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Challenges for Digitalisation in Building Renovation to Enhance the Efficiency of the Process: A Spanish Case Study

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Abstract: Although construction is one of the largest industries in the world, it is one of the least digitised and its productivity is still very low. Excesses of time and cost are common and are even more accentuated for building renovation. Recently, the building information modeling (BIM) methodology has strongly entered in the construction sector and appears to be an effective paradigm shift. Considering all of the previously mentioned aspects, this article addresses the identification and analysis of the critical barriers of renovation and the potential for digitalisation to overcome them using BIM. The methodology that was used is based on an open innovation approach called Living Labs, where consultations with the key stakeholders of the construction process aims for a higher digitalisation to focus on real needs and fitted to the user's requirements. Starting from a worldwide survey, the analysis of the Spanish casuistry is deepened. From the analysis of barriers and opportunities, the necessary requirements for an optimal BIM application in renovation are highlighted. After identifying the key aspects that each stakeholder' typology has considered as relevant, a set of key performance indicators have been selected, to monitor the improvements in the renovation process when BIM is adopted.

Keywords: BIM; building renovation; digitalisation; efficiency; retrofitting; Living Lab

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1. Introduction

The construction sector is the poorest performer in Europe in terms of productivity [1]. This is partly explained by the difficulties of the construction sector to embrace digital innovations [2] that could help to improve both productivity and profitability, as explained in McKinsey's the digital future of construction [3]. In this context, the opportunities for the renovation market in Europe, in particular an improvement in productivity, are very promising [4].

Digitalisation, defined as the development and deployment of digital technologies and processes, is considered crucial for the required transformation of the construction industry to improve productivity according to the report of World Economic Forum [5]. At the European level, Directive 2014/24/EU on public procurement establishes the need to use software in processes for contracting construction works [6]. With regards to this directive, article 22 highlights the use of building information modelling (BIM) tools or similar [7]. Also, the recent report that was published on April 2021 "European Construction Sector Observatory. Digitalisation in the construction sector. Analytical Report. April 2021" [8], points out the emerging technologies for the digitalisation of the sector. Among those technologies which will revolutionise the sector in particular, BIM has been identified in the last few years as the main paradigm to solve the inefficiencies of the construction process and as a general solution to increase collaboration between participant stakeholders, aiming for a more efficient and productive sector [9]. This is particularly relevant when

it comes to information management and collaboration between agents as well as for anticipating construction decisions [10,11]. While most stakeholders acknowledge the importance of BIM in the construction sector, its adoption by the industry is often limited. Also, the approach of BIM is still very focused on new construction buildings and the use in renovation involves added hurdles which must be specifically addressed [12]. Taking all the aforementioned aspects into account, the current paper addresses the identification and analysis of critical barriers of the renovation process and the potential for digitalisation to overcome them using BIM methodology [13]. Other research is being developed as part as a European-funded research project involving a total of 23 European partners, called BIM4Ren [14], however, the current paper presents the research that has specifically been developed for the Spanish case.

Regarding the methodology to be adopted, some previous investigations that were carried out at an international level have considered the use of surveys to stakeholders, aiming to identify the drawbacks and benefits of using novel technologies [15]. Other studies have used interviews with those stakeholders involved in a case study [16]. Although the survey is a valid research tool [17], it is a method that limits the feedback process to exchange bidirectional information, as such, some studies have combined surveys with interviews to stakeholders that represent the sector looking to collect more specific information [18]. In both cases, the information that is collected is partial and limited to the sample that is being considered for making these consultations and cannot be generalised. Apart from that, in some projects the information that is collected through surveys and interviews has also be complemented with inputs from a case study that was monitored in real time. This allows better a understanding of the relationships between stakeholders and identification of the paths to optimise the implementation of BIM using specific methods such as Social Network Analysis (SNA) [19], that are also applicable for renovation works [20]. These studies have greater reliability since they can empirically measure the optimisation potential of the networks that are intervening in the project process, however, they also have certain limitations as, in many cases, these studies are developed under an academic approach which, therefore, limits their application. The majority of the construction industry in Spain, like in many other countries, is participated by small and medium enterprises (SMEs) that do not have the capacity to invest in Research & Development & innovation activities. Therefore, it is difficult for them to access these data and interpret the results as they consider that these results are far away from their everyday problems. Consequently, SMEs are not effective in progressing to the decision of increasing the digitalisation level of their company, nor in the effective implementation of BIM in the construction process.

Aiming to overcome these limitations, a methodology that was based on Living Labs (LL) has been used in this research as a new concept for considering the relationship between stakeholders. The Living Lab concept was first proposed in the late 1990s by the MediaLab of the Massachusetts Institute of Technology (MIT), as a user-centred research methodology for sensing, prototyping, validating, and refining complex solutions in multiple and evolving real-life contexts [21]. Living Labs seek to contribute to innovative processes where the users become active actors and not just passive recipients. They are established as a real test bed to respond to the needs that have been previously identified by means of surveys, interviews, and workshops carried out by the involved stakeholders [22–24]. LLs have been used in the past to facilitate the implementation of innovative technologies in pilot cases in construction [25], even for the development of advanced integrated platforms based on BIM [26].

Researchers that are based in LLs, have been focused on the creation of the Living Lab's own ecosystem, allowing them to bring together the four helices of the society: users, public actors, private actors, and knowledge institutes. In this way, the detection of barriers and opportunities for digitisation with BIM becomes a cooperative and agreed process. This type of approach allows, on the one hand, an industry, an internal agent of the process, to develop digital products (software/platforms) attending to the particular needs of the end user and, on the other hand, to define some key performance indicators (KPI) [27], that

can measure the needs of different agents (time and cost reduction) to clearly demonstrate the benefits of digitalisation and BIM in a series of pilot cases in target countries [28].

Consequently, current research focuses on the effectiveness of the application of Living Labs in this challenge of digitalisation through BIM. It is generally known that technological innovations by themselves cannot achieve sustainable life and practices, and that knowledge of the real response of the end-user behavior is crucial for the effective implementation of technological innovations [29]. Even if many scientific publications can demonstrate the benefits of BIM, stakeholders that are linked with the Spanish case are willing to measure and monitor those improvements in a simple and clear way to verify the benefits in their own specific companies. This approach is generating a cooperative climate of trust and increasing the commitment of the participants towards higher digitalisation levels.

2. Materials and Methods

The current work is focused on the assessment of barriers and opportunities of digitalisation and, particularly of BIM in the renovation sector, is based on eliciting information from stakeholders that are involved in the renovation process. The approach starts from an overall analysis of the use of BIM in Europe to particularly focus it on the distinctive features of the Spanish case.

The methodology is based on an open innovation approach focused on Living Labs (LL), as part of the insight that was adopted by the BIM4Ren project. The information that is obtained is devoted to analyse the requirements for the use of BIM in renovation, driven through the active end user's participation and involvement in the LL. Therefore, the LL activities enable direct feedback from the pilots' agents, key stakeholders, and targeted beneficiaries throughout the project. In this way, it ensures that the user-centered developments are focused on the real needs and requirements through enquiries to the key stakeholders. In addition, the different insights allow the identification of the barriers and opportunities of BIM by the type of stakeholder with the goal of addressing them separately.

The methodology to elicit the information from stakeholders is based on 3 instruments of data collection:

- On-line questionnaire, as a method of primary data collection. It has been addressed to a vast range of companies and roles in the value chain of construction sector, all around Europe and beyond. It is aimed to gather general information to identify the general trends, barriers, and challenges in digitalisation, particularly in the field of residential renovation.
- Interviews with key agents of the construction field focused mainly on the renovation sector. The interviews have been specifically oriented to complete the information that was obtained from the surveys about barriers and opportunities.
- Workshops that were dedicated to check and validate the results of the survey and interviews through the dialogue with closest stakeholders. The workshops have been held around the Spanish pilot case of the BIM4Ren project in the city of Donostia-San Sebastian.

Although the basis of the general study encompassed a geographically wider framework, this paper reports the results of the LL activities with a focus on the Spanish Case. This was performed by gathering the survey results from the Spanish respondents, as well as the findings of the interviews and workshops that were developed around the Spanish pilot case. These are aimed at defining the major barriers and opportunities for the use of BIM technologies for building renovation in the Spanish market and provide a comparison reference for the rest of the countries.

The investigation process that was adopted is shown in Figure 1. The necessary balance between the four helices of the system (users, public actors, private actors, and knowledge institutes) are presented as required by the Living Lab strategy. The application to the BIM4Ren project and the methodology that was applied to collect and process the data is highlighted, as well as the main intended goal of the investigation looking to identify ways to improve the currently used renovation processes.

