

Veronika BOLSHAKOVA, Annie GUERRIERO, Gilles HALIN

# Identifying stakeholders' roles and relevant project documents for 4D-based collaborative decision making

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**Abstract** To fully understand and effectively implement 4D building information modelling (BIM) models and methods, we need to develop a precise knowledge of which project digital documents should be used and how they influence the decision-making (DM) process. This article studies the convergence between uses of 4D BIM and digital project documents. We hypothesize that a clear visualization of the construction simulation through a 4D model is a useful source of information and a support for DM at collaborative meetings. Through this research, we continue to progress toward a new 4D-based collective decision device, so these elements will contribute to propose 4D BIM as DM support on architecture engineering construction (AEC) projects. Further, the present research will be complemented by results from questionnaires given at a later research stage. The article presents a brief review of BIM context to consider ways of fostering the implementation of all 4D BIM uses (not only visualization). It then introduces a proposition for 4D

BIM uses implementation by the project development phase. It concludes by summarizing stakeholders' roles and documents relevant to 4D BIM uses.

**Keywords** BIM, 4D BIM, 4D BIM use, AEC project management, collaboration, decision making

## 1 Introduction

This article offers an extended version of the “Identification of relevant project documents to 4D BIM uses for a synchronous collaborative decision support” paper (Bolshakova et al., 2018). First, to complete the previous work, it describes the design approach of a 4D-based collective decision device. Second, to set context, this paper provides additional details on current tendencies of the digital era for architecture engineering construction (AEC) and a place of 4D building information modelling (BIM) diffusion. Third, the article summarizes BIM project complexity to understand the current context and its limits. Fourth, we introduce a synchronous collaboration context. Finally, the article will review 4D BIM uses and their relevance to each phase of project development. In addition, we will close by considering project stakeholders' roles on 4D BIM uses.

## 2 Research toward a new 4D-based collective decision device

Being a part of the 4D Collab ANR/FNR research project, this article contributes to a team design of a new decision-making (DM) device configuration and collaboration scenarios with 4D. The main research subject is synchronous collaboration, and the objects are 4D BIM uses and natural user interfaces (NUIs). The methodology includes a user-centered approach (International Organization for Standardization, 2010) for the design development. Figure 1 illustrates the main methodology steps.

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Veronika BOLSHAKOVA (✉)

UMR n°3495 MAP-CRAI Mixed Research Unit Models and Simulations for Architecture and Heritage-Research Centre in Architecture and Engineering, Nancy 54000, France; CNRS—The National Centre for Scientific Research, Paris 75794, France  
E-mail: bolshakova@crai.archi.fr

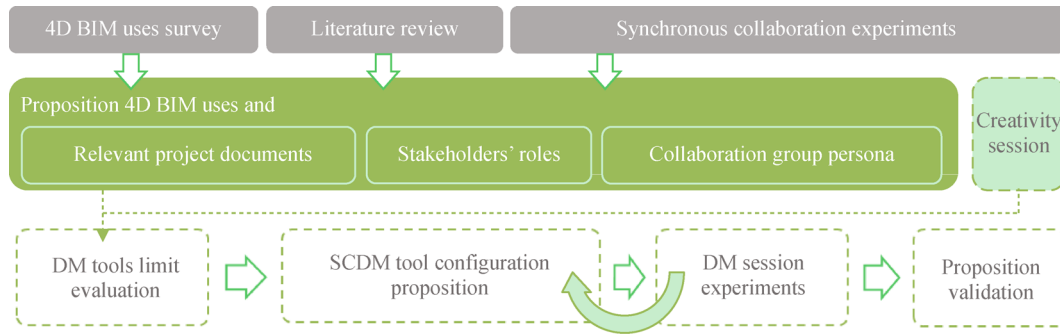
Annie GUERRIERO

LIST—Luxembourg Institute of Science and Technology, Esch-sur-Alzette L-4362, Luxembourg

Gilles HALIN

UMR n°3495 MAP-CRAI Mixed Research Unit Models and Simulations for Architecture and Heritage-Research Centre in Architecture and Engineering, Nancy 54000, France; University of Lorraine, Nancy 54000, France

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**Fig. 1** Summary of methodology steps for decision-making support proposition (v.2 extended).

## 2.1 Completed research steps

The research team has already conducted a few series of experiments with existing collaboration tools (multi-touch table and vertical screen and “Shariing” by Immersion) with groups of invited AEC professionals. During the sessions, participants worked together on a project task proposed by the research protocol with a 3D or 4D simulation as a main discussion support. With 4D, the task required a schedule improvement or a construction method improvement for a large public building on an early preconstruction phase. The 3D-based tasks required design review and decisions (Bolshakova et al., 2017). In addition, the research team conducted a 4D BIM uses survey.

In addition to a literature review, these research steps have resumed current limits of the proposed collaboration solution and revealed users need for more natural and industry adapted interactions during a collaboration session.

## 2.2 Further research steps

The next research step is a proposal of relations between project phase and 4D BIM use, between 4D BIM uses and project documents, and between project stakeholders' roles and influences on the uses. In addition, a study of a collaboration-group persona (Bolshakova et al., 2019) and creativity sessions complement the proposal. This step will provide the DM support design team with field information for the future AEC adapted interface, interactions, and collaboration session scenarios.

The following step will evaluate previously listed elements of the proposal with a series of thematic interviews among AEC professionals (Braun and Clarke, 2006), who provide us with real practices and experience vision. The results will be integrated into DM tools for evaluation and specification. These steps will complete a 4D-based synchronous collaborative decision-making device proposition. Finally, DM sessions with use of 4D

in a case study with a real construction project are used to evaluate the proposed decision device.

## 3 BIM context of the AEC industry

A BIM model becomes core of shared skills and is encompassed by stakeholders collaboration (National Institute of Building Sciences, 2015), which fosters further digitalization for design and construction. Building information modeling and management brings changes to many aspects of AEC project development to every construction market. This section provides an overview of global tendencies to assess the position of 4D BIM, as well as introduces contexts in France and Luxembourg.

### 3.1 Recent AEC market tendencies

The AEC industry is no longer so oriented to local conditions as before. Recently, many countries have focused on sophisticated technologies and materials for innovative and challenging designs. However, they frequently do not possess all the necessary skills or resources. Thus, the industry has focused on skill sharing and improvement apart from the tendency to become coherent with international standards and practices.

In terms of market view, AEC is dependent on a particular geographical location and related to its local demands. Every location exists in a context of diverse project demands (Hillebrandt, 2000; EU BIM Task Group, 2017). The indicated conditions directly influence the implementation of digital and BIM approaches. For some projects, the value and pertinence of BIM are more evident than others in terms of market context, demands, location, and project type.

The current tendency of the market is the increasing frequency of demands for additional services, design and construction phases, and services related to project maintenance or facility management phases, especially for newly built projects (Volk et al., 2014). The basic

service provisions for a project, which consists of design, construction, and management tasks, are frequently accompanied with services for the client, such as ownership and operation (Dodge Data & Analytics, 2017).

### 3.2 Dynamics of BIM implementation

Various surveys and barometers have been launched during the last two decades (Smart Building reports, Scandinavian market studies, Eurostat reports, Digital Transition Plan in the Building Industry (French original: Plan Transition Numérique dans le Bâtiment), and information technology (IT) barometer surveys). BIM research surveys and studies with industry professionals often show high interest in a strong collaboration, or they show a belief in quality improvements due to BIM. Notably, BIM is perceived in various ways by AEC industry professionals (Becerik-Gerber and Rice, 2010; Vass, 2017). A critical realist description of BIM experiences provides improved standing points (Fox, 2014). Project stakeholders vision frequently depends on how well they are informed on the subject and on their experience. However, majority of accurate data comes from feedback on projects from firms with a high-level BIM implementation. The feedback on the subject from a firm that has not conducted a BIM project is slightly different from a firm that has already accomplished a pilot BIM project or developed a number of projects.

According to AEC market reports, the percentage of contractors with high BIM implementation levels intensively grows and varies from 40% to 80% for the major markets (Japan, New Zealand, South Korea, Canada, the UK, France, Australia, Germany, Brazil, and the USA) (McGraw Hill Construction, 2014). The leaders in BIM implementation and practices are the USA and Scandinavian countries (Smith, 2014). Building and facility construction and transportation infrastructure projects have been progressing using BIM, with approximate use in half of projects (the USA, the UK, France, and Germany) (Dodge Data & Analytics, 2017). BIM studies show the highest ease of integration in Singapore and Norway due to the governance policy and economic influence factors (Smith, 2014).

For the types of construction stakeholders and their benefits from BIM, contractors generally reach a positive return on investment more quickly than design professionals (McGraw Hill Construction, 2014). Thus, contractors may become the leaders in implementation and play a major role in fostering the competence development of other stakeholders. Moreover, BIM expertise slowly becomes an important requirement for project team composition, with a percentage from 20% to almost 40% in the leading markets.

In addition to market reports, scientific research on BIM adoption and measurement of BIM maturity has covered 21 countries and analyzed the current situation with a

maturity matrix, which shows that none of the countries has achieved a high level, and the current leader is the UK (Succar, 2010; Kassem and Succar, 2017). Various levels of granularity may be applied for analysis; however, objectives, benchmarks, skills, and technology infrastructure (software, hardware, and networks) are important components of the system.

In the spectrum of these global situations, our main interest and study fields are France and Luxembourg (because the research project 4D Collab remains attached to the professional context). Luxembourg has developed a national BIM strategy and BIM execution plan (Eurostat, 2018) and a strong initiative and support at the governmental level. On the basis of an IT barometer survey, firms were not familiar with BIM (in 2014), with the highest awareness among architects (about 40%) (Kubicki and Boton, 2014). Thus, architecture professionals may eventually adopt the role of innovators for industry changes.

According to the European Commission report on the French AEC industry, even if the efforts on BIM implementation are particularly relevant, only a little more than 10% of firms have declared using BIM regularly (Eurostat, 2017). It stays relatively new to the implementation concept and awaits further development of national policies (Hochscheid and Halin, 2018). For about a half of firms, the main concerns of future implementation are the cost and complexity of BIM.

French digital initiative has conducted a survey that identifies three main advantages of BIM perceived by professionals. The first advantage is stakeholders' encouragement for strong exchanges on a project; the second one is a reduction of design errors; and the last is the project quality improvement (PTNB, 2017).

However, within the above advantages, three main perceived disadvantages of BIM were identified as the lack of internal skills (suggested by more than 45% of participants), software costs (suggested by more than 40% of respondents), and lack of standardization (suggested by more than 35% of respondents) (PTNB, 2017). These concerns are mostly related to the technological core and professional practices.

The aforementioned demands foster an enlarged vision of project work in relation to design and execution. They also make the project more attractive as an investment opportunity. Finally, they suggest the need for strong communication on the project and bring new roles and relationships to the project (Singh et al., 2011), as well as novel opportunities for AEC professionals (for example, with integrated project delivery and lean management).

### 3.3 4D BIM on a global scale

Currently, 4D BIM is mainly used to visualize the planned construction process. However, other uses of BIM have not been fully integrated into construction practices (Guerrero

et al., 2017). In addition, the benefits and limitations of 4D BIM must be considered because it is inevitably joined to construction time management (Mahalingam et al., 2010). As a part of time management, 4D BIM can become a valuable source of information for DM. However, visualized project information and BIM model development level correspond to the objectives of collective DM session (Boton et al., 2015).

In the last two decades, various studies have been conducted, and 4D BIM adoption rate has been frequently concluded to stay relatively low (Mahalingam et al., 2010; Boton, 2013; Kubicki and Boton, 2014; McGraw Hill Construction, 2014). The adoption and implementation of BIM and *n*D BIM are a dynamic, continuous process, which are highly dependent on local market conditions. The percentage rates of diffusion indicate the market advancement and potential for studies. However, the rates progressively change annually.

For example, the experience of some pilot projects have already indicated a successful application of 4D simulation for communication on construction sequencing for a number of projects in the USA, Finland, and China (Hartmann et al., 2008). We continue to hear from companies who implement 4D BIM in their work. On the basis of the international smart market report, many contractors have committed to the integration of models with schedule on design and pre-construction phases as their top three organization leverages on BIM, with an average percentage of 29% for all regions (9 largest construction markets), with 39% in France (McGraw Hill Construction, 2014). An IT barometer survey in Luxembourg in 2014 showed that one-fifth of respondents is familiar with 4D (Kubicki and Boton, 2014).

4D BIM diffusion dynamics in the UK have been investigated in detail in the last two years, in which a survey indicated that more than half of survey participants currently use 4D BIM in their practices, with a high level of personal 4D BIM use in organizations and high level of BIM maturity. In addition, the adoption was either an authority decision or a collective consortium decision (Gledson, 2015; Gledson and Greenwood, 2017). In Australia, the adoption of 4D stays at the basic level, and

companies tend to delegate their 4D- and 5D-related tasks to specialist external firms (Pyung et al., 2016).

Every context has its own dynamics and specifics, but the global interest and shared problems are similar for all the markets. Global tendencies frequently reflect a local market. With new benefits and opportunities, AEC professionals face new challenges, such as the complexity of project data and work process organization with project growth. Therefore, the industry requires efficient management methods to increase efficiency in terms of construction and project quality.

## 4 Complexity of a construction project and 4D uses

This section overviews project complexity to better understand the project in details. A 4D relation concept is defined to distinguish the information types presented in 4D. Next, this section investigates time management methods and the relation of 4D BIM uses to a project phase.

### 4.1 Understanding project complexity and “4D relation” concept

The previously mentioned complexity of BIM encompasses project complexity (building function and structure, construction method, urgency of the project schedule, project size/scale, geological condition, and neighborhood environment) and organizational complexity (agent interactions, design aspects, engineering, and management) (Wood et al., 2014). In addition, the multiplicity and ambiguity can be acknowledged as a part of the information processing approach to task complexity (Campbell, 1988). Figure 2 summarizes these influences.

On the basis of UK standards and classification of BIM maturity levels, such sophisticated models and collaborative BIM appear as Level 2 and assure the full transition to iBIM (Level 3) (The British Standards Institution, 2014). In addition, the development level, which grows through the project development phases, provides the progressive

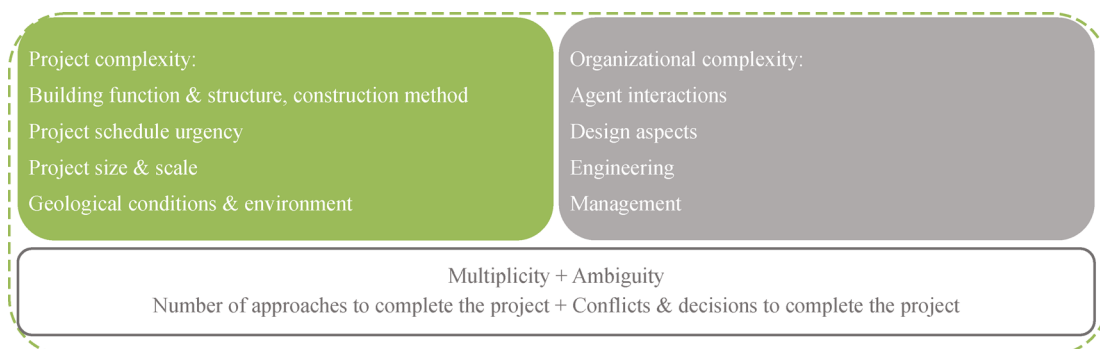


Fig. 2 Project complexity influences schema.

complexity increase to the system. Project document set depends on a type of project, its development phase, and phase corresponding level of detail. BIM standards and guides provide professionals with methods and examples (Sacks et al., 2016).

The complexity of data organization is created by a number of project documents. A 3D BIM model is frequently the core of a project, and it is linked to all other data on the project. This data integration builds a number of dimensions into a holistic model, which covers the entire lifecycle of the project (Lee et al., 2005; Hartmann et al., 2008). Thus, 3D ( $x, y, z$ ) + time management models are 4D, and models with additional information on costs are denoted as 5D, 6D, and 7D for other resources.

BIM associates the virtual 3D model of a construction project with a construction schedule, which mostly occurs at the pre-construction phase of project development (Hu and Zhang, 2011). Construction projects with 4D implementation are a common means of proceeding for large construction projects rather than pilot projects, because 4D BIM improves cost control, eliminates errors, and makes scheduling and coordination efficient.

The BIM model evolves with the evolution of the project by gaining new data, new connections, and new actors. Considering that “conceptually 4D CAD represents a type of graphic simulation of a process” (McKinney et al., 1996), what is actually represented in 4D should be determined.

The dimensions are “time” and “3D,” and we still see “3D” and “time” in visualizing 4D, which are represented through the animation and/or a time diagram, progress line, and task list. An added value is a “new component” created by a relation established between the elements of 3D model and tasks, which share and combine assigned data and technically create their own new concept of a “4D relationship,” as shown in Fig. 3.

#### 4.2 Time management and project development relation

The precise titles and types of AEC project phases depend on the context of the project. Various stages of advancement hold different names and have assignments based on the country, region, project type, and contract type. At a large scale, the project starts with the planning, passes through design and construction, and has only maintenance interventions after delivery (except facility management as a part of project contract and proposed services by contractors).

Most of the project-related risks should be designed during the planning and design stages and managed during the construction (Zou et al., 2017). In addition, time management is introduced in advance to the project to provide proper resources and cost and liability management. An early-stage project has an established program, with estimated time and cost. Meanwhile, the project advances the planning, which is created by a group of professionals based on their experience (The Chartered Institute of Building, 2018). Thus, during this collective DM activity, all the parties must have easy access to the BIM data on the project. The activity must be held with customized supports, such as project documents and DM assistance tools. The planning output provides documented decisions on work organization. They are used as a basis for detailed scheduling with calculations, plans, resources, and risks attached (The Chartered Institute of Building, 2018). A dynamic schedule is used during the pre-construction and construction stages (Fig. 4).

Time management can be approached with different methods (Boton, 2013), such as the classic critical pass method (CPM), and program evaluation and review technique (PERT), which have been used for numerous decades but do not show the highest efficiency due to the lack of resources or prediction inaccuracies; linear projects (linear scheduling method (LSM), and line of balance

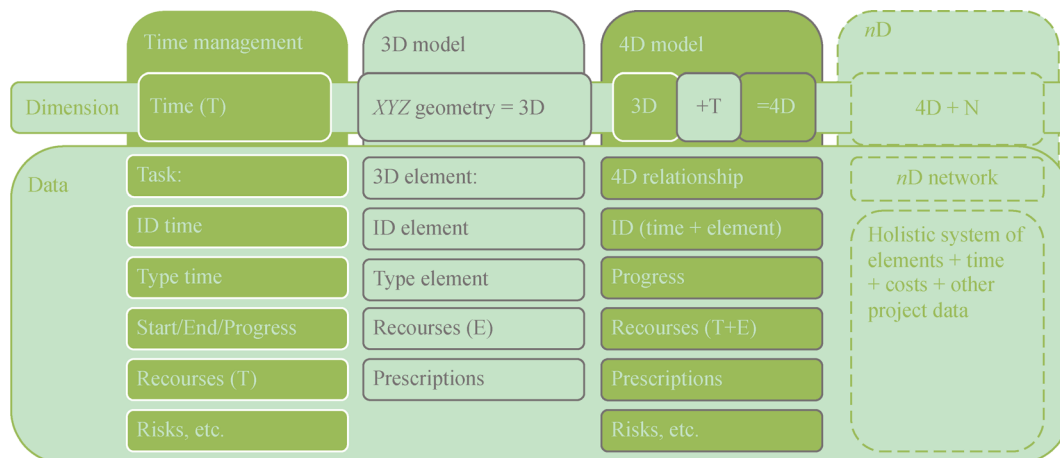
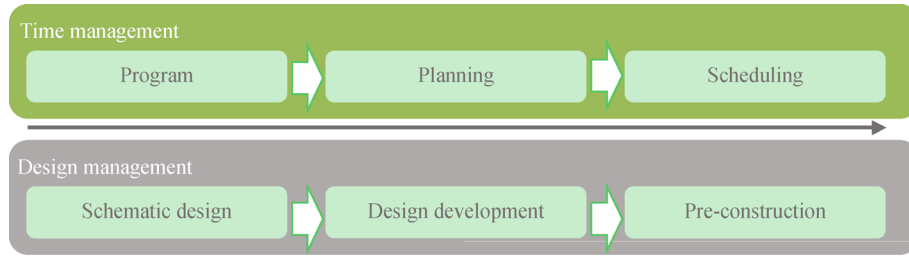


Fig. 3 Dimensions and data concepts as parts of 4D model.



**Fig. 4** Time and design management elements sequence for project development.

(LOB)); and existing approaches (Last Planner System (LPS), critical chain method (CCM), virtual construction (VC)).

Adaptive dynamic time management may combine these approaches to determine the best fit for each section of the project (The Chartered Institute of Building, 2018). The program and early planning start at the same time with the concepts and design, the time aspect is introduced and developed when the project shape is defined, and resources follow. An efficient dynamic schedule assures review, revision, monitoring, updates, and impacts. For a complex BIM project, a single approach is inefficient. Thus, early anticipation and a holistic systematic approach should be implemented.

4.3 4D BIM uses and project development

Study of 4D BIM uses follows a general study of BIM uses, where “BIM use: a method or strategy of applying BIM during a facility’s lifecycle to achieve one or more specific objectives.” (Kreider and Messner, 2013).

Guerriero et al. (2017) proposed the following 4D BIM uses: 4D scheduling, 4D clash detection, 4D safety management, 4D site lay-out and environment management, 4D constructability management, 4D monitoring, and 4D visual communication as a core use.

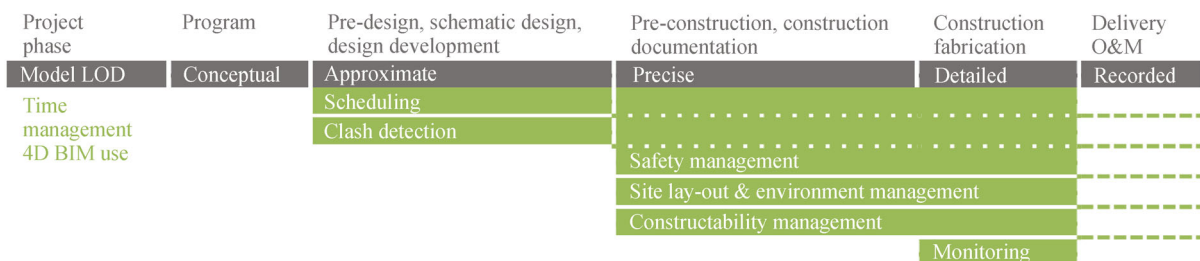
4D BIM can be integrated on any project development phase. The availability of 3D and time dimensions and accompanying data are occasionally valuable on the negotiation stage. In practice, for some complex projects, 4D models are also useful in a dialogue with authorities (Fischer and Kunz, 2004). Interestingly, survey respondents with few BIM experience tend to identify visualiza-

tion as a major benefit from BIM, and more experienced respondents find the value of work process organization. In the same way, 4D BIM value is perceived as a visualization. However, other potential uses have not been widely applied in practice. 4D BIM is frequently recognized as a complementary scheduling instrument (Rolfsen and Merschbrock, 2016), and it is used to review the work sequence and improve constructability (Fischer and Kunz, 2004).

Information accessibility and clear visualization are the major benefits of 4D BIM, where all actors have access to a 3D model, attached schedule, simulations, and analysis. All the uses involve stakeholders’ expertise and collaboration. 4D BIM uses potential introduction and implementation by project phases and with a corresponding level of development (LOD), as summarized in Fig. 5. The operation and maintenance phase are not in the scope of this research due to the phase specifics and main relevance in a domain of facility management.

**5 Synchronous collaboration and software solutions**

BIM is the current philosophy of digital project development tools and methods, where the project data are mostly digital. Project stakeholders collaborate on a shared virtual 3D model of the project that is enriched by virtual simulations and estimations. First, this part describes a BIM socio-technical system to understand the position of collaboration and synchronization in BIM work context. Second, we overview software types and DM session interactions.



**Fig. 5** Project phases and model LOD, 4D BIM use potential introduction.

### 5.1 Describing socio-technical system of BIM

In particular, with BIM, project stakeholders use a single virtual model as a source of information and design and modeling support. In BIM workflow, the project development relies on a sociotechnical system (Sackey, 2014). The intelligent models and information management represent the technical core of the system. These elements are created and operated with specific software tools.

According to Kennerly (2013), the core is enclosed by social elements, such as synchronous collaboration, coordinated work practices, and institutional and cultural frameworks. The institution has its own intersocial order, which is created by the interactions and influences among the institutional professionals (Jacobsson et al., 2017). These elements are framed by design and management methods, which highly rely on the technical core. BIM makes transformational effects on work processes when it enables an integrated collaboration among actors (Jacobsson et al., 2017).

The actors are frequently focused on project quality as the central priority. A BIM project itself, as a system, is non-linear and adaptive, and it is interdependent with a considerable number of Influences involved. Thus, it must be approached with an adaptive management.

### 5.2 Synchronization point and collaboration

A collaboration improvement is the second most cited BIM benefit after the reduced errors and omissions (McGraw Hill Construction, 2014), where more than 80% of respondents expect an increase in collaboration of an owner and a contractor (KPMG, 2015). These aspects indicate the value of intense collaboration and professionals' attention to workflow organization.

Digital workflow is frequently interfered after preparation to stakeholders' meetings. At this moment, synchronization occurs, which indicates that meeting objective(s) are set, and relevant project stakeholders are invited to meet. They prepare an up-to-date project information and extract documents that appear to be the most relevant to meeting objectives.

The meeting is called a DM session. Our study focuses on DM session for design development or value engineering within synchronous co-located (same place, same time) collaboration. According to Himmelman (2004): "Collaborating—exchanging information, altering activities, sharing resources, and enhancing the capacity of others for mutual benefit to achieve a common purpose."

During a collaboration, all users share the same environment to achieve a shared vocabulary to a work process and project information (Achten, 2002; Wilkinson, 2005). Collaboration technology, apart from real-time exchange of opinions, requires information on work awareness and teamwork progress (Wilkinson, 2005). Collaboration efficiency is reduced when project stake-

holders do not share the same organization, do not have equal access to information, and DM weight is not mutual (Dossick and Neff, 2010). A study of Lee and Jeong (2012) suggested the implementation of domain-specific, intelligent filters to facilitate users' interactions on the selection and interpretation of task relevant information during the work with BIM model viewers and shared filters to improve the understanding between disciplines.

A collective decision device (hardware and software) should be integrated into DM sessions to sustain the connection to digital documents and document management systems. Moreover, with a digital technology integration, a project maintains design integrity, and project team members benefit from a distributed access to project documents (Fischer and Kunz, 2004).

### 5.3 Document management systems

Complexity increases through a project lifecycle and places 3D into a center of collaboration and exchanges. Thus, it gathers and connects numerous types of documents, where some of them are originally digital and some are digitized to be integrated into document management systems.

Currently, distant collaboration solutions, such as document management systems (clouds or intranets), allow AEC project team to automate uploads, validation, approvals, and distribution of project documents (Singh et al., 2011). Many cloud-related solutions have proposed various collaborative modeling features (Boton, 2018). Real project case studies have proven that cloud-based synchronization and project design information exchanges are possible, and yet they lack improved AEC and BIM adopt better tools (Munkley et al., 2014). Moreover, BIM users face intra-organizational challenges, mostly in piloting documents for internal work practices and in following managers' requirements (Vass and Gustavsson, 2017). Thus, cloud-based solutions are part of a usual practice. However, they must integrate customized task management apart from document management.

According to Munkley et al. (2014), cloud computing platforms and services still lack wide range of functionalities specifically to BIM project development. In addition, such solutions are not specifically targeted to synchronous collaboration for DM sessions although they possess democratic interactions and discipline filters. Future document management systems must maintain the connection to DM session tools for a digital continuum.

### 5.4 4D collaboration solutions

BIM software purposes classify the tools into services, catalogues, servers, viewers, modelers, mobile, checkers, management, simulation, communication, publishing, query, and utilities (Wallner and von Both, 2017). For 4D software, "4D CAD" and "integrative application"

types (Porkka and Kähkönen, 2007) are the most relevant to viewer-modeler-checker classes and allow BIM-based collaboration situations.

Various types of examples are obtained from the software development industry and from the research of 4D modeling and simulation tools (Navisworks, Synchro Pro, Navigator, iTwo, Vico Control, Asta PowerProject, Fuzor, BIMXtra, etc.). They provide various instruments, such as animations and simulations, planning and scheduling, scenario comparison, 4D clash detection, reports, tracking, export and import options, and a distant collaboration for some cases. Apart from these tools, various 4D tracking automation approaches (Park et al., 2018; Kropp et al., 2018) and new planning systems are available (Ivson et al., 2018).

Malsane and Sheth (2015) summarized that 4D must be created and modified in alliance with project planning activities. Thus, a collaborative DM is a means to benefit from the potential of 4D BIM uses. The tools mainly focus on 4D simulations, quantities, and cost management rather than on co-located synchronous collaboration. In addition, the interface support is designed for single-user interactions with 4D model information and some touch gestures.

Virtual reality (VR)-based collaborative propositions, such as collaborative 4D simulation environment (Boton, 2018), iRoom (Fischer et al., 2002), and VCE (Waly and Thabet, 2003), provide interactive and collaborative solutions. However, they are limited to VR technology. As an alternative, we present a real physical environment with a touch table to maintain collaboration close to the classic “around the table” discussion type of meeting. Synchronous collaboration environments for BIM must provide its own view of the project model for each discipline, assure all the updates, and show them to all users in real time (Isikdag and Underwood, 2010).

## 6 Identifying elements for 4D collaboration

### 6.1 Parameters for a new collaboration device and user interactions

On the basis of case studies (Haymaker and Fischer, 2001), after sessions with 4D, different members of the project team increase and are committed into collaboration and resolution of project problems. 4D may provide a benefit because it outlines settled parts of a project within the points to develop or rethink (Haymaker and Fischer, 2001). Experiments with portable distant collaboration devices on site show positive feedback from construction professionals (Svalestuen et al., 2017). Furthermore, a 4D construction simulation improves project understanding and workflow for a construction team.

A number of features must be considered with the future 4D-based collaboration device proposition. For example,

4D visualization as DM support requires the development of new appropriate means for reporting (Porkka and Kähkönen, 2007). Adjustable level-of-detail relevant to different disciplines must be integrated into future 4D simulation solutions, with many user-oriented transