especially adjacent tasks of the kitchen installations. In the discussion one of the main topics was the modular bathroom and how to verify its readiness according to the preset definition of done. This was because in this particular site the kitchens are installed to one of the walls of the modular bathroom and thus relevance of these adjacent tasks was high.

Questions and answers

The main question was that how the technological tools could improve the daily management of the installation work. The results of the questionnaire were used as background material for the discussion.

Top results from the questionnaire for the barriers:

- Need for complete integral change in the way of working on site and
- Lack of development of the necessary technology and incompatibility between tools
- Many different teams and companies participate, with different working procedures, (protocols, used programs, etc.)
- Lack of development of the necessary technology and incompatibility between tools
- Large amount of collected data
- Lack of skills needed for the use of technology

Conclusions

The outcome of the discussion was that sites need easy to use and understand reports of the situation on site. In practice this would mean solutions such as predefined work breakdown structure and task sequence of the product / component which will be installed. This information then would have to be updated with the completion status of the tasks. Additionally, any obstacles for the work must be recorded and solved transparently within this solution. Similarly, the possible change orders and any other updated information related to the product or it's installation process would have to be highlighted in the solution. This way the site management and the workers would always have up to date and shared understanding of the site, meaning that everyone would know what the situation is and what should be done next by whom.

Annex 3: Spanish Workshop

General Information:

The Spanish workshop happened in Barcelona on March 04th, 2021, and had a hybrid format that combined a face-to-face meeting with ACCIONA workers of the construction site and one BIM2TWIN representative from ACCIONA, and the virtual presence of the project partners from TECNALIA via Teams. At the presential part of the workshop, located at the construction site of the Spanish Pilot, the participants were the professionals in charge of production management, quality management, technical office management and the site foremen.

The digital interaction between the partners from TECNALIA and the participants was made with a shared presentations and instant surveys with the aid of QR codes from the application Mentimeter in which the participants could scan and answer to the questions in a dynamic way.

On site, the project partner representing ACCIONA conducted the physical part of the workshop by leading the participants on the activities and discussions. The responses to each activity were made with colorful stickers and posts, in which each color would represent one participant.

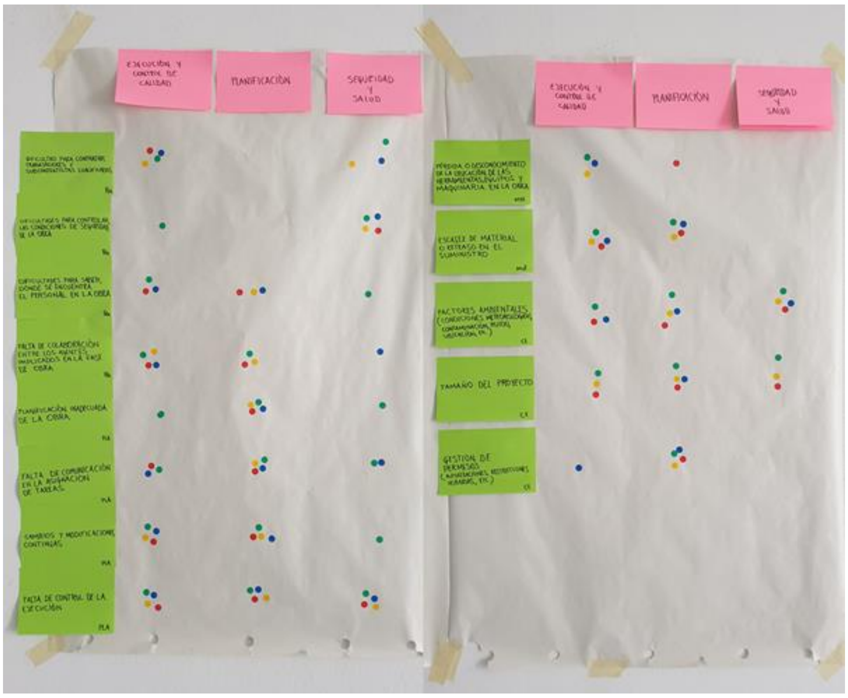
Questions and answers

Based on the information TECNALIA brought to the workshop in form of presentations, the participants had to answer the questions in both digital and physical ways.

Activity 1

Classification of inefficiencies according to BIM2TWIN domains (Execution and Quality Control, planning, and H&S). Each participant has placed a sticker with a different color to identify the respondent's role to be able to interpret results, being:

- Red – Site Foreman
- Yellow - Production manager
- Blue - Quality manager
- Green - Technical office manager.



Activity 2

At first, the participants had to analyze all types of inefficiencies in construction management brought by TECNALIA, and then rank in how much they affect the work in ACCIONA. The survey happened them instantly via the digital tool Mentimeter.

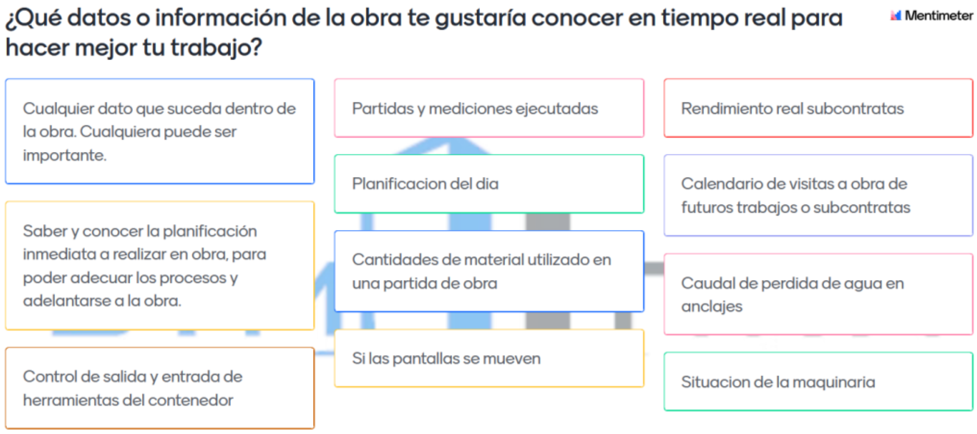
The second part of this activity was based on the four inefficiencies most voted by the participants:

i. lack of qualified workers.
ii. lack of cooperation between the different parties involved in the field.
iii. lack of control of the execution.
iv. inadequate construction work planning.

For each of them, three questions must be answered:

1. How to solve it?
2. How can technology improve these inefficiencies?
3. Which role/process partner could contribute the most to the improvement?

In the end, the participants had to answer the open question about which information in real time they would like to know that would help them improve their work.



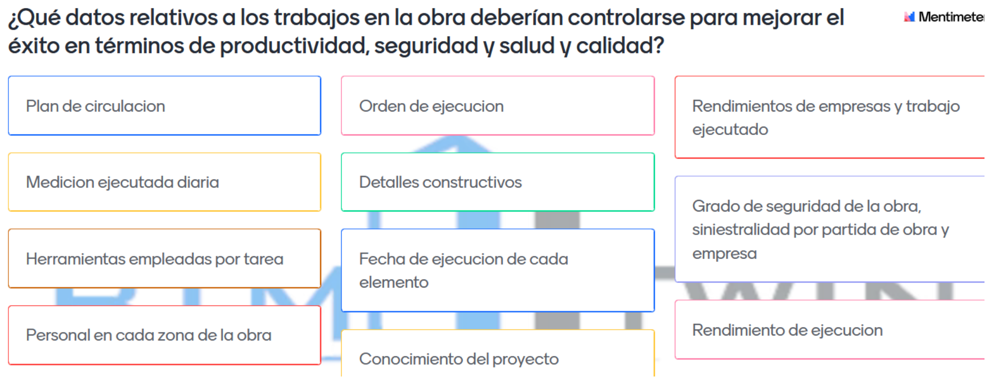
Activity 3

The third activity focused on the barriers that a digital process of construction could face to be implemented, considering the specific case of the pilot project. First, following the same model of the previous activities, the participants were invited to rank the barriers that they thought were the most important for ACCIONA.

Then, based on the four barriers classified as the most relevant by the participants via instant poll, the participants had the answer the following question:

- From your point of view, how do you think these barriers can be overcome?

To conclude, the participants answered the last open question about what information should be controlled at the work site for improving the efficiency in terms of productivity, safety and quality.



Conclusions

For the ACCIONA construction team, the most important information that the workers would like to know on real-time at the building site are what are the subcontractors working on in the construction, the monitoring of materials (what is going in or out of the storage, and the quantity of material being used), and the current situation of the machineries on site. Some additional ideas also arose from the discussion, as the workers reflected on the current issues happening on the site on the phase of excavation and foundation. There is the need of monitoring infiltration points on the construction, in which technology could support solving.

The participants demonstrated openness towards using new tools for digitalizing the work. For the tools, a combination of phones and tablets would be ideal, since the needs can vary in each part of the work - the phone is a preferred tool on the daily use for using the platform (usually workers carry many tools around the site), and other construction inspections could be done by tablets. The chosen digital platform for digital construction management should be practical enough for introducing data in a simple way, where each input gives an immediate output.

Photographies