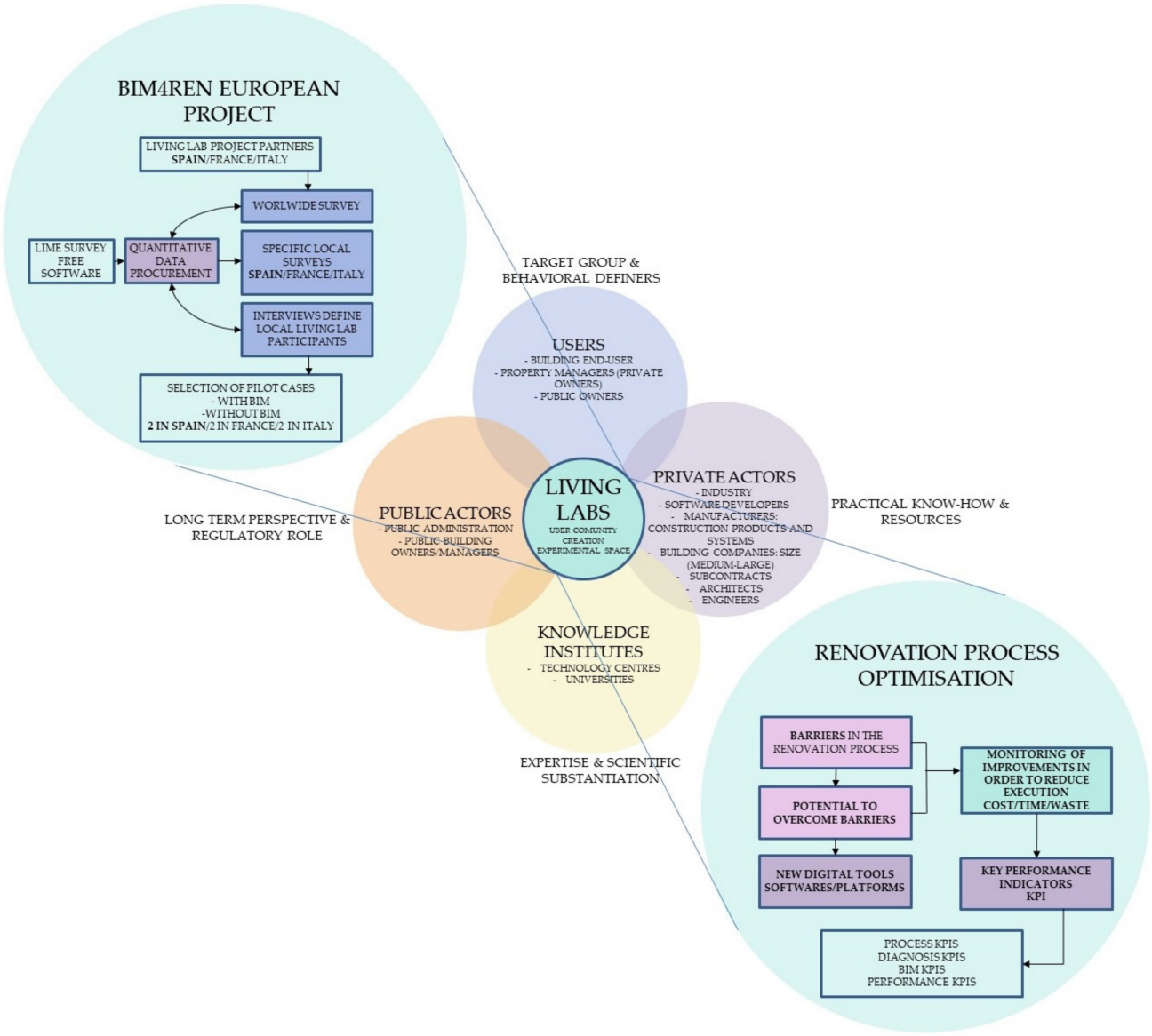


Figure 1. Resume of the investigation process adopted.

2.1. Questionnaire for Data Gathering about Stakeholder's Requirements and Constraints

The research was initially focused on an on-line questionnaire in the frame of the BIM4Ren, "survey about the BIM implementation in renovation processes" that was addressed to the overall AEC sector.

2.1.1. Structure of the Questionnaire

The questionnaires have been designed to obtain the following information:

1. Identification of the barriers in the renovation process: This section is structured according to the role of the respondent in the value chain, mapping the different use cases with regard to the phases and stakeholders that were involved, typology of works etc. It is also aimed at assessing the factors in a renovation process which have more relevance for every stakeholder group.
2. The potential to overcome the barriers in renovation process through digital tools: In this chapter requirements that digital technologies must have to meet the demands of the respondent are defined.

The on-line questionnaire was designed through the open-source software, Lime Survey [30], and was active for collecting answers from December 2018 to February 2019. It was constructed according to a cost-benefit criterion to collect as much information as possible with scarce resources. It addressed the questions by the categories that were relevant for the findings of the project (such as the specific role in the value chain or stage of the renovation process), to draw specific conclusions that were differentiated by those categories. The survey was designed to reach different agents with varying levels of expertise in digital technologies and varied links with the renovation process.

2.1.2. Classification of the Respondents and Their Link with the Renovation Process

The target group of the questionnaire were the members of the Architecture Engineering and Construction (AEC) sector. It was distributed to the stakeholders that were related to the renovation activities representing the whole value chain, by the members of BIM4Ren Consortium, social networks, associations, and digital means. A total of 229 surveys were answered by companies of different sizes and expertise in the construction field and representing the main roles in the construction sector. The stakeholders that responded have been clustered using the following categories (Table 1).

Table 1. Categories of the stakeholders according to the BIM4Ren classification.

Categories of Stakeholders	Sub-Categories of Stakeholders
Designer	Project Manager Architect Structural Engineer Survey and data gathering Services Engineer Work controller
Contractor and Subcontractor	On site worker Cost controller Quality controller Installer Security manager Site manager Others Data gathering
Building owner and/or resident	Site manager Buildings manager Facility manager/Maintenance Building administrator Others
Public administration	Local authority Waste manager Industrial Department Security authority
Industry	Supplier Manufacturer Others
Others	Software developer or consultant External certificatory Funders Education and training on BIM software

The survey aimed also to identify the typology and phases of the renovation works that were performed by the respondents, to allow the connection of these different subjects with the barriers of the process. On the whole, the typologies of the renovations that were undertaken (inspection and maintenance works, internal refurbishment, interventions on the envelope, structural retrofitting, service improvement, accessibility improvement, and deep renovation) were varied and similarly represented among the respondents. Similarly, the participation of the respondents on the different renovation phases that were defined (strategic definition, information gathering and survey, diagnosis, renovation conceptual design, renovation technical project, construction, handover and close out, and in use) were also well balanced.

2.2. Interviews

The main goal of the interviews was to collect direct and specific information about renovation from key stakeholders that were involved in the process and linked to local LL that were based in the Spanish pilot case. In that way, additional information can be gathered that is related to the general trends, barriers, and difficulties in the renovation process, as well as about promising technologies to address the drawbacks. The following relevant stakeholders that were related to the Spanish pilot case, were interviewed: architects, private and public owners, contractors, suppliers, manufacturers and subcontractors, such as an insulation supplier and manufacturer, services suppliers, and façade installers.

2.3. Workshops

Finally, workshops were conducted throughout 2019 and 2020 in Donostia-San Sebastianin to validate the preliminary results that were obtained from the surveys and interviews through discussions among stakeholders from different perspectives. This involved: the agents that were involved in the pilot cases, early adopters (as first agents adopting a new technology or process which give initial feedback about their advantages and disadvantages), and other key agents of the renovation process that were linked to the project.

In particular, the following issues were addressed in the workshops: barriers in building renovation, the requirements of the stakeholders for the digitalisation of the process, and the potential for BIM to overcome those barriers.

The workshops enabled us to reach clear and distinctive conclusions about the barriers in the renovation process, requirements of the stakeholders for use of BIM, and the potential of BIM for renovation from different insights. Some topics that were related to the opportunity for improving the process through digitalisation have been discussed among the participants. Questions such as "what are the main inefficiencies in the renovation process?", "at what time are they produced?", and "how could it be addressed with technological solutions?" were addressed and the main outcomes that were collected from the workshops in Spain have been gathered in this paper.

3. Results

This section is divided into three sub-sections. The first (Section 3.1) addresses the results of the general survey, presenting the role of the respondents, their level of digitalisation and use of BIM, as well as the technologies they use. The second (Section 3.2) presents the results of the investigation that focused on the Living Lab of the Spanish Case. These results reached a greater level of detail since certain aspects of the surveys can be made more specific by means of individual interviews, finally culminating the process with the results of the workshops. Section 3.3 presents the summary of the results as a resume of the content that was presented in the two previous sections.

Figure 2 graphically represents the process that followed at each stage, describing the main findings as well as the main focus on the Spanish Case Study.

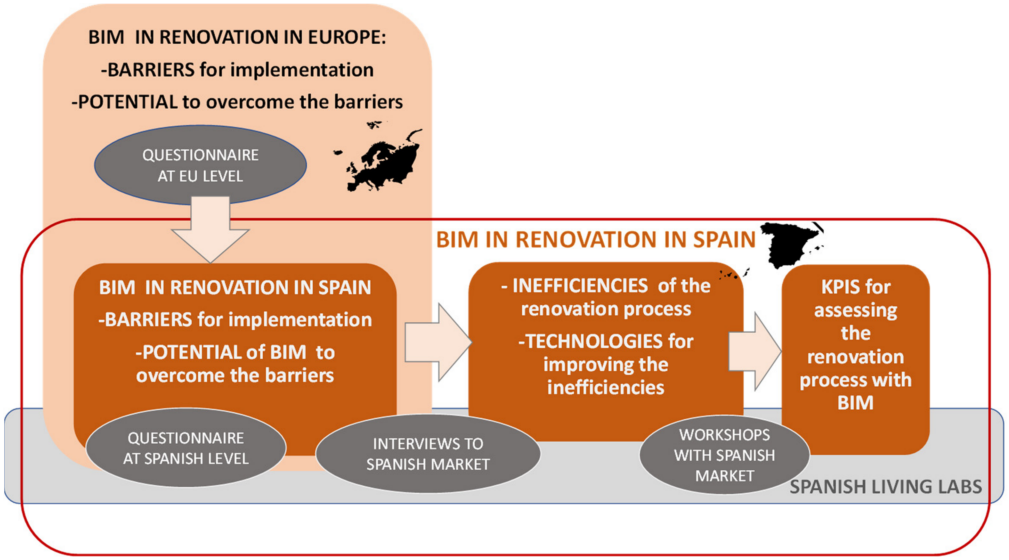


Figure 2. Graphical representation of the research process followed for the Spanish Living Lab.

3.1. Results Obtained from the Overall Questionnaire

The survey was completed by participants from 24 countries, most of them European, but also some from other non-European countries such as Australia, India, Taiwan, Costa Rica, and Bolivia. The majority of the contributions came from Italy, Spain, France, Netherlands, Lithuania, Switzerland, Ireland, and Germany, in that order. In overall terms, the relevant groups of the digital construction value chain were embodied in the questionnaire (architect (23%), contractor (17%), building owner (7%), service provider (10%), manufacturer and supplier (3%), subcontractor (6%), and others such as public administration, consultants, or software developers. Additionally, all types of companies participated in the survey: large (27.5%), medium (17%), small companies (19%), and micro enterprises (31%), being vastly represented the SME companies, the target group of the BIM4ren project goals.

In relation to the level of digitalisation of the overall respondents (Figure 3), it was shown that 24% of the respondents never have used BIM, 29% has participated in collaborative projects with BIM, followed by 16% that were just software users. For those who have declared not to use BIM in renovation (59%), the most probable reason of not using BIM is the lack of human resources specialised in the company (33%) followed by the consideration of not being necessary for their work (20%), as well as the insufficient time available for training (20%) and the cost of the tools (15%). Other issues regarding technical solutions, such as the interoperability or the difficulty in finding suitable software that was adjusted to their needs, were also considered as a barrier. Although the lack of resources was fairly common in the concerns of all of the stakeholders, this reason is crucial in the case of the ownership and subcontractor while contractors declared a main cause the lack of time for training. It also is highly remarkable that a large amount of the interviewed architects state that BIM is not necessary for their work. The difficulties of interoperability between tools was seen as a difficulty only for the service providers.

As for the technologies that were used by the respondents to carry out their everyday work, these were assessed according to the impact that they could bring to business in terms of time- and cost-savings. Once categorised as high, medium, and low impact by the respondents, the results were averaged so that each technology ranged from 1 to 7 in descending order where "1" represented the technology that provides more time/cost savings. The assessment lead to the following prioritisation (Table 2):

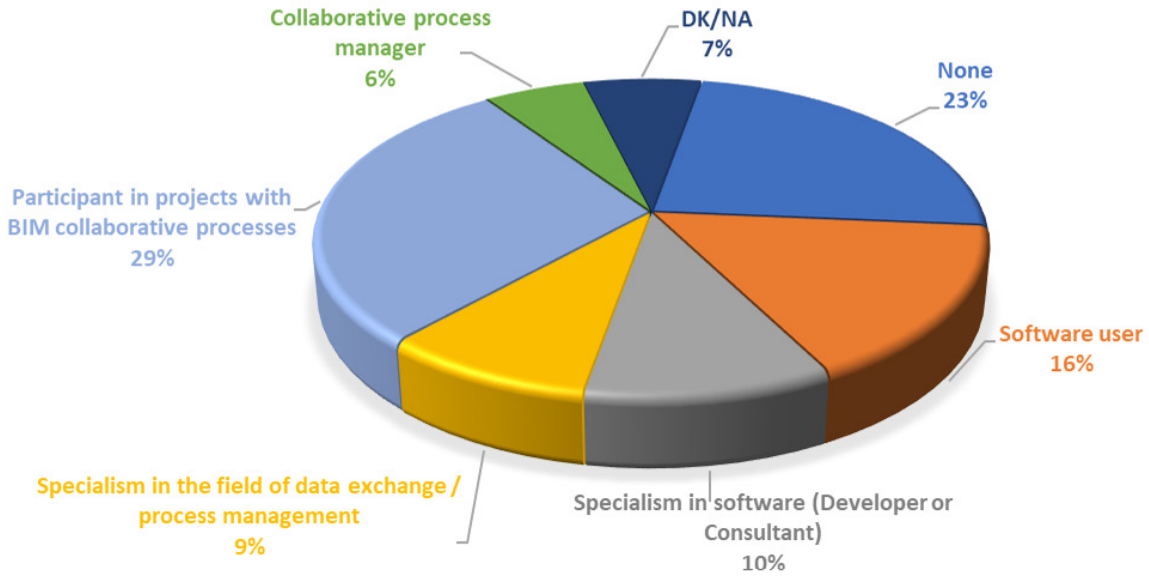


Figure 3. Level of implementation of BIM in the companies that responded to the survey.

Table 2. Impact of the technologies that were used in renovation on the stakeholders' business.

Prioritisation of Used Technologies			
According to the Time Savings They Bring		**According to the Cost Savings They Bring**	
1	Laser scanner	1	Laser scanner
2	Smartphone/Tablets	2	Embedded sensors
3	Thermography Camera	3	Smartphone/Tablets
4	Embedded sensors	4	Thermography Camera
5	Drone	5	Drone
6	Virtual/Augmented reality	6	Virtual/Augmented reality
7	Robotics	7	Others
8	Others	8	3D printing
9	3D printing	9	Robotics

On the whole, the outcomes were fairly similar considering the time- and cost-savings, highlighting that the use of embedded sensors brings relevant cost-savings rather than time savings. The results show that laser scanner was the technology that was used in renovation which impacted more positively in the stakeholders' business, leading to cost- and time-savings, followed by smartphones and tablets, and thermography cameras. Nevertheless, emerging technologies such as robotics, 3D printing, or virtual and augmented reality were not yet seen by the respondents as relevant tools to improve the productivity.

3.1.1. Identification of the Barriers in the Renovation Process

When it came to the phases of the project, the overall results of the questionnaire revealed that the most critical phase of the process was the technical project, followed by the diagnosis phase and the conceptual design (Figure 4).

The results that were obtained from the answers allowed the identification of common problems that have a significant impact on the stakeholders' businesses, differentiating new construction projects (Figure 5), and renovation projects (Figure 6).

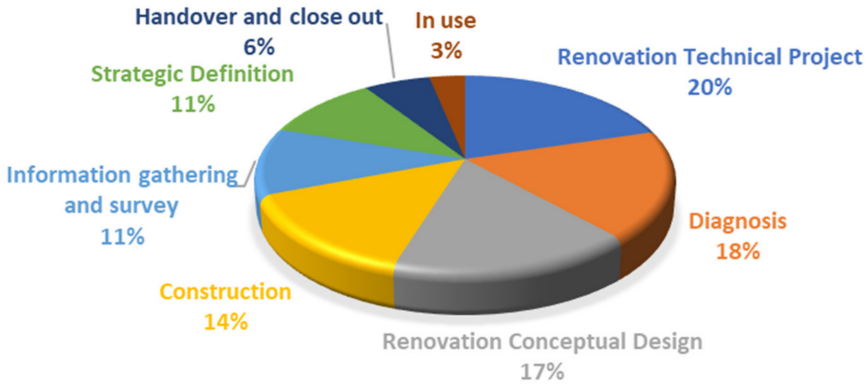


Figure 4. Phases of the renovation process where higher difficulties are present according to the overall questionnaire.

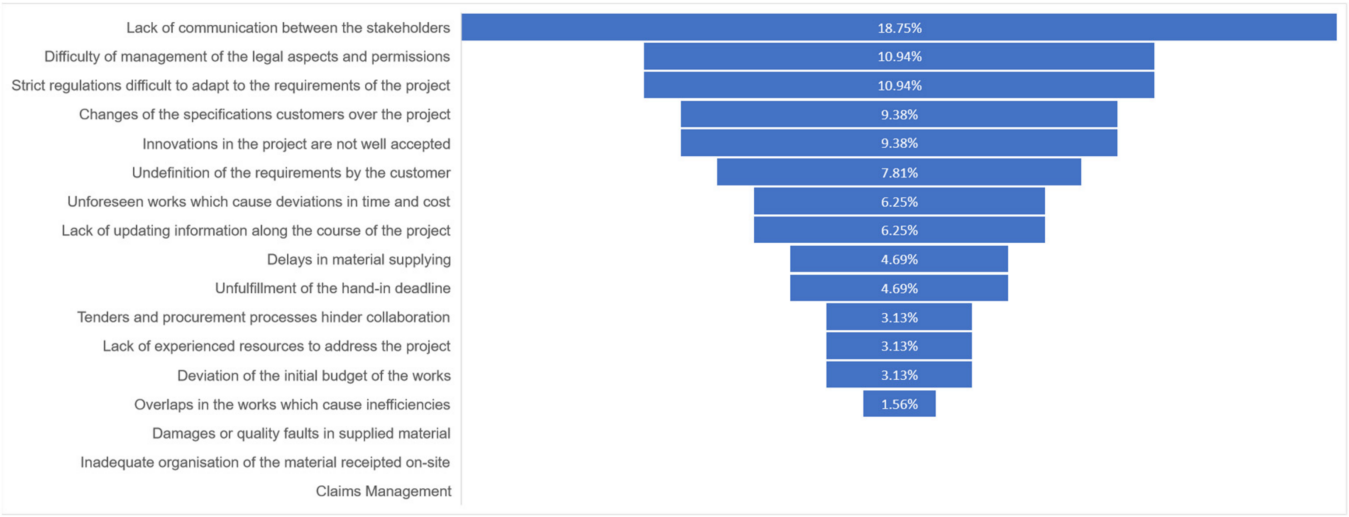


Figure 5. Prioritisation of the inefficiencies according to the impact of a new construction project on the stakeholder's business.

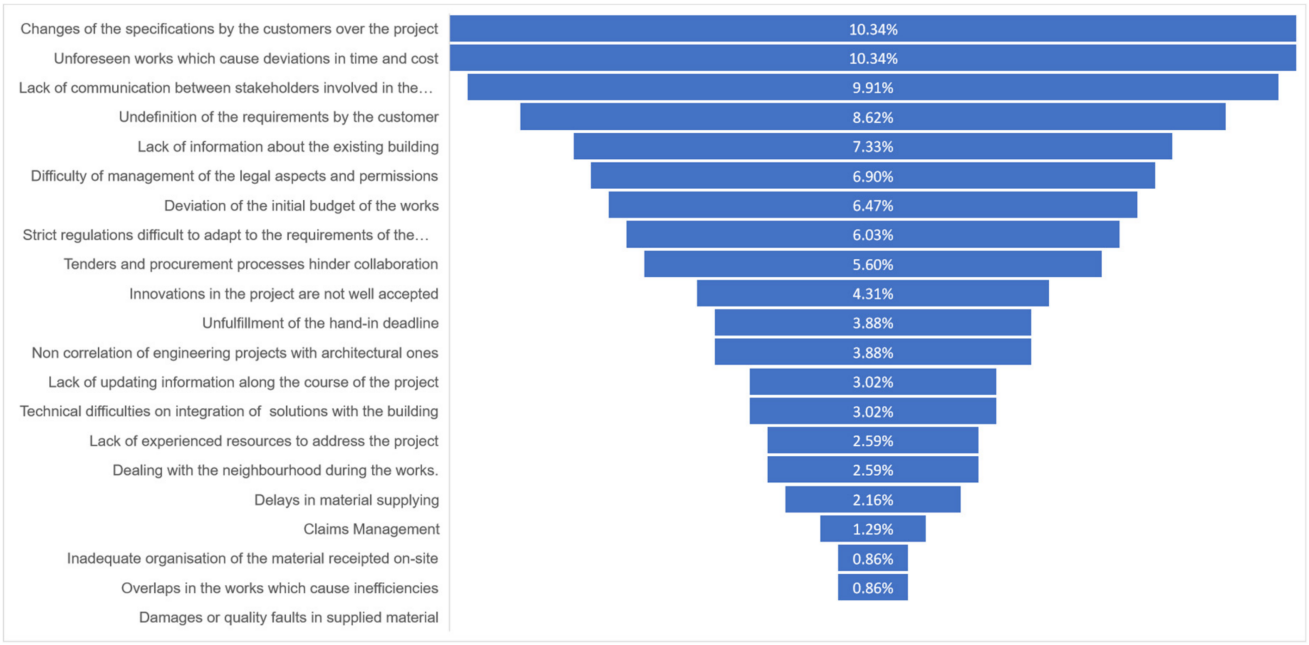


Figure 6. Prioritisation of the inefficiencies according to the impact of a renovation project on the stakeholder's business.

In new construction, the lack of communication is clearly perceived as the first drawback in relation to the stakeholder's business. Nevertheless, when it comes to renovation, the common problems differ significantly to the previous ones, and their importance is more balanced. The changes of the specifications, the unforeseen events, together with the lack of communication seem to be critical issues that are specific for the renovation.

3.1.2. Potential to Overcome the Barriers in Renovation Process through Digital Tools

The survey provided valuable information about the user's perspective regarding the potential of digitalisation to face the inefficiencies of the renovation process. The current section gathers the main findings of the survey regarding these topics that were related to the opportunities of digitalisation, particularly the BIM, for enhancing the renovation process. The charts below represent the distribution of the answers according to those topics related to digitalisation (Figures 7–10).

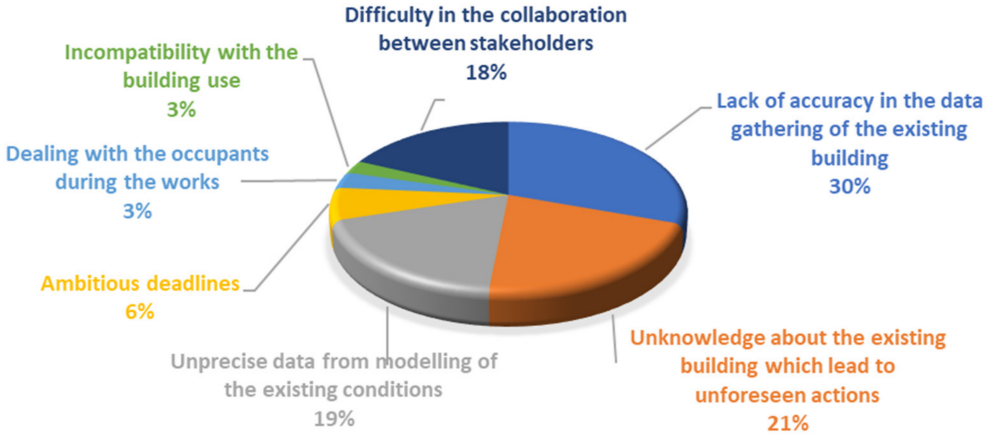


Figure 7. Common issues in renovation that can be overcome using BIM.

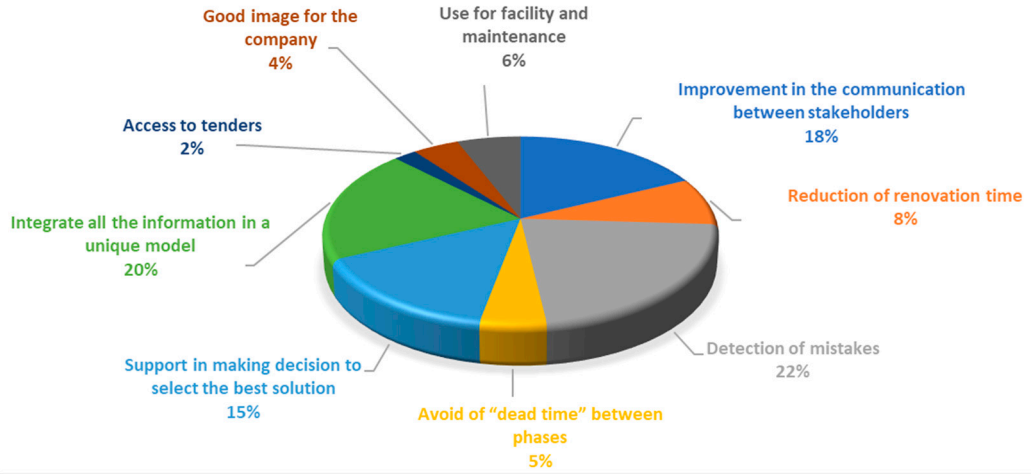


Figure 8. Benefits provided by digital tools in a renovation process that impact positively on the stakeholders.

A set of indicators about the key aspects in renovation have been proposed to the respondents to link their relevance with the typology of stakeholders. Even if several indicators are common to all, some specific indicators are presented for each stakeholder group and are uniquely evaluated by the corresponding stakeholder category. This assessment allows to better fit the functionalities of the digital tools to the user's requirements and specifically by stakeholders' category.

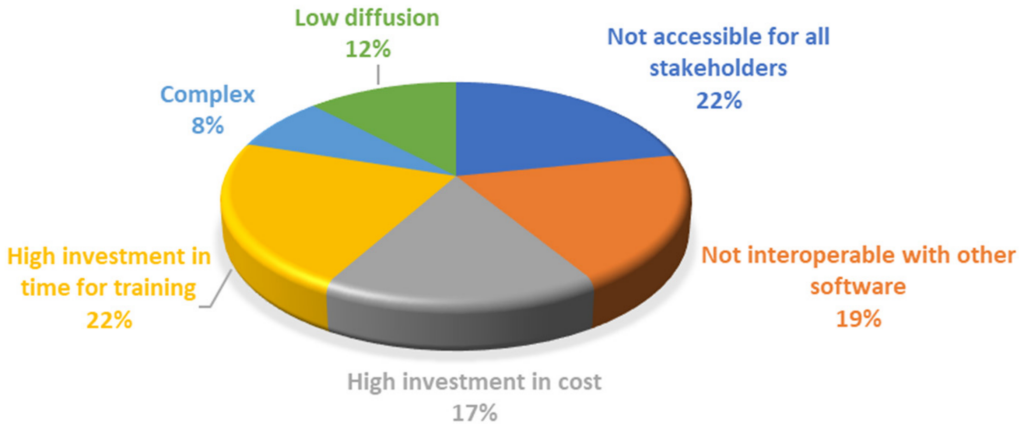


Figure 9. Barriers of using digital tools/platforms in a renovation process those which impact more negatively on the stakeholders.

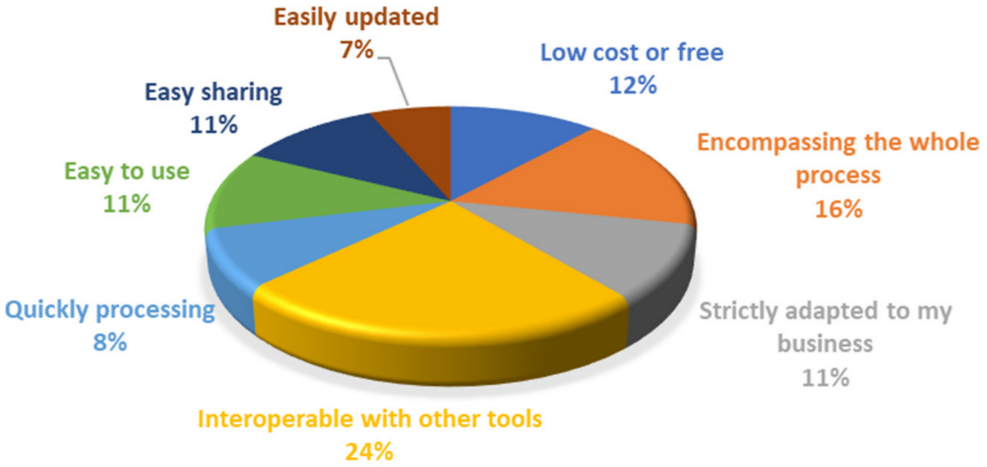


Figure 10. Features of a digital tool/platform that are more helpful for the renovation process.

According to the results of the survey, where each indicator's relevance is categorised with high, medium, or low impact by the respondents, the importance of each indicator for each stakeholder's category was obtained. Consequently, in the Table 3, the relevance of the indicators for each stakeholder was categorised as minimum (*), medium (**), and maximum (***). Note that the blank cells correspond to the indicators not proposed to the corresponding category and therefore not assessed by those respondents.

Table 3 shows that some topics are highly relevant for all of the typologies of stakeholders, such as accuracy of the data gathering of the existing building [31], easy visualisation of the solution, reduction of delivery time, organisation of the documentation, and cost reduction. In contrast, the importance of some specific aspects to some categories can also be identified, such as the reduction of the execution works for the contractor or the maintenance cost reduction for the owner. In general, the main issues affecting the designer have a major relevance for most of the other stakeholders as they are directly linked with the importance given to the diagnosis, conceptual, and technical project stages (Figure 4), where the designer is the main actor intervening.

Table 3. Relevance of indicators regarding the key aspects of renovation according to the stakeholder's category.

Key Aspects for the Success of a Renovation Process	**Relevance**				
	Designer	**Contractor & Subcontractors**	**Building Owners**	**Industry**	**Others**
Accuracy of the data gathering of the existing building	***	***		*	***
Easy visualisation of the solution	***	***		**	**
Reduction of delivery time	***			***	**
Organisation of the documentation	***	**		**	***
Cost reduction	***	***	***	***	**
Improvement of the company's reputation	**	**		*	**
Create best practices	**				
Validation of the standards compliance	**	**		*	**
Justification of the Decision Making	**	**			
Easy replication	**	**			
Easy collaboration with the client	**	**			
Integration of requests from residents	*				
Reduction of the visits to site	*	*			
Complaint management	*	*		**	*
Access to financial subsidies			**		*
Maintenance cost reduction			***		**
Energy savings			***		***
Resident's comfort improvement			***		**
CO_2 and other pollutant emissions reduction			**		**
Support to the control quality		**			***
Longer building lifetime			***		**
Aesthetic improvement of the building			**		*
No need for the resident to leave the building during the works			*		*
Reduction of accidents on site		**			*
Reduction of unforeseen events on site		***			**
Reduction of execution works time		***		*	
Easy interaction with the designer		***		***	
Easy collaboration with suppliers		**			
Reduction of number of workers on site		**			
Support to classification of the material on site		*			
Integration of requests from residents		*		***	**
Eco labelling (LEED, BREEAM, CASBEE . . .) of the building after renovation			*		
Space optimisation			*		
Increase in the building value			*		**
Organisation of the material onsite				***	
Easy interaction with the contractor				**	

3.2. Results Focused on the Living Lab of the Spanish Case

3.2.1. Results Obtained from the Questionnaire Focused on the Spanish Case

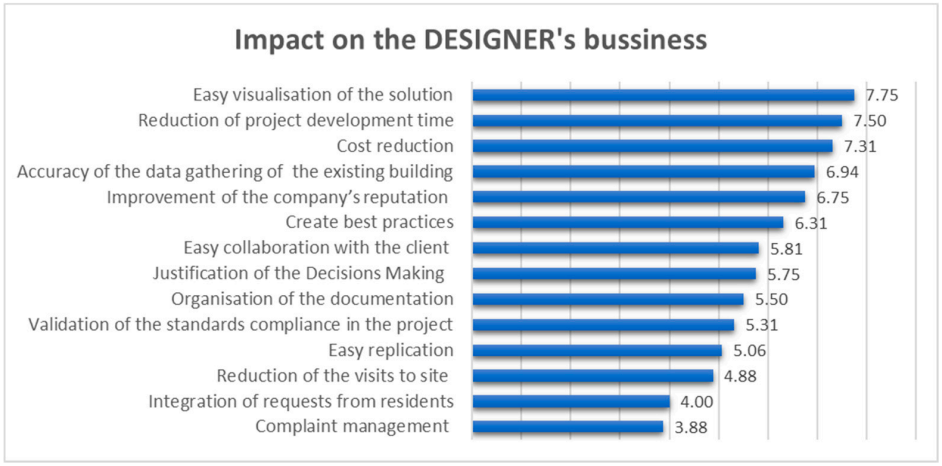
To monitor the starting point of the Spanish respondents, the answers that related to the use of BIM and digital tools were extracted. On this basis, the main issues to highlight about the Spanish context according to the survey's findings are summarised below:

- Most of the respondents have participated in projects with BIM collaborative processes (52%), 18% were declared as BIM software users, and 20.5% had no experience with BIM. The rest were related to BIM as software developers as well as in the fields for research. These outcomes might be partially biased in comparison with the general sector due to the profile of the companies that are interested in this type of questionnaire, and they do not represent the current situation regarding digitalisation. There is still a challenge for further digitalisation even in the companies that state that they use BIM.
- Overall (61%) of the organisations were planning to invest in BIM (training, hardware, and software) while 11% had not planned any kind of investments;
- The vast majority associate BIM with concepts such as collaborative and information management, a few with the terms efficient, 3D model, and digital information, and none declared BIM as "expensive";
- The most extended use for BIM among the respondents was architecture, construction, design, and maintenance, and very few respondents (if any) used it for environment, demolition, quality control, planning, or augmented reality;
- Regarding the software that was used in their organisations, the most used were AutoCAD ADT, Revit, and Navisworks, while software such as All plan, Tekla, Solibri, MicroStation, Bentley, or Synchro were minimally used by the Spanish users according to the results;
- The results showed that, for Spain, there were no specialists in the domain of exchange data or a collaborative process manager among the respondents, as have been identified in other countries.

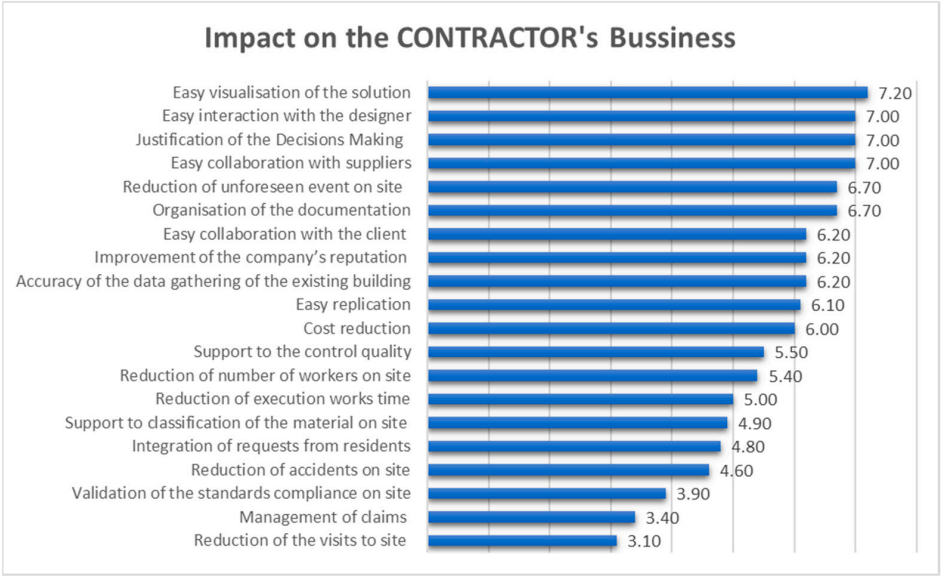
Regarding the typologies of the renovation works that were addressed by the Spanish respondents, they state that mainly these were oriented to interventions in the envelope that was devoted to improve the energy efficiency (such as façade energy retrofitting, framing and glazing replacement). Updating of building accessibility wase also declared and at a lower level, they also addressed deep renovation projects. In addition, the foremost typology of renovations were dedicated to residential buildings, followed by educational buildings or offices and, particularly, in tower buildings or groups of apartment blocks instead of single family or terraced houses, which were more represented in the overall survey covering the rest of countries.

Once the main barriers in the sector for a higher digitisation level were detected for the Spanish case, some aspects of the renovation process that was related to the potential benefits of technology and particularly BIM, were assessed. The aim of this assessment was to settle the prioritisation of the indicators by the type of stakeholders which will later lead to the definition of requirements for the digital tools being successfully used in renovation.

The answers were assessed through weighting of the proposed indicators according to their impact on the stakeholder's business and the outcomes that were given by stakeholders'. The high impact was rated with a 5, the medium as 2.5, the low as 1, and 0 for those indicators that have not been valued. To get comparable findings, the results were normalised, giving a result a number between 1 and 10, with 10 being the highest that is considered most relevant for the stakeholder. From that point, the prioritisation of the indicators was stated, leading to the definition of requirements for the digital tools to be successfully used in renovation. In Figure 11 the outcomes are given by the type of stakeholders in descending order according to their importance. The most representative 3 categories of stakeholders for the Spanish context are presented.



(**a**)



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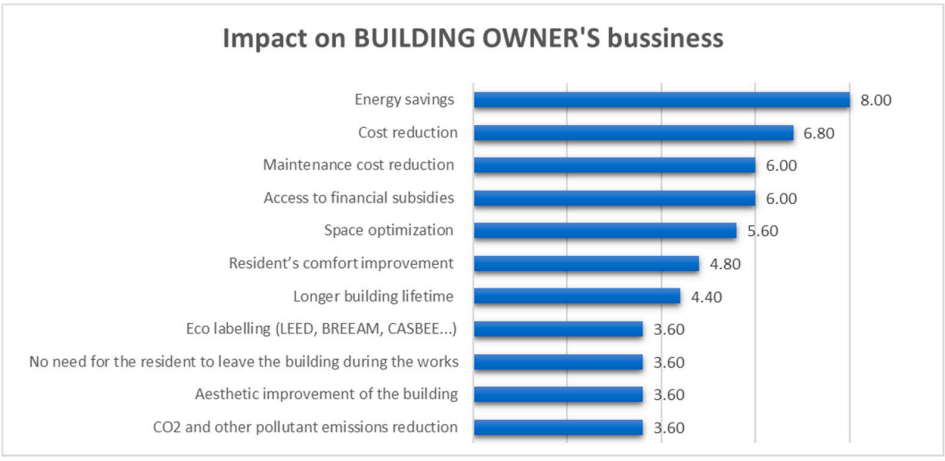

(**c**)

Figure 11. Assessment of key factors in a renovation process according to different stakeholders in Spain: (**a**) Impact on the designer's business; (**b**) Impact on the contractor's business; (**c**) Impact on the building owner's business.

3.2.2. Results Obtained from the Interviews

The interviews that were carried out individually with the main agents were intended to find out the causes of mistrust with other stakeholders, as well as the main barriers of the renovation process [32], focusing on the use of BIM as a key methodology to solve them. These results are presented by typology of the stakeholder interviewed:

a. Main barriers identified by the private building owner:
   - The lack of information about the progress to the owners does not allow them to follow the project and provide inputs;
   - Taking into account that the renovation is requested when some relevant damages appeared in the building affecting to resident's comfort conditions, the key aspect is to solve those pathologies. Otherwise, the purposes of the renovations are not appreciated by the owner;
   - The technical project is not usually delivered to the owner at the end of the design phase; only a document is provided at the end setting the conditions of use of the renovated building for maintenance purposes.

b. In the case of a social housing company as a public owner [33], the highlights differed slightly with the ones that were identified by the general private owner as it is shown below:
   - The energy retrofitting in the residential sector is currently driven by funding, rather than by conviction about the improvement of sustainability, energy savings, and comfort conditions [34];
   - Distrust about the joint participation of the architect and contractor in public tenders were highlighted, leading to a lack of persuasion about the advantages of BIM as a collaborative process. They believed that the main advantage of BIM was the possibility of generating visuals and 3D models which helped to persuade the residents to perform the renovation;
   - The current public engagement procedures in Spain do not allow the engagement of the Architect and Contractor at the same procedure. These constraints come from the idea that the architect must oversee the contractor's work and that each stakeholders' function must be clearly differentiated assuming their own responsibilities;
   - In the case of renovation of building blocks, the potential of replicability is not leveraged due to the necessity of designing each one from scratch. It gives rise to important time and economic losses which can be overcome through the use of BIM models;
   - Although BIM is considered as a useful tool, a long time is needed to train the staff and it is not a priority for a public organisation;
   - In residential use, the preventive facility management after renovation was not common due to the difficulties of registering, managing and following the maintenance activities in the building;

c. Main barriers identified by the contractor [35]:
   - The mistakes are cumulative along the project (in phases of data gathering, diagnosis, and design) and the contractor must solve all of the problems at the end when the cost of solving is much higher;
   - The complexity of increasing industrialisation and the use of advanced tools on the renovation process are limited due to the difficulties of accurate data gathering. The culture of working on-site to adapt components and to manage the inaccuracies is a clear origin for several errors and deviations in the project;
   - The lack of traceability and common information to be shared between different stakeholders (architect, contractor, subcontractor, etc.) was a source of issues due to partial information or not updated information, etc. Also, the differences in the specific format to exchange this information the between stakeholders can also contribute to additional errors;

- Lack of confidence among the stakeholders, i.e., the owner usually sees the role of the architect as the controller of the contractor's work. Even the public engagement procedures are intended to engage separately the different roles, not affording to work in a collaborative way from the beginning.

d. Main barriers identified by the architect:
   - The data gathering of the façade in the design phase is manually performed using topographic instruments, instead of automatic means (3D scanners photogrammetry, etc.). The drawings are mapped from scratch or from the original drawings if they exist, and the work is often tedious;
   - Technical difficulties of collecting information about the materials and constructive systems of the existing building in the design phase, due to the current techniques, are invasive. This creates uncertainties in the construction phase leading sometimes to important economic losses;
   - Lack of confidence among stakeholders. The involvement of the residents in the decision making is crucial to ensure their acceptance and, consequently, the success of the project, but a culture of trust is necessary. For that purpose, the owners and residents must be properly informed and oriented on the activities that will affect them to manage their expectations [36];
   - Legal issues to solve responsibilities in the project. Currently the architect subcontracts services for designing the structure and main services of the building and they would share duties and responsibilities in case of accident. This is a worrying issue that must be tackled if BIM is used;

e. Main barriers identified by the industrials/suppliers
   - Their systems and products are often requested in the construction phase, without having been consulted in the design phase. This leads them to select the system that better matches the budget rather than the most suitable according to the specifications, dismissing other proposals due to economic reasons.
   - They are highly constrained by the price adjustments since they are pressed by all of the stakeholders (architect, contractor, and subcontractor) in the corresponding phase (project and construction phases) to achieve good deals.
   - The analysis revealed that there were some technical troubles about the interoperability between the tools and different file formats that the stakeholders manage. In particular, regarding the case that focused on façade rehabilitation, the exchange format for the 3D model of mouldings was not readable or editable by common BIM programs. This lack of interoperability hinders the moulding suppliers access to the market when the projects are highly digitalised.
   - Unawareness of the potential of BIM in the sector. The graphical information is exchanged in dwg format which is understandable by all of the agents that are involved in the project. Only 3D rendering is considered useful to give more value to their job under a commercial perspective.
   - The use of BIM requires a strong investment and it is not viewed as necessary in the sector at this moment.

3.2.3. Results Achieved from the Workshops

The workshops with all of the stakeholders were a key activity for the Living Labs, as these are helpful to share insights and merge thoughts to find common ground as a first step for collaborative works, as required by the BIM methodology. The starting point of the workshops was the recognition of the barriers that were identified in the surveys, leading to the main inefficiencies of the renovation process, which have been widely contrasted in the interviews. The discussion has allowed the user's to set their expectations for using BIM in renovation in a successful way. The most remarkable result of the workshops that were performed was a series of key indicators that were proposed, discussed, and agreed by the stakeholders that were participating in the Living Lab. This represents a valuable

set of parameters to monitor the progress of those real renovation projects that were used as pilot cases for testing.

Once the inefficiencies that were identified in the renovation process in the workshop were deeply analysed, they were categorised to address them separately as follows:

- Inefficiencies that arise because the information that is necessary for the development is not accessible, it is not homogeneous, it is not updated, and it is not very detailed, etc.
- Inefficiencies that arise due to lack of communication and a good interrelation between the agents that are involved in the rehabilitation process, i.e., a lack of understanding among the agents of the sector, poor communication between agents, non-shared information, and technicians and owners have few communications, etc.
- Inefficiencies that are related to the economic issue, i.e., budget deviation, difficulty to focus/specify prices, and a request of new budgets by the owners (changes of opinion), etc.
- Inefficiencies that are related to the execution of the tasks themselves, i.e., ineffective data collection (erroneous measurement, lack of evidence), lack of supply of materials, lack of planning, and difficult coordination of work times, etc.

After identifying all of the negative aspects, in the second stage of the workshop the key technologies linked to BIM for overcoming the barriers in renovation process were defined. According to the results of the workshops, it was decided that BIM and other digital solutions are the best options to address the difficulties in a more efficient way, particularly those that related to coordination between the stakeholders. This is because the inefficiencies that are considered as priorities are those that are related to the information, communication, and interrelation of agents. Some of the technologies and technological solutions that have been considered as key by the value stakeholders that participated in the Spanish workshops are the following:

- Sensory, IoT monitoring, 3D scanning, 360° cameras, computer vision, and a digital building book for the improvement of data collection and diagnosis [37].
- Market price database tool (currently there is no database for energy renovation) to facilitate pricing.
- Last planner system, a constructive model of the building (with costs and planning) to improve the execution process of the work [38].
- Virtual reality and augmented reality that are intended to facilitate visualisation to users/owners [39].
- Easily understandable BIM models (visual, management), digital communication platform, and applications for the improvement of communication between stakeholders that are applicable to the whole rehabilitation process to improve both the quality of the information and that it is accessible, such as communication and interrelation between agents [40].

Taking into account the main interests of the Living Lab of the Spanish use case, the workshops were also intended to agree on indicators to monitor the renovation processes with BIM. These measurements are potentially usable to demonstrate that the productivity and the overall renovation process is improved thanks to the incorporation of such novel technologies, rather than using traditional project management tools. Therefore, a set of key performance indicators (KPI) will be adopted which will enable the characterisation of the renovation process, as well as to provide individualised information to each category of stakeholder [41,42]. KPIs are measurement parameters that are focused on those aspects that are critical for the success of any project or activity. The monitoring of such aspects must be continuous and must be systematised within the activities that are carried out in the construction process, aiming to obtain reliable information that can be used to support decision making. Key indicators in construction have traditionally been those that are associated with costs, planning, quality, productivity, and safety. Based on the classification that is provided by Cruz et al. [43], the workshop has allowed a deeper insight of the whole value chain in the renovation process. To sum up, Table 4 collects the main indicators that

were selected for each category, and the interrelation with the requirements as expressed by different stakeholders.

Table 4. Categorisation of indicators for renovation process.

Indicator Group	Identified Indicators	Expectations Covered	Related Stakeholders
Process indicators	Cost	Reduction of time	All stakeholders
	Time	Cost reduction	All stakeholders
	Quality	Accuracy of data gathering	Designers
	Forecast accuracy	Improvement of the company's reputation	Designer
	Customer satisfaction	Easy visualisation of the solution	Owners
Diagnosis Indicators	Data's accuracy	Accuracy of the data acquired	Designers
	Cost for acquiring the data	Reduction of unforeseen events	Contractor
	Level of specialisation required		
	Level of linkage of the data with the model		
BIM indicators	BIM maturity	Reduction of time	All stakeholders
	Training required for BIM	Cost reduction	All stakeholders
	Integration of requirements	Accuracy of data gathering	Designers
	Workflow definition	Improvement of the company's reputation	Designer
	BIM model accuracy & effectiveness	Easy visualisation of the solution	Designer, contractor, and others
	Conflicts & adjustments	Reduction of unforeseen events	Contractor
	Interoperability between tools	Accuracy of the data acquired	
Performance indicators	Energy Saving		Owners
	Operation and Maintenance Costs		Owners

3.3. Summary of Results

As a summary of the main findings that were achieved in the Spanish Living Lab, Appendix A presents Figure A1, that aimed to describe, in a simplified way, the main findings of the research. The figure depicts the process that was followed in the methodology with the main results that were obtained from the different instruments that were used during the development of the Living Labs.

As a first step, the questionnaire has provided some quantitative results according to barriers, technologies, and benefits. These have been gathered at the European level but also at the Spanish level. Then, from the detailed results for the Spanish use case, qualitative results have been achieved through the Living Labs. Following the same method of findings to normalise the results as explained in the Sections 3.1 and 3.2, a comparative analysis is presented of the results that were obtained for the overall case and for the Spanish case. After this, and focused on the Spanish findings, the information has been detailed in a qualitative way through consultations with key stakeholders in the Spanish sector of renovation. As a result, and as depicted in the Figure A1, the main outcomes that were obtained are the barriers of the renovation process, the technologies capable of overcoming those, and the key indicators for monitoring the potential improvements once digital solutions are included in renovation activities.

4. Discussion

The discussion allows the summarising of the findings that were obtained with the three instruments that were used in the proposed methodology: the questionnaire, the interviews, and the workshops. This section will focus on two main issues: First, the foremost barriers of the renovation process will be presented, focusing on the main inefficiencies that were detected by the agents that were involved in the process. Secondly, the discussion is concluded with the most meaningful issues that related to the potential for digitalisation, and particularly the BIM, to overcome barriers. This second part culminates in the defini-

tion of the key indicators which will enable the definition of the user's requirements for the digitalisation of the process to fit to real expectations

4.1. Main Barriers Leading to Inefficiencies on the Renovation Process

Regarding the link between the barriers and the phases of the process, it is stated that even considering that the most represented phases among the Spanish respondents were the design phase and the data gathering phase, they have clearly identified the construction phase as the one where the most difficulties arise, followed by the technical design and diagnosis phases. Although the number of Spanish respondents is not as representative as the ones that have answered to the general survey, this conclusion must be mentioned since it differs significantly from the overall results. This could represent the main focus where effort needs to be strengthened to improve the efficiency of the renovation process in Spain. The sequence of importance of the phases is set by all type of agents, being especially remarkable that the designer and building owner both perceive the construction phase as the most problematic despite not being forcedly linked with it. Overall, the reasons that were pointed out by the Spanish stakeholders about the difficulties in the construction phase are related to the lack of knowledge about the building (absence of preliminary studies), as well as unforeseen situations during the works due to the building state. According to them, these circumstances lead to over-costs and difficulties in fitting to the planned schedule [44,45]. They said that the errors coming from early stages and inaccurate data gathering are accumulated along the process and the consequences become crucial in the construction phase. To sum up, the phase where more difficulties arise in the Spanish context was the construction work phase. Several problems that were related mainly to this phase, was the delay in supplying of materials or the incorrect material organisation on site, representing a negative impact in the renovation project, according to the answers.

As for the inefficiencies, the lack of communication appears to be one of the critical inefficiencies for new construction but also for renovation, as well as the changes by the customer who has slightly more importance in the renovation projects. In the case of renovation, new barriers regarding the lack of accuracy or knowledge about the existing building are key while the regulatory barriers move down in terms of relevance. It is also highlighted that unforeseen works which cause deviations in time have more negative impacts in renovation in comparison with new projects.

The previously identified topics not only cause negative effects to the renovation project, but also lead to losses in terms of business to the stakeholder's company. It is also revealed that the impact of the inefficiencies on the stakeholders' business is not always related with the success factor in the project. The most severe losses are related to the lack of accuracy in the data gathering and modelling of the existing condition as well as the lack of knowledge about the existing building. Nevertheless, the issues that are linked with the interaction of stakeholders or the residents is not considered as the cause of high losses, although they are recognised as fairly negative in previous questions.

The results about the inefficiencies, according to the impact of a renovation project on the Spanish stakeholder's business, are quite similar to the general responses. It is remarkable that the problems causing a major negative effect on the success of the renovation project are also related to the unforeseen works and the changes of the specifications from the customer. Other acknowledged problems have been the lack of knowledge about the building, lack of communication between stakeholders, and the "unfulfillment of the hand-in deadline", which is more representative in Spain in comparison with the European framework. Nevertheless, the issues that were related to on-site works, such as the quality faults, claim management, inadequate organisation of the supplied material, or technical difficulties on integration with the existing building seem not to be very relevant for the Spanish respondents. As to the type of stakeholder, the designer appears to be more worried about the lack of information describing the existing building, and the undefinition or changes of the specifications by the owner. The designed shares this last concern with

the contractor. However, the major concern for the building owner seems to be the delays in the hand-in deadline. Regarding the losses that were caused by the inefficiencies to the companies that were involved in the process, although the results are quite similar to the overall responses, it must be highlighted that the contractors appear to be more affected by the difficulties of collaboration between stakeholders.

4.2. Potential to Overcome the Barriers through the Digital Tools

As a summary of these findings about the potential for digitalisation and BIM in the renovation process, the following statements are helpful to define the user's requirements.

- The results revealed that most of the stakeholders think that the issues that related to the lack of accuracy and knowledge about the existing building, and imprecision on the modelling conditions can be overcome thanks to the BIM, as well as the lack of communication between stakeholders.
- The major benefits that are provided by digital tools for renovation are the detection of mistakes and the integration of the work in a unique model, followed by the improvement of communication, Aspects such as the time savings, access to tenders, or the use of the models in operation are not considered meaningful.
- Nevertheless, the participants have stated that the reasons for being reluctant to the use of digital tools are the high investment in training and cost, the difficulty of the interoperability between tools and, mainly, because they are not accessible to the whole value chain of the construction process.

The participants in the Spanish Living Lab consider that a digital tool/platform must be interoperable and encompassing the whole process, as well as low priced. Other features such as easily updated and quick processing are not seen as key as the first features for improving the renovation process.

Finally, the critical concerns of the whole value chain regarding the digitalisation of the renovation process are presented. Thanks to the use of the proposed indicators as shown in the Section 3.2.3, these aspects are intended to be monitored and assessed.

- Designers are particularly concerned about the technical issues of the process. Indicators that are related to the accuracy of the information about the existing building are especially relevant for them, as well as other technical issues that allow them to improve the process, such as the organisation of documentation and visualisation. Even though they do not consider cost reduction as a direct priority, they are concerned about the time savings in the part of the process that they are involved, which is obviously related to the cost savings. It is remarkable that, based on the survey, social indicators are not crucial for designers, apart from the social reputation of the company.
- For contractors and subcontractors, economic indicators are the most relevant. Cost reduction is the main priority, followed by other technical and economic issues [46]. It is also noticeable that there is interest in some technical issues, such as the easy visualisation of the solution, the reduction of unforeseen events on site, and the accuracy of the data gathering. These technical aspects may affect the budget significantly, so they could also be indirectly considered as economic indicators. Additionally, the indicators defining the safety and organisation on site seem to be important, but not as much as the indicators defining the collaboration with other stakeholders, which are rated positively. Finally, social aspects that are related to the end user requirements are neither considered nor critical for this group.
- The building owners consider that the most important indicators are economic aspects such as: energy savings, maintenance cost reduction, works cost reduction, and access to finance. Surprisingly, the increase of the building value was not found to be crucial for building owners. Some social indicators that, a priori, could seem to be relevant for building owners, such as space optimisation, aesthetic improvements, or not needing to leave the building during the works are also not as critical for this group. The label

or certificates after renovation is the only technical indicator that was rated in the list and is not ranked at all as a priority.

- The industrial companies said that the indicator with a major effect on their businesses is the construction project's delivery time. Additionally, some technical indicators such as organisation of the material or documentation, easy visualisation of the solution, and easy interaction with the designer and, to a lesser extent, with the contractor, were found to be critical. It is remarkable that the integration of the end-user's requirements is relevant for the industrials, more than for any of the other stakeholders. In general, the answers from the industrial group differ significantly from those that were gathered from other stakeholders. In this respect, it is particularly noticeable that data accuracy and the improvement of the company's reputation are not seen as relevant for industrials, while they are for the designers and contractors. In contrast, claims management was found to be of considerable importance for industrials whereas it is not a key indicator neither for designer nor for contractors.

These points provide a set of indicators that can be used in a digitalised renovation process, based on the prioritisation of the respondents representing AEC sector stakeholders' requirements. They measure either the performance of the renovated building or the quality of the renovation process. Digitalisation allows them to reach benefits in both contexts since it enhances the process and makes it possible to implement solutions for renovation that are strictly tailored to the end-user's requirements, performance targets, and renovation processes.

5. Conclusions

The research presented has addressed the identification and analysis of critical barriers of the renovation process and the potential for digitalisation to overcome them using BIM methodology [47–49]. From the analysis of barriers and opportunities, the necessary requirements for an optimal BIM application that is focused on the renovation context have been highlighted. The investigation was developed through an approach that was based on Living Labs, whose strategic role in the digitalisation process of the local construction sector is evident. The following benefits summarise this interest:

- To socialise the technology that will enable the improvement of technological progress.
- To generate a technological demand representing a social progress.
- To promote R&D and/or innovation projects that are centered on the users that participate on those contexts.
- Develop research activities with a user ecosystem. Investigations with users entails the creation and dynamisation of user-based communities generating social and cultural capital.

As a general conclusion it seems that main concerns of the stakeholders in renovation projects are related with time savings, cost savings, and the collaboration process. In this sense, there is a need aimed at monitoring the improvements in terms of savings in a clear and simple way, through some key indicators. Current research has provided a first identification of relevant information that each stakeholder group is aiming to monitor (expressed as key performance indicators) during renovation activities to consider the successfulness and compliance of their requirements. In the list provided, unlike other investigations, a specific list of BIM-KPIs have been included that are intended to be used to quantify the BIM maturity level of the pilot case, and as result, enabling the link of the empirical results that were obtained for those projects with the benefits provided by the application of BIM to those cases. This will allow the comparison in the reduction of costs and time in relation to the BIM maturity level for both the companies as well as for the specific project defined to renovate each pilot case. To analyse this BIM maturity level, the application of relevant documents will be monitored, such as the employer information requirements (EIR), or the BIM execution plan (BEP). Moreover, the definition of the BIM models will be valuated, considering for these, the level of development (LOD) that was used, as well as the degree of centrality, interlinked information, and also the use of a

centralised storage system for the information by means of a platform that avoids the use of archives.

Nevertheless, the renovation has specific hinders that are related to the data gathering of the building's characterisation parameters and the reliability and management of this data representing the actual building. Even if there are currently a set of promising technologies that play an important role for those data gathering activities, there is still a big challenge to convert, manage, and interact with this information in formats that are compatible with collaborative processes. This is the key issue to solve in renovation and one of the main concerns among stakeholders, where the data accuracy represents one of the main concerns for architects and stakeholders intervening in the design phase. Related with this aspect, the Living Lab helix that corresponds to the industry is currently developing specific solutions to overcome the deficiencies that were detected.

Regarding the limitations of the research that was carried out, the list of identified KPIs are currently being applied to the pilot cases that were considering the use or absence of BIM. The selection of those indicators has been agreed upon the participants. As a result, the users are currently measuring the savings in costs and time. The stakeholders that have participated in the Living Labs are representative of the sector, but there may be some stakeholders in other types of renovation works that have difficulties that have not been covered in these Living Labs. The research has an initial phase that is focused on the Living Lab of the European project but has later been specifically for the case of Spain. This does not imply that the outcomes of the Spanish case can be significant and interesting for the rest of the countries that were included in the project, an aspect that needs to be assessed case by case.

Future research and following the steps of the investigation that are presented are going to be based on the second stage of the European BIM4REN project, where the methods of the Spanish case will be replicated in the rest of the countries. In that phase, the pilot cases will be monitored using the proposed KPIs, to estimate the savings in time and costs that were achieved thanks to the use of BIM. Once these benefits are detected and quantified, the optimisation and significant necessity of collaboration between stakeholders will be highlighted. This is a field that can be studied in more detail with methods such as social network analysis (SNA) or the technical acceptance model (TAM).

As such, digitalisation and, in particular BIM, can meet the challenges of achieving an efficient renovation process, allowing for the optimisation of the renovation processes for buildings in improving the construction industry as a whole. When taking into account that buildings and construction have a significant impact on energy consumption, CO_2 emissions and waste generation, this improvement in the efficiency will have a positive impact on the environmental sustainability, aligned with the latest climate and energy framework as well as in relation to the key targets to be met by the EU for 2030.

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Institutional Review Board Statement: The study was conducted according to the ethics requirements established by European Commission's Horizon 2020 Legal Framework.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data collected during research activities has been partly published in public reports of the BIM4Ren Project. Available at https://bim4ren.eu/publication-results/project-deliverables/ (accessed on 1 July 2021). The complementary data is confidential and with restricted access, mainly due to personal data protection aspects.

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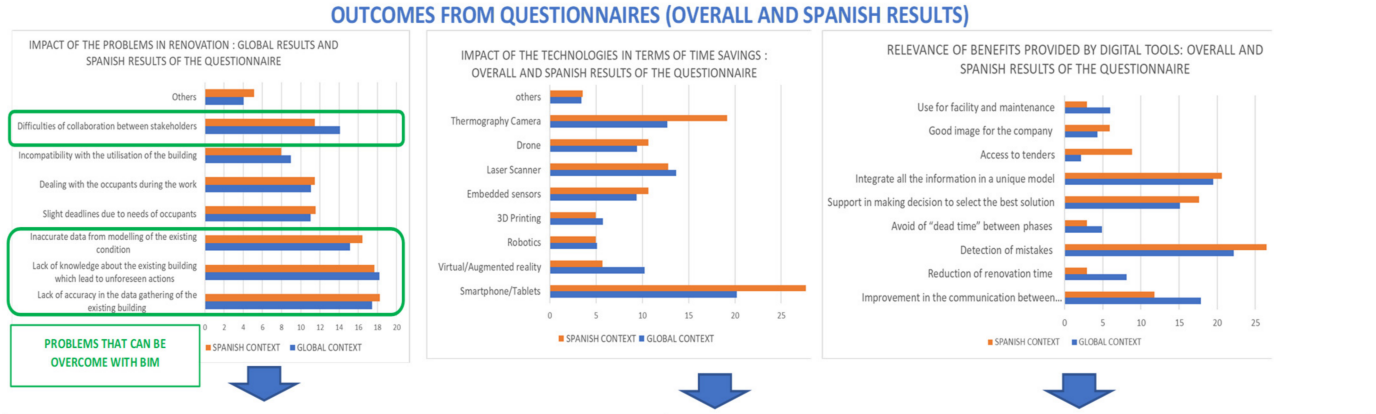
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A



OUTCOMES FROM INTERVIEWS (SPANISH RESULTS)			OUTCOMES FROM WORKSHOPS (SPANISH RESULTS)		
CATEGORY OF STAKEHOLDERS	**BARRIERS IN THE CURRENT RENOVATION PROCESS**	**CLASSIFICATION OF THE BARRIERS**	**KEY TECHNOLOGIES LINKED TO BIM FOR OVERCOMING THE BARRIERS**	**KEY INDICATOR**	**EXPECTATION COVERED**
PRIVATE OWNER	Lack of the progress updating to the owner	Related to the communication and collaboration	Virtual and Augmented Reality, BIM,	Customer satisfaction	Easy visualization of the solution
	Focused mainly on the improvement of the comfort's conditions	Related to the execution of the tasks	IoT monitoring, Thermography	Customer satisfaction, quality, energy savings	Improvement of the reputation
	The technical project is not usually delivered to the owners at the end.	Related to the access of the information	Digital Building Logbook , BIM	Customer satisfaction, Workflow definition, Operation and Maintenance Costs	Easy visualization of the solution, Improvement of the reputation
PUBLIC OWNER	Energy retrofitting mainly motivated by funding	Related to the budget	BIM (as tool for cost saving)	Cost	Time reduction
	Distrust about a joint collaboration between architect and contractor, since the architect is seen as the supervisor of contractor	Related to the communication and collaboration	BIM , Last Planner System	Interoperability between tools, BIM maturity, Conflicts & adjustments , Workflow definition	Time reduction , Reduction of unforeseen events, Improvement of the s reputation
	The potential of replicability in building blocks is not leveraged, leading to time of economic losses	Related to the budget	Market price database tool	Cost for acquiring the data	Reduction of unforeseen events
	Need of investment in training on BIM	Related to the budget		Training required for BIM	Cost reduction
	Difficulties for preventive facility management due to the troubles on managing the maintenance during the whole life of the building	Related to the access of the information	Digital Building LogBook	BIM model accuracy & ffectiveness, Interoperability between tools, Operation and Maintenance Costs	Easy visualization of the solution, Accuracy of the data acquired
CONTRACTOR	As final stakeholder involved in the process, the contractor must overcome previous problems leading to high costs	Related to the execution of the tasks	Last Planner System	Conflicts & adjustments	Reduction of unforeseen events
	Complexity of an accurate data gathering and need of use of advanced tools	Related to the execution of the tasks	3D scanning, 360º cameras	Level of specialization required, Level of linkage of the data with the model	Reduction of unforeseen events, Time reduction, Accuracy of data gathering
	Lack of traceability of the information between the stakeholders	Related to the access of the information	BIM	BIM maturity	Time reduction
	Lack of confidence among stakeholders regarding their roles	Related to the communication and collaboration	BIM, Last Planner System	BIM maturity	Time reduction
ARCHITECT	The current manual data gathering leads to tedious and slow work	Related to the execution of the tasks	3D scanning, BIM	Level of linkage of the data with the model, Level of specialization required	Accuracy of the data acquired
	Uncertainties about the building state and technical difficulties for collecting information about it (materials, constructive systems...)	Related to the execution of the tasks	Last Planner System	Integration of requirements, data´s accuracy, BIM model accuracy & effectiveness	Accuracy of data,Gathering, Easy visualization of the solution
	Lack of confidence among stakeholders regarding their roles	Related to the communication and collaboration	BIM	BIM maturity	Time reduction
	Difficulties to track the legal responsibilities of stakeholders	Related to the communication and collaboration	BIM	Workflow definition	Improvement of the company's reputation
INDUSTRIALS /SUPPLIERS	Involvement of the supplier at the end of the process, without any opportunity of changes	Related to the access of the information	BIM	Workflow definition, Quality	Improvement of the company's reputation, accuracy of data gathering
	Constrained by price reductions demanded by all stakeholders	Related to the budget	Market price database tool for renovation	Cost	Time reduction
	Troubles with the interoperability between tools and formats exchanged	Related to the access of the information	BIM	Interoperability between tools	Accuracy of the data acquired
	Unawareness of the potential of BIM in the sector, which consider a 3d model enough for their purposes	Related to the communication and collaboration		BIM model accuracy & effectiveness	Time reduction , Easy visualization of the solution
	Need of strong investment in BIM, not considered necessary	Related to the budget		Training required for BIM	Cost reduction

Figure A1. Visual representation to describe the main outcomes of the research for each stage, questionnaires, interviews, and workshops.

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