Practitioners' Concerns about Their Liability toward BIM Collaborative Digital Mockups: Case Study in Civil Engineering

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Abstract: Building information modeling (BIM) involves the use of collaborative digital mock-ups of an asset to streamline design, building, and operation processes. Collaborative work and the use of an integrated digital mock-up offers many advantages but raises several problems regarding the liability of stakeholders in construction projects. Practitioners involved in the design process of a building (engineers and architects) practice very high-liability professions for which the use of a digital mock-up implies potentially high stakes. Although liability issues have been identified in the literature as a hindrance to BIM implementation, practitioners' concerns toward their liability have only barely been investigated. In this paper, we propose to explore engineers' concerns about their liability toward using BIM collaborative digital mock-ups with a case study in civil engineering. We documented these concerns through an exploratory study consisting of semi-structured interviews. The main contribution of the paper is therefore an organized list of concerns. These include: the alignment between their way of working and professional rules, the clarity of the assignment of liabilities, and the reliability of the digital mock-up. These stem from a liability risk that practitioners perceive because of uncertainty about liability allocation and uncertainty regarding the reliability of digital mock-ups. Our research work is part of an overall effort to understand the problems faced by practitioners when implementing new practices associated with BIM and to provide solutions. The results are therefore extensively discussed in order to identify hypotheses and avenues of work to address the identified concerns. The specific context (engineers, in Quebec) and the exploratory nature of the study implies that the results are not generalizable to a wider population. However, the identified concerns may be likely to emerge in similar context like high-liability professions involved in design stages of BIM projects. This paper is a very first step toward identifying these concerns in the construction sector and must be subject to future work. **DOI: 10.1061/JCEMD4.COENG-12764.**

Practical Applications: Our research work is part of an overall effort to understand the problems faced by practitioners when implementing new practices associated with the use of digital mock-ups and to provide solutions. Building information modeling (BIM) and product lifecycle management (PLM) involve the use of collaborative digital mock-ups of an asset to streamline design, building, and operation processes. They offer many advantages but raise several problems regarding the liability of stakeholders in construction projects. Practitioners involved in the design process of an infrastructure practice very high-liability professions for which the use of a digital mock-up implies potentially high stakes. In this paper, we propose to explore and document engineers' concerns about their liability toward using and signing BIM-PLM collaborative digital mock-ups with a case study in civil engineering. Our results show that engineers are concerned about the alignment between their way of working and professional rules, the clarity of the assignment of liabilities, and the reliability of the digital mock-up. These identified concerns are extensively discussed in order to provide hypotheses and avenues of work to overcome them, including technical solutions, organizational solutions, and legal solutions.

Author keywords: Building information model (BIM); Liability; Practitioners; Designers; Civil engineering; Product lifecycle management (PLM); Liberal professions; Digital mock-up.

Introduction

The Construction Sector and Its Digitization

The architecture, engineering, construction, and operations industry (AECO) is known to be quite slow to adopt innovations (Harty 2005; Havenvid et al. 2019; Nam and Tatum 1988; Slaughter 2000; Winch 1998). This industry is characterized by a project-based approach, inter-organizational collaboration (Harty 2005; Nam and Tatum 1988; Winch 1998), and power distribution among organizations (Harty 2005; Slaughter 2000; Winch 1998). Some innovations are meant to be used by multiple disciplines;

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these are called unbounded (Harty 2005), and are the most difficult to disseminate in the sector.

Building information modeling (BIM) is defined as "the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" (ISO 2018). It differs from well-known traditional computer aided design technologies (CAD) by the level and type of information that is being used and produced (Ashcraft 2008). BIM processes rely on the sharing of information rich 3D models that are created collaboratively (Ashcraft 2008; Eastman et al. 2008; Sebastian 2010). Consequently, BIM is typically an unbounded and radical innovation that concerns several professional bodies, the technologies they use, the processes they implement, and more generally, how they collaborate.

BIM adoption is encouraged in many countries, but its implementation is difficult and raises multiple challenges at the micro, meso, and macro levels (Eastman et al. 2008; Kassem and Succar 2017; McGraw Hill Construction 2014; Smith 2014). In fact, the adoption of BIM practices requires a significant change in working methods and processes within firms (Arayici et al. 2012). Moreover, collaboration processes between multidisciplinary and interorganizational project teams must be adapted (Poirier et al. 2017; Sahil 2016) and significant regulatory, educational, and technological changes must be done (Succar and Kassem 2015).

BIM practices are progressively being implemented within organizations, but some questions are still unanswered. At the beginning of the diffusion process of any innovation (and BIM), the first adopters bring out new issues and contribute to the development of good practices associated to this innovation (Hochscheid and Halin 2019; Rogers 2003). This is why it is interesting to document these issues. However, very few studies have investigated BIM implementation problems from the viewpoint of professionals.

Practitioners' Liability in the Construction Sector: A Core Concept

Some professions are more prone to liability issues than others; this is the case of engineers and architects. For the remainder of this article, in order to simplify the text, we will refer to engineers and architects collectively as practitioners but the case study is about engineers only. In most countries and in the context of our study (Québec, Canada), professions involved in the design phase of a building—such as architects and engineers—are regulated and liberal professions. This means that they have a professional order, a code of ethics (Government of Quebec 2020b, a) and their activities are strictly regulated by law and reserved to holders of documents attesting to their training. Moreover, these professionals are accountable for the professional acts they perform (Duţescu 2017). Thus, the order of professional engineers' specifies that "engineers must assume the full extent of their responsibilities to the public, their employers, their clients, their peers, the profession and themselves. Failure to comply with the rules and requirements of the profession may result in disciplinary action" (Ordre des Ingénieurs du Québec 2021). This liability can be divided into three aspects:

- Professional liability (e.g., engineers can be disqualified from practicing);
- Civil liability (e.g., they are liable for the damage caused to others because of their acts, errors, negligence and/or omissions in the performance of their professional duties); and
- Criminal liability (e.g., they may incur penalties with pecuniary consequences or deprivation of freedom).

Liability is therefore a key concept in the engineering profession. Engineering documents are the documents (paper or digital supports) that embody an engineer's professional acts for which they can be held accountable. The accuracy of the information presented on these official documents is therefore of utmost importance. It is also a key issue in the context of the digitalization of work processes and deliverables that specifically concerns information, as BIM.

Liability, a Key Issue for the Digitalization of Construction Processes and Deliverables

Risks related to the exercise of the liberal professions in the construction industry are strongly linked to the accuracy of information that professionals receive and produce, the stability of decisions, and the observance of deadlines (Duţescu 2017); digitalization—and consequently BIM—directly impacts these three core aspects of professional practice. During the 1980s–1990s, the development of innovations increased the complexity of construction projects, making it more difficult to allocate liability (Fain 1995; Holland 1985). Liability claims and malpractice suits against engineers and architects increased in tandem (Holland 1985).

While BIM is supposed to improve the performance of work processes as to gain in efficiency and convenience, it also incurs issues and risks, including legal ones (Arensman and Ozbek 2012; Hsu et al. 2015; Jo et al. 2018; Thompson and Miner 2006; Ussing et al. 2016). BIM implementations generate uncertainty for practitioners in construction projects with a consequence that practitioners can offer limited warranties to users (Azhar 2011; Hsu et al. 2015; Ussing et al. 2016). Legal risks are an important barrier to the implementation of BIM practices (Arensman and Ozbek 2012; Eadie et al. 2015; Hsu et al. 2015; Jo et al. 2018; Sebastian 2010). While the legal implications of BIM have been discussed in the literature, studies that investigate this issue are rarely empirical and are still in their infancy (Fan et al. 2018). They seldom address the perspective of practitioners to identify their reactions and the way in which they perceive these risks in the context of BIM projects. Furthermore, in the research on the legal risks associated with BIM, the liberal and regulated professions (whose liability is considerable) are rarely mentioned.

Scientific Background and Selection of a Working Angle

Legal issues raised by the adoption of BIM practices have been documented over the past decade (Arensman and Ozbek 2012; Chao-Duivis 2011; Eadie et al. 2015; Fan et al. 2018; Ussing et al. 2016). However, the scientific literature has not addressed the topic of practitioners' concerns about their liability from their subjective point of view.

The specific topic of digital signature adoption is discussed from a technical [how to technically authenticate a document (Chao-Duivis 2011; Mahamadu et al. 2013)] and a regulatory perspective [what are the consequences of signing digital documents instead of paper documents (Sebastian 2010)]. But these topics have not been examined from practitioners' subjective perspective (how this change is perceived). The impact of digital deliverables on practitioners and their acceptance of signing BIM models (digital mock-ups) is not addressed either.

Furthermore, practice-grounded approaches and empirical data on BIM legal concerns are quite rare and thus research on BIM legal issues is still at an exploratory stage (Chong et al. 2017). Some studies observed practitioners' concerns and reluctance to work with BIM through semistructured interviews like Chao-Duivis (2011), Ussing et al. (2016), and Arensman and Ozbek (2012); or with questionnaire surveys like Eadie et al. (2015).

However, the main objective of these studies was to identify legal issues. Documenting and understanding practitioners' reactions still need to be addressed, and this is what we propose to do via interviews in our case study.

Context, Objectives and Methodology of the Study

In this section, we present the context of our industrial partner involved in the case study, the objectives of the study and the research methodology.

An Exploratory Study

In this research, we explore practitioners' concerns about their liability toward a collaborative digital mock-up through a case study. We worked with an industrial partner that reported difficulties with replacing its regular 2D digital engineering documents by 3D mock-up engineering documents because of liability issues reported by their engineers. We documented the engineers' concerns about their liability when they use a collaborative digital mock-up. These results allowed us to tackle the topic with a new research perspective in an effort to answer the following question in the discussion: "why does the use of a digital mock-up in the context of a construction project seem to be a risky operation for practitioners and how can we overcome this issue?".

An Industrial Context and Operational Inputs as a Starting Point

Our industrial partner is a large company in the province of Quebec, Canada. This company's operations involve construction projects and therefore it has a department dedicated to asset/building design and construction and another one dedicated to facility management. We collaborated with the design and construction department, which has expertise in civil engineering to designs buildings and infrastructures. Engineers who work in these departments use Catia software as an enabler for PLM (PLM—Product Lifecycle Management). Some subcontractors and teams within the company also use BIM tools like Revit. The company therefore integrates tools and processes inherited from both BIM and PLM practices. This hybrid work environment (mixing BIM and PLM tools and processes) is atypical but not completely unique: many similarities exist between BIM and PLM processes (Aram and Eastman 2013; Mangialardi et al. 2017; Pourzarei et al. 2020). There is an interest in crossing these practices because they can contribute to each other (Pourzarei et al. 2020).

Top management requires engineers from the design and construction department to sign digital mock-ups instead of 2D drawings. The demand had the unintended but fascinating consequence of causing practitioners to be hesitant to sign digital mock-ups for reasons that were not expressly specified and did not appear obvious or simple to discern.

Research Objective

Our research work is part of an overall effort to understand the problems faced by practitioners when implementing new practices associated with BIM and to provide solutions. In this paper, we focus on a specific objective which is to identify practitioners' concerns toward their liability when using a digital mock-up. The contribution of this paper is therefore *a rich description of these concerns* and constitutes *a very first step toward identifying them for the construction sector.* The importance of identifying these concerns from a practitioner's perspective is to be able to address them while maintaining good working conditions while implementing BIM practices.

Our results are discussed in two different ways. First, scientific literature is explored in order to identify areas of work to address uncertainties associated with the listed practitioners' concerns. Alternatively, our results have been discussed with PLM experts to get an external perspective, given the hybrid BIM-PLM nature of our company's work environment and the fact that studies have shown that a mutual contribution between PLM and BIM is possible (Jupp and Singh 2016; Mangialardi et al. 2017; Pourzarei et al. 2020).

Methodology: An Exploratory Study

As our research question has only been minimally addressed in the literature, we have chosen to rely on empirical data with an exploratory study; such an approach is specifically used to explore or document a phenomenon that has not yet been well defined, as it can help delineate a reality to be studied and select methods or data sources to investigate (Reiter 2013; Stebbins 2001; Waters 2007). We use interviews to investigate a poorly documented phenomenon.

Reliability of a research study is the capacity of results to be stable in time when operations of a study (such as data collection) are repeated (Golafshani 2003; Yin 2018). Exploratory inductive research can achieve reliability when research is conducted in a structured way and when researchers are aware of limitations and bias of the study (Reiter 2013). Methodology of this study is explained in detail in this section; and scope, limits, bias, nongeneralization and future work are therefore extensively discussed in a dedicated section in the discussion of this paper. These precautions ensure the reliability of this exploratory research.

The interviews and analysis were the subject of a masters student research effort (Falardeau 2020). The interviews were conducted with practitioners to document their concerns regarding their liability when they work with a digital mock-up.

The interviews were conducted in three phases (Fig. 1). The first phase consisted of preliminary interviews and took place with two engineers to refine the interview guide, and to identify other participants. The topics addressed during these preliminary interviews mainly focused on BIM implementation issues and the responsibility of engineers in BIM processes within their work environment. Following this phase, the questions were oriented less on implementation issues and more on liability, distinguishing between professional and legal liability. The second phase was in the form of individual semistructured interviews with five engineers identified during the first phase. This phase was the most important one, with long one-on-one interviews lasting between 45 and 80 min. The third phase—conducted with the same participants as for the second phase—allowed us to deepen a point that had been highlighted by some participants in phase 2: the difficulty of working with the large amount of information contained in a digital mock-up.

Data Collection: Interviews Preparation and Conduct

Before the interviews were conducted, all members of the research team were expected to sign a confidentiality agreement. During the interviews with the respondents, the researchers clearly stated that these interviews were confidential and anonymous. All respondents were given the choice to participate or not in the research on a voluntary basis. The preparation of the research questionnaire began by verifying the vocabulary to be used to describe BIM in the context of the company under study. We asked the study participants, to answer a short questionnaire to guide us on the vocabulary

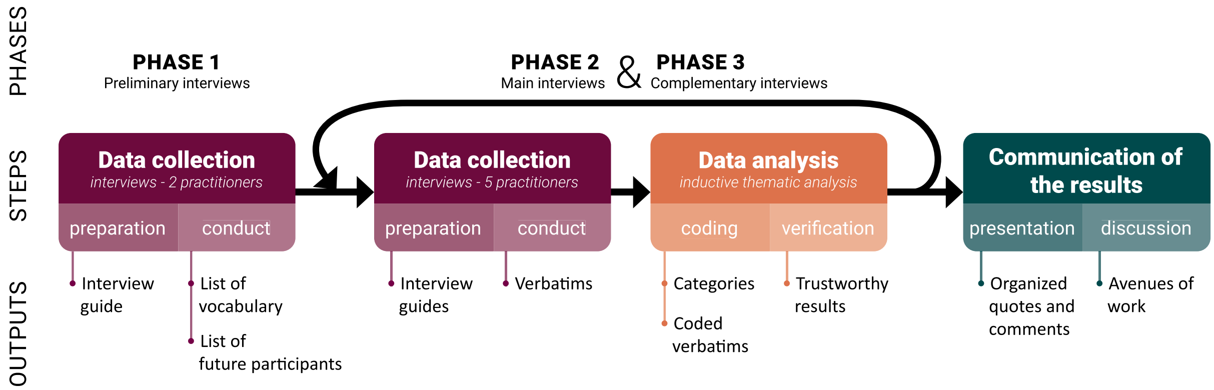

Fig. 1. Research process and methodology.

to use. The questions used in the semistructured interviews had to be completely understood by all respondents using appropriate vocabulary. The questions were therefore short and only addressed one aspect at a time. The questions were organized to first establish a climate of trust with the interviewee. Halfway through the interview, we got to the heart of the matter. The last questions were optional so that an interview could be shortened if necessary.

Our panel of participants only included engineers who work on construction projects, had already been confronted with BIM projects, were likely to have signed a PDF3D digital mock-up, and are registered with the *Ordre des ingénieurs du Québec* (the professional engineering order in Quebec). These criteria made it possible to identify about twenty people within the company. Among them, seven engineers agreed to participate in our study. Three of these seven respondents were expected to sign digital mock-ups as part of their work. Two of the seven helped us to adjust our interview protocol and questions, and the other five were interviewed individually to collect data. The panel was therefore constituted by seven engineers with various profiles and disciplines, as well as various levels of experience with BIM processes (Table 1).

Data Analysis

The analysis seeks to bring a plausible phenomenon based on the data (Braun and Clarke 2006). We therefore sought to highlight potential liability issues with digital data during BIM implementation, and to improve our understanding of them. The difficulty in identifying elements related to our research objective in the literature led us to conduct an inductive analysis. Quotes and collected comments were then grouped by themes in a coding process: we conducted a thematic data analysis in order to describe patterns in the qualitative data collected.

For this analysis, a first researcher analyzed the raw data, developed a set of categories, and coded verbatims according to these categories (preliminary results). Another researcher was called upon to validate the interpretation and meaning attributed to the raw data and discuss the coding. Coded verbatims and categories were then presented and discussed with the resource person of the company in order to establish internal validity.

Results: Practitioners' Concerns about Their Responsibility When Using a Digital Mock-Up

This section presents the results of our interviews. For each quote, the number of the interviewee is indicated from P1 to P7, as listed in Table 1. Also, the term *responsibility* has been used indiscriminately from *liability* during the interviews because the interviews were conducted in French, which has the same word for *legal liability* and *responsibility of a task*. The relevance of this distinction had not been identified before the interviews. As we did not want to misinterpret participants' statements in the transcript, we use the term *responsibility* throughout. Nonetheless, it can mean either responsibility or liability, depending on the interviewee and the addressed topic.

Regulatory Framework

The alignment between what engineers do and the OIQ's (*Ordre des Ingénieurs du Québec*) code of ethics is a major concern in their work: "we always follow the rules of the game … the ethical rules of OIQ" (P5). However, respondents also indicated that the OIQ does not seem to accept the exclusive use of a 3D digital mock-up as an official deliverable: "the law in Quebec says that you can't go to the construction phase without having 2D drawings signed by the engineer" (P2). Some signatories do not understand the importance of signing the digital mock-up as it is not an official deliverable.

Table 1. Participants characteristics

Participant	Discipline	Relevant experience
P1	Information systems	Engineer, design team manager
P2	Mechanical engineering	Engineer, uses and builds shared digital mock-ups
P3	Industrial and processes engineering	Develops 3D modeling methods with Catia (software), multidisciplinary 3D coordination, 4D modeler
P4	Civil engineering	BIM implementation consultant
P5	Mechanical and Civil engineering	Implemented Catia (software) within the company, as well as BIM practices
P6	Information systems	3D modeling team manager, produces BIM guides for the teams
P7	Information systems	Engineer, 3D projects manager

Discussions are underway at OIQ to authorize digital mockups as official deliverables. The OIQ has started to work on this topic: the use of different document formats such as 3D PDF files or the native Catia format to sign documents are examples of the progress that has been made. According to the study participants, the doubts surrounding the use of BIM may limit the updating of such legislation: "we need new legislation surrounding BIM and contracts (. . .) but today the operationality of BIM is lacking: we still have doubts about formats and many other things" (P3).

Participants mentioned the suddenness of the need to sign-off on a digital mockup and how it adds to their responsibilities despite the uncertainties surrounding the use of the digital mockup: "overnight, engineers had a new tool, a new way of representing their designs that they had to sign-off on and be responsible for" (P7). They generally consider that the move to 3D (and especially the demand to sign the digital mock-up) affects responsibility issues: "the shift to 3D mode has influenced responsibility and responsibility issues" (P7), "the contractual agreement is a source of issues from the moment the model was signed. The commercial, legal or professional responsibility has been changed and not a little" (P3).

Finally, some engineers pointed to a possible solution to responsibility issues for BIM digital mockups: "The OIQ is looking into redefining the role of integrator-engineer, which existed at one time in certain industries. This role was abolished or not recognized by the OIQ because it was not mechanical, electrical or civil: it was integrator" (P2) and "the integrator-engineer would help the case for the signature and the legal responsibility" (P2).

Engineers have thus evoked their two main concerns: the uncertainties related to the reliability of BIM practices (due to their novelty), and the regulatory framework of BIM work.

Perception of Liability within the Firm

Perception of responsibility distribution between the firm and its engineers is not uniform within the company. Most interviewees highlighted the importance of an engineer's responsibility: "is it an individual who is held responsible or is it the company? Honestly, I know there is an engineer's responsibility, no one else" (P3); "it is the engineer who signs off, so he is the one responsible and not necessarily the company" (P7), "the engineer puts his seal on things, therefore he's the one who's held liable, not the organization" (P7). One interviewee evokes a transfer of responsibility from the engineer, agreed with the company: "the company made me a letter stating that they take responsibility for what I had done while I was here. With this letter, I was able to close my business insurance" (P6). A few interviewees also mentioned the company's responsibility: "we are responsible for the model, but there is a responsibility related to the work environment in which the digital mock-up was created. This is the company's responsibility" (P4); "we are responsible for the model, but there is also responsibility for the model's surroundings. The firm is in charge of its working environment" (P4); "if there is a problem, they will go after the engineer who is professionally responsible, and they will go after the company because they have the ability to pay" (P3).

The consequences of an error and responsibility distribution also vary depending on when an error is made: for a call for tenders it is a commercial risk but for a construction assignment it is a responsibility risk: "for the calls for tender, there is a commercial risk. Alternatively, when you do a construction mission, you are legally liable" (P3). If a problem occurs during the call for tender phase, "the blame will be on the person, but there will be no penalty. It's just going to cost the company a little more, and it's going to take longer" (P6).

The impact of the transition from 2D to 3D is also not perceived uniformly by the interviewees. Three points emerged during the discussion: the nature of the work done, responsibility, and work organization. Participants' opinions differed, particularly with regard to the impact of the 2D-3D transition on responsibility. Some found that the change was important in terms of responsibility: "the switch to 3D mode has influenced responsibility" (P7); "in a traditional 2D world, the 2D document signed by the engineer was done by a draftsman under his supervision, he was 100% responsible for the content of the drawing. Today, when we talk about a 3D model, it is a little difficult to delimit the area of responsibility of an engineer" (P2). On the contrary, other engineers mentioned unchanged roles and responsibility: "our roles remain the same, the job remains the same, but it is easier to see the interfaces" (P1), "I don't see any issue; the organization has not changed, if the organization has not changed, does it have an impact on the responsibility in relation to the model?" (P3). Most stakeholders explained that the roles and organization of work had not changed within the company.

The collaborative and multidisciplinary character of digital mock-ups seems to be a problem, but it is more a problem of attribution of information in the model than responsibility for the design process: "all these disciplines are interrelated and have their responsibility. But here we ask them to sign a model together and [so] the responsibility of one implies the responsibility of the other" (P6). For the participants, the scope of their professional responsibility seems to be relatively clear in relation to the design: "when you do an interdisciplinary design review, you can see very quickly who made a mistake" (P2).

Division of Work

Division of work with external firms is framed in an *instruction book*—a document describing the limits of roles and responsibilities—produced by the company: "We issue an instruction book in the 3D calls for bids (. . .) where we will specify the role of 3D in relation to our responsibility and the responsibility of the contractor's deliverable(s)" (P3). Some engineers also mention the need to share common objectives with these partners and to not "play one against each other".

Several internal engineers from different disciplines are involved in each project. The responsibility interfaces of these engineers are managed internally by a work breakdown structure (WBS), and each engineer is well aware of the extent of his professional responsibility: "it is clear where the roles and responsibilities end" (P4). However, several participants reported noting a difference in their reluctance in signing the digital mock-up depending on the discipline concerned.

The relationship between engineers and modelers (employees who make 3D digital mock-ups according to engineers' indications) seems to be critical in terms of responsibility in the context of the use of 3D digital models. Respondents indicated that specific skills are needed to navigate through the model and to verify it. However, "quite often, engineers do not even touch the model" (P6). They therefore rely on the modelers to evaluate the quality of the models: "we trust the modelers and they also have a fairly large responsibility in relation to that" (P5). But modelers are not liable; engineers are liable for the work that is done under their supervision. These elements may partly explain the engineers' reservations about 3D models: "even if they are used, there are still many engineers who do not completely trust the model" (P1). Some respondents even mention a lack of interest: "in the worst case, engineers just want to see the drawing (. . .) because that's what they'll sign" (P7). The level of trust between the engineer and the modeler also seems to be linked to the degree of comfort in signing a model: "if there is a great bond of trust with his modeler, the engineer will perhaps be more at ease in approving the model" (P1).

Perceived Characteristics of the Digital Mock-Up

During the interviews, the perception of digital mock-Up has been addressed. First of all, many engineers feel uncomfortable working with 3D models: "not everyone has the same comfort with the model, and there is a lot of individuality in this" (P7). Some participants added that "engineers who do the modeling themselves are rare" (P2); yet "you have to have an engineer who is able to go into the model, find the information he needs and then understand it to be able to validate" (P6). Some engineers also mention the discomfort of working with representation standards that are not yet generalized. We note, however, that none of the interviewees questioned the usefulness of working with a 3D model during the design phase.

The amount of information contained in a 3D model and the control of this information also impacts the comfort in working with digital mock-ups: "the model contains a lot of information, and engineers are not comfortable validating that all the information in the model is good" (P4). The lack of information control can also be linked to a technical problem according to the participants: "when you do a conversion or a printing, I have a risk of distortion" (P3).

Engineers mentioned the need to extract views from the model in order to manage the quantity and quality of information to validate: "the infinity of views that there are in the model, that's what creates discomfort" (P4). Creating views is also a way to limit the amount of information to be liable for. It is then either a matter of isolating information relating to a particular discipline: "we know how to isolate certain portions of the model and say who made it, and there the engineer is ready to sign" (P2). Or sometimes it is a matter of isolating information within the same discipline: "by having a document in which we have kept only what was visible, we reduce the amount of information that can be confusing or that could be contentious" (P7).

Working in 3D also forces one to deal with certain issues during the design process that were not necessarily addressed at an equivalent level of progress in the 2D process: "When we design an [asset], we make for example two sections on which we work in particular. But what is in-between these two sections? The technician represents something in 3D without it having been really defined [by the practitioner]" (P4).

Finally, engineers are concerned about the use that can be made of the 3D model: "they want to make sure that no one will be able to modify it once it has been sealed" (P3). But they see the use of a digital mock-up as an advantage in authenticating files: "with a digital mock-up it's easier to establish whether a document is an original or not" (P7).

Synthesis: Practitioners' Concerns and Uncertainties about Their Liability

During the interviews, several themes emerged related to liability of engineers in the context of work with a digital mock-up. These include:

- The regulatory framework: the possibility to consider a digital mock-up as an official deliverable, and the professional responsibility when a collaborative digital mock-up is used;
- Perception of responsibility within the firm: the sharing of responsibility between engineers from different disciplines within the firm, the consequences of an error in the model, and the sharing of responsibility between engineers (employees) and the organization;
- Division of work: the division of responsibilities with external firms, between different disciplines within the firm, and the working relationship between design engineers and modelers; and
- Perceived characteristics of the digital mock-up: the discomfort perceived by many engineers about working with information whose production and destination is not well controlled.

Through these different themes, the engineers indicated their discomfort in signing a digital mock-up by mentioning their concerns.

Discussion

Our study allowed us to identify practitioners' concerns about their liability with regards to BIM collaborative digital mock-ups in the case of civil engineering. This topic has barely been addressed in the literature, even though it is a significant issue for the liberal and regulated professions. The use of a collaborative digital mock-up for civil engineering projects appears to generate discomfort for practitioners because they identify this practice as a liability risk. We reviewed BIM legal problems and risks in the literature with the following question in mind: "why does the use of a digital mock-up in the context of a construction project seem to be a risky operation for practitioners and how can these risks be overcome?" in order to discuss our findings and shed light on the situation observed in the surveyed company.

Why are Practitioners Concerned about Their Liability and How Can These Concerns be Overcome?

Risk can be defined as "the effects of uncertainties on objectives" (ISO 2018). Implementing BIM practices modifies the roles of the actors in a collaborative work perspective. However, the legal framework, protocols, technologies, contractual measures and best practices in BIM projects are still at an early stage of development (Chong et al. 2017; Jo et al. 2018).

If we synthesize our results from a risk perspective, the interviews have brought to light two main uncertainties that can affect the acceptance of use of a digital mock-up in a liability-intensive context: (1) liability/benefits' allocation uncertainties, and (2) digital mock-up information reliability uncertainties (Fig. 2). These uncertainties are addressed in the scientific literature on the legal aspects of BIM adoption. We have categorized the reasons for these uncertainties into three main issues (Fig. 2): legal issues and inertia of the law, technical issues and organizational issues.

From this point in our work, we will distinguish between liability (which is more a matter of engaging one's civil, criminal, or professional liability) and responsibility (which is a matter of the tasks someone has been assigned). The two can be distinct; a modeler can be responsible for their model but the engineer can be held liable for tasks performed under his/her supervision (Fig. 2).

Uncertainties about Liability and Benefits Allocation

Uncertainties related to liability and benefits allocations are implicitly identified in the literature as arising from two main challenges. First, the use of a collaborative digital mock-up involves very new legal issues (Fig. 2, *Issues* column, block a). On the contrary, the evolution of law is always slow, which creates a gap between the implementation of practices and the development and maturity of the regulatory framework. The new legal issues associated with BIM development can be divided into two different uncertainties:

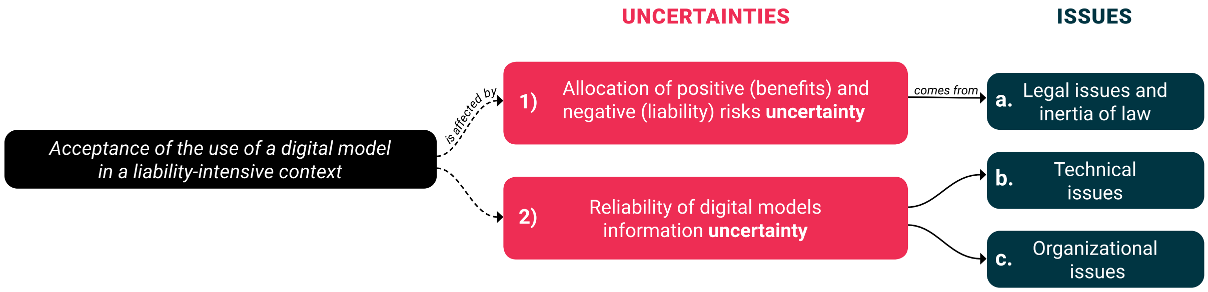

Fig. 2. Graphic synthesis of issues and uncertainties identified in the literature that can lead to difficulty in accepting the use of digital mock-ups in a liability-intensive context.

the allocation of negative risks (how liabilities are allocated when a problem occurs), and the allocation of positive risks (how benefits are allocated).

Negative risks can, for example, be liability claims for non-compliant design. Actual regulations do not distinguish between liability for the design and liability of the information in the deliverables. Practitioners are liable for all the elements presented in the engineering documents, but the integrated nature of BIM practices blurs the level of liability (Azhar 2011; Chao-Duivis 2011; Sebastian 2010) and displaces traditional areas of responsibility (Arensman and Ozbek 2012; Foster 2008; Sebastian 2010; Ussing et al. 2016). Should practitioners then be liable for the integrity of data in a collaborative mock-up that involves information and design parts that are not attributed to them? The recent literature on legal issues related to BIM implementation distinguishes between three types of liabilities and responsibilities assigned to different specialists or roles:

- liability for the design attributed to practitioners, i.e., control of the design quality, being liable for non-compliant design (Eadie et al. 2015; Fan et al. 2018);
- liability for the collaborative model integrity; this responsibility and liability is generally attributed to a BIM manager, i.e., control the entry of data, supervising the process of collating all the information that feeds into the integrated model, updating the information model and ensuring its accuracy, assuring that the model is reliable and being liable for inaccuracies (Azhar 2011; Eadie et al. 2015; Fan et al. 2018; Holzer 2007; Thompson and Miner 2006); and
- liability for the work environment, attributed to the security manager or the BIM manager, i.e., choosing and setting up a reliable and secured technological interface for the project participants (Thompson and Miner 2006).

When the various parties work closely in a collaborative environment, distinguishing design liabilities from information problems is not always easy (Arensman and Ozbek 2012). In our case study, the lack of distinction between liability for the model, liability for the design and liability for the work environment in both professional regulations and the company's policy seemed to be problematic. Engineers are implicitly and automatically liable for all of these because the company's internal policy is not clear about liability attribution. It would be a step forward to clarify this point. Clearer rules would reduce practitioners' concerns about their liability, but the regulatory level does not yet allow the separation of these different kinds of liability. In a more general way, collaborative work and the use of an integrated digital mock-up sets the construction legislation in a new light regarding the responsibility, liability and privileges of stakeholders in construction projects (Ussing et al. 2016). The existing laws are based on an individualistic perspective, whereas BIM is based on a collectivistic perspective (Chao-Duivis 2011; Ussing et al. 2016). In fact, there is a serious lack of legal framework addressing liability and benefits issues in BIM projects (Jo et al. 2018).

The distribution of benefits related to the implementation of BIM practices is not yet well-regulated either. This mainly concerns the ownership of the digital information and intellectual property (Arensman and Ozbek 2012; Eadie et al. 2015; Fan et al. 2018; Foster 2008; Hsu et al. 2015; Jo et al. 2018; Sebastian 2010; Ussing et al. 2016). Since BIM practices require more time for the inputting and reviewing of data, specific skills and costs (Azhar 2011), the distribution of the benefits of BIM can also concern the right to rely on the mock-up and remuneration for additional missions (Arensman and Ozbek 2012; Sebastian 2010). This problem did not come up in our case study. However, we noted a potential inconsistency: the company seems to have the intellectual property of designs and models, but legal risk may be attributed to practitioners. The sharing of benefits and risks is therefore unbalanced.

We have identified three proposals in the scientific literature that aim to overcome liability problems from a legal point of view. The first one is the application of economic loss doctrine which allows a reasonable liability allocation through parties (Chao-Duivis 2011; Fan et al. 2018). This refers to the promotion of relational contracting approaches to improve collaboration (Fan et al. 2018). Traditional contractual approaches carry several major problems (Matthews and Howell 2005) that can be surrounded with an integrated project delivery (IPD) approach (Fan et al. 2018). The IPD approach is characterized by a multiparty contractual agreement that typically allows risks and rewards to be shared among project stakeholders (El Asmar et al. 2013). However, in our case study, this proposal is not really possible because all the departments and practitioners work in the same firm. The second proposal is the use of covering contracts (Chong et al. 2017; Fan et al. 2018; Mahamadu et al. 2013; Sebastian 2010) that should specify responsibilities and roles within BIM teams to cover new roles like data management (coordinating, updating and maintaining models) (Fan et al. 2018), or BIM team responsibilities. Not explicitly affecting these new roles and the associated liabilities is tantamount to assigning them by default to the traditional actors. Many standard contractual structures have been proposed in various countries (Sebastian 2010); players can implement them if they are compatible with the regulations being applied. Again, in our case study, this proposal cannot be implemented because it is an intrafirm problem. Contracts may, however, be replaced by work procedures and processes. The third proposal aims to overcome liability problems from a legal viewpoint through the development of new kinds of professional insurance that can cover new roles and responsibilities (Chong et al. 2017; Fan et al. 2018). Liability exposures to design errors and non-compliant designs are already covered by professional insurance (Fan et al. 2018), but there is a knowledge gap in terms of what is insurable or not with regard to BIM (Eadie et al. 2015). These should also cover risks and responsibilities involved in BIM models, software, and hardware-like transition errors, loss of data. or data misuse (Chong et al. 2017; Fan et al. 2018). Some additional technical questions should also be addressed, such as the validity of electronic signature or the obligation to retain electronic information (Chao-Duivis 2011).

All of the previously presented proposals for overcoming liability problems are mainly issues on which companies have little direct impact and must be addressed at the macro level (updating legislation). However, at the meso (interorganizational project teams) and micro (internal to a company) levels, companies can clarify their policy about liability for the work environment and have a clear policy about roles and responsibilities (Thompson and Miner 2006). In our case study, the liability problem cannot be addressed exclusively by the firm; it must be addressed by an update of the regulatory framework.

Uncertainties about the Reliability of the Digital BIM Model

One of the implicit conditions for practitioners to be able to commit to their responsibility for a professional act is their ability to control the results. In BIM processes, this implies being able to trust the information found in the digital mock-up. However, BIM processes are still relatively new and the framework for producing, using, and maintaining information in BIM models is not yet fully stabilized. This creates uncertainty regarding BIM models' reliability (Fig. 2, *Uncertainties* column, block 2) and erodes stakeholders' trust in digital mock-ups (Eadie et al. 2015; Ussing et al. 2016). We identified and classified the possible causes and levers for action presented in the literature to overcome these uncertainties in two categories: technical and organizational issues (Fig. 2, *Issues* column, blocks b and c).

Technical issues can come from software and interoperability limitations, such as data loss due to a lack of standardization or incapacity of the software to identify incomplete data (Aljarman et al. 2020; Chong et al. 2017; Eadie et al. 2015; Hsu et al. 2015). These can also be related to security and privacy problems (Aljarman et al. 2020; Das et al. 2021; Mahamadu et al. 2013). Digital mock-up nonreliability is, however, not only due to technical problems: it can also come from organizational aspects. It is vital to be able to control the work processes in order to ensure the reliability and thus the dependability of BIM models. Responsibilities for information management in the model are still generally unclear within organizations (Chong et al. 2017; Eadie et al. 2015; Mahamadu et al. 2013; Sebastian 2010). Someone has to be responsible for data accuracy in order to have reliable digital mock-ups (Azhar 2011; Eadie et al. 2015; Holzer 2007; Thompson and Miner 2006), because BIM processes require more skills and time for inputting and reviewing BIM data (Azhar 2011). This issue must be considered by top-management and project managers when they implement BIM and attribute roles within organizations and project teams. Not adjusting work processes when using BIM tools and producing BIM deliverables generates a considerable amount of uncertainty, results in unreliable models and raises the risks linked to BIM use.

In our case study, practitioners have indicated their concerns about the reliability of the digital model and the control of its use. There are several avenues of work for this concern. The training of design staff on BIM tools and processes is one, as interviewees indicated that all practitioners do not use these tools the same way. Training would facilitate the verification of models by their practitioners, and decrease the likelihood of error. For example, actors who indicate that there are no 3D representation conventions as in 2D do not use the concepts that supersede such 2D conventions in 3D, such as LOI (level of information) and LOD (level of detail). This concept is key to being able to agree on the content of a digital mock-up used as a deliverable.

The engineers surprisingly indicated that they were very clear about where each practitioners' professional liability ended, but that it was unclear for them who is responsible for each element of the digital model. This might be addressed by designing specific BIM processes [responsibility matrix can be found in the professional literature based on implementing the ISO 19650 (UK BIM FRAMEWORK 2021)]. In the scientific literature, it is the delimitation of design responsibilities that seems to be more of an issue than the delimitation of information responsibilities. The clarity about practitioners' professional liability found in our case study was achieved thanks to the implementation of a work breakdown structure (WBS) in our partner company. This practice identified by our partner thus seems to be a good way to improve BIM work processes.

During the interviews, practitioners also talked about the difficulty of auditing a digital mock-up in order to verify information. This has also been identified in the literature as a challenge to making BIM models more reliable (Fan et al. 2018; Klusmann et al. 2020). Some software and application functionalities that allow addressing the problem of model incompletion are being developed and integrated to BIM modeling tools, model checkers, or common data environment (CDE) (Preidel et al. 2018). However, as there are no standards for data naming conventions and information requirements for BIM projects, actors usually must develop their own data checking processes and algorithms.

BIM implementation and especially 3D PDF documents as deliverables were recent in our partner company. A few interviewees told us that tools have been changed, some processes have been changed but the general way of working had not changed. Developing specific processes that integrate BIM issues is therefore an avenue of future work (to deal with model update issues, work environment issues, BIM objects' responsibility assignment, etc.). Indeed, the implementation phase is always difficult within companies because it increases the risk of errors and decreases productivity; for several months, the actors need time to appropriate the innovation and to master the new tools and work processes. They specifically need time to absorb the decrease in productivity due to the difficulty of implementation (Hochscheid and Halin 2019). We also note that a policy for managing the organizational risks of implementing BIM practices is not often addressed in the literature (instead, policies are generally more about project-related risks), despite the interest in this type of approach (Bonanomi et al. 2016; Hochscheid and Halin 2019). Clearly identifying the risks to BIM implementation within a firm (decreased productivity, increased risks of errors, difficulties related to change, liability issues) and addressing them will create a smoother BIM work environment. Among the literature on BIM implementation risk management, the specific treatment of liability issues in the regulated and liberal professions does not seem to be addressed. This is an interesting area of work highlighted by our case study.

The problem of model reliability and liability allocation is far from being an irrational fear of the actors; it is a reality. The refinement of technologies, the development of best practices, the training of actors and the reorganization of work processes to release the necessary resources (in time and skills) and the development of the legal framework are levers of action to make BIM practices and models more reliable and develop professional's trust toward BIM. Furthermore, there are three types of players involved in BIM practice development: policy players (who develop the regulatory

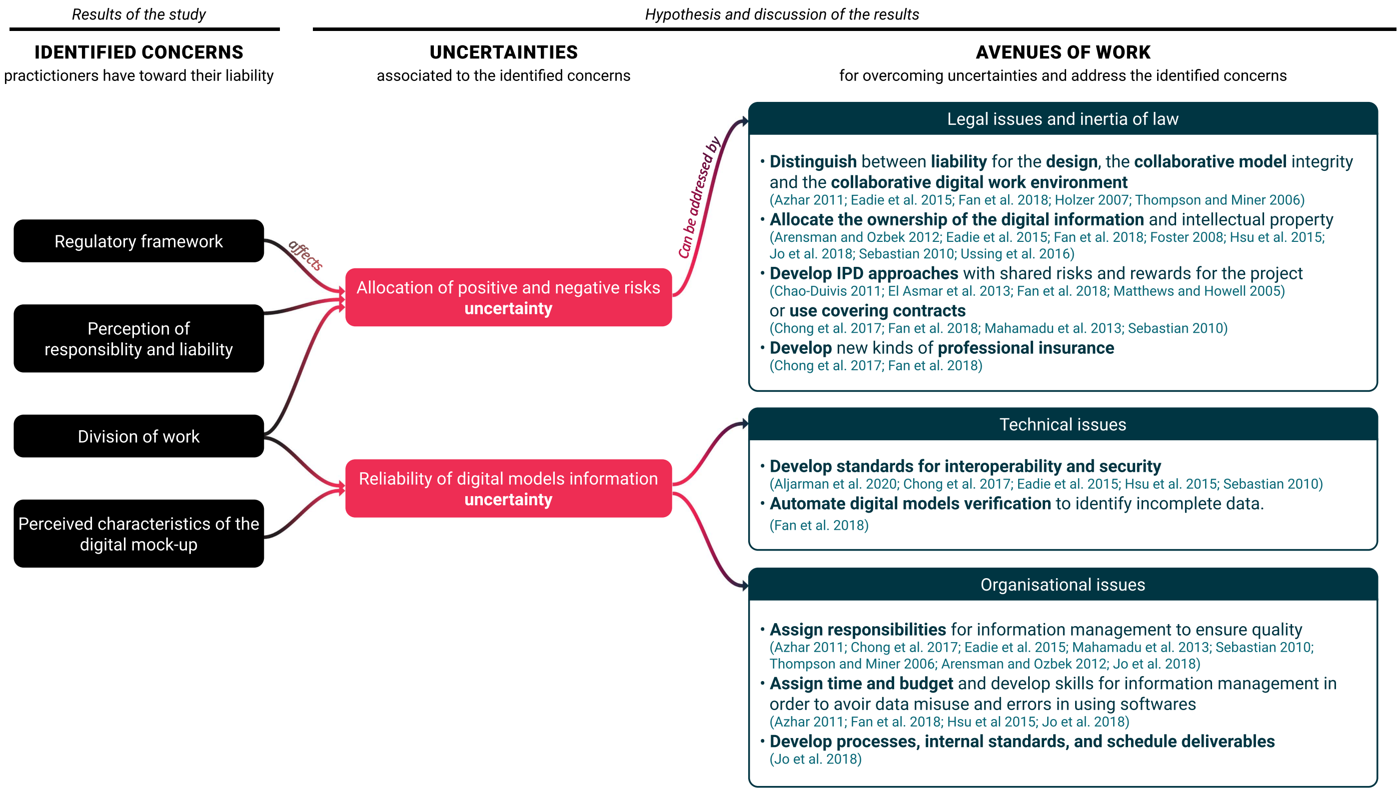

Fig. 3. Graphical synthesis of our results and discussion.

framework), technology players (who develop the tools) and professional players (who develop the best practices and work methods) (Succar and Kassem 2015). Only some of the proposals previously mentioned are within the reach of professional players: companies have today a limited margin of maneuver to implement BIM processes. They need a reliable legal and technical framework.

A Graphic Synthesis of Our Results and Discussion

The results of our study are synthesized as an organized list of concerns that practitioners have regarding their liability when using a collaborative digital mockup in the specific context of the partner company we worked with. Although the scientific literature does not address the question of practitioners' concerns, it does address issues that make BIM practices more reliable. Our results (the identified concerns) were therefore discussed with a view to identifying avenues of work present in the literature that could help address these concerns. The following Fig. 3 represents a graphical synthesis that links our results to the hypotheses and avenues of work identified in the literature.

Perspectives of Two Experts in Digital Mock-Up in Aeronautical PLM on Our Observations

We discussed the points raised in our interviews with two experts from the aeronautics sector with significant experience in using digital mock-ups in a PLM context. The objective of these discussions was to get a perspective on the use of digital mock-ups in design stages in another sector in order to identify other possible areas of work. Indeed, the aeronautics sector has been using digital mockups for longer than the construction sector. Furthermore, several studies investigate the potential mutual contribution between BIM and PLM, which offers a significant potential (Jupp and Singh 2016; Mangialardi et al. 2017; Pourzarei et al. 2020).

The two experts indicated that in aeronautics, the use of a digital mock-up for the operation phases was not much more advanced than in construction. The model seems to be used only for design and referencing. The validation of documents (which seems to be a problem in our interviews because of the complexity of the model) is instead done from pieces of models or 2D documents extracted from aeronautic models. Moreover, they identified the signature of 2D documents as more adapted to their needs than the signature of a 3D model. The current problems in aeronautics concerning the use of digital mock-ups are close to those in construction, even with a greater time lag on the use of digital mock-ups in aeronautics than in construction. In aeronautics, practices are not necessarily more advanced, contrary to what one might initially assume.

We also note that the development of a CDE in BIM practices is also moving more and more toward the connection of different documents via information containers rather than a centralized digital model (Bucher and Hall 2020; DIN 2019; Klusmann et al. 2020; Senthilvel et al. 2020).

The vision of a single digital mock-up containing all design information (and the elimination of 2D documents in favor of the 3D model) is common, as in our partner company. However, recent advances in CDEs that exploit a diversity of documents in the project, as well as feedback from PLM experts in the aeronautics sector, suggest that the elimination of 2D documents is not necessarily possible or desirable. While the use of a collaborative digital mockup is of interest, it is not clear that the substitution of 2D deliverables with 3D deliverables, and the practice of having practitioners signing a digital model and engage their liability on it rather than on 2D documents is desirable or possible.

Scope and Limitations of the Study

The objective of the study was to document the practitioners' concerns regarding their liability when using a digital mock-up. Therefore, an exploratory method was employed to be able to produce a rich description of the phenomenon studied by interviewing practitioners. It should be noted that the thematic analysis method used to analyze interview's verbatims may introduce some bias: we only present the results that we identified as the most relevant aspects—we may have missed some points that participants made due to our own bias. This bias is limited insofar as we have of having the coding of verbatims verified by a second researcher, but is not completely ruled out. The internal validity of the results was ensured by several precautions, in particular by checking the choice of participants and the results of the interviews with a resource person within the company. The results of this study therefore have a scope of validity that concerns our partner company, which has a hybrid BIM-PLM work context, in a regulatory and liability context for engineers that is very specific to Quebec.

External validity is "the extent to which the findings from a case study can be generalized to other situations that were not part of the original study" (Yin 2018). As underlined by Yin (2018), generalization is a common concern about case study research. There are two categories of generalizations from empirical studies (Yin 2018): (1) statistical generalization consists in making an inference about a population on the basis of empirical data collected from a sample from this population; and (2) analytical generalization consists in shedding empirical light on theoretical concepts. The topic addressed in this paper has not been documented in the scientific literature yet. No theoretical concept or model have been produced about our topic yet: analytical generalization is therefore difficult in this case. Populations groups studied in case studies are generally too few in number to serve as an adequately sized sample to represent any larger population. Also, it is not recommended to consider statistical generalization from one or a few case studies (Yin 2018). Given the unexplored nature of the topic studied and the methodology used (exploratory case study), the findings of this study are not generalizable, either in an analytical or in a statistical way. However, this study does bring out hypothesis about practitioners' concerns that should be looked at in the future and which could also appear in other organizations and situations.

Future Work

In this study, several themes related to engineer's concerns in the context of work with a digital mock-up were identified. Although the study focused only on engineers from certain disciplines and from a given company in Quebec, the authors assume that these concerns are likely to emerge in similar contexts. A similar context might be, for example, practitioners that work in high-liability contexts and involved in collaborative BIM design (as architects and other engineering disciplines). Future work should be conducted on this type of population in order to establish whether they are subject to the same type of concerns or not. Future work should include various research methods in order to increase validity.

Conclusion

The diffusion of BIM practices and their implementation among organizations is greatly disrupting to work practices. In the construction sector, practitioners (architects and engineers) work in high-liability contexts: they commit their liability based on documents that are increasingly impacted by BIM processes. How practitioners perceive these new practices and their impact on their liability has been very little studied and documented in the scientific literature.

We conducted an exploratory study in a large company in Quebec (Canada) that designs, builds, and manages facilities in order to identify and document practitioners' concerns about their liability. The result of the study is an organized list of concerns that has been discussed in order to identify avenues for possibly overcoming these issues.

We identified concerns for engineers in terms of liability from a 3D model like the alignment between their way of working and the OIQ rules, the clarity of the assignment of responsibilities, and the reliability of the digital model with the control of its use. Practitioners seem to be reluctant to use and engage their liability on digital mock-ups because it appears to be risky for them.

The discussion of these results, based on a literature review, suggests that this risk can be associated with two uncertainties: uncertainty about the distribution of liability risks and benefits (mainly due to a lack of a legal framework), and uncertainty about the reliability of the models (due to technical and organizational issues). All of these uncertainties partly stem from the fact that the regulatory, legal and organizational framework for BIM implementation is not yet fully developed and reliable.

Among the avenues of work identified to reduce the risk of liability for practitioners, some rely on policy players (such as professional insurance), others on technological players (such as the development of interoperability and the development of model checking applications) and some only rely on professional players (updating work processes, training or reassignment of work roles). However, there are a number of practices that companies cannot implement yet, because they would need to rely on the regulatory framework and the regulatory context in which they operate (such as the implementation of a new type of contract or the evolution of professional insurance to consider new kind of risks). Our case study underlines the very important impact of BIM implementation on high-liability professions (generally liberal professions), such as practitioners in the construction sector. The use of digital mock-ups in a context where BIM practices are still under development increases engineers' liability exposure, which likely has a determining impact on their willingness to sign digital mock-ups. However, and to conclude, in the field of aeronautics and associated PLM practices, the practice of signing digital models does not seem to be more developed than in the construction sector.

Data Availability Statement

Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions.

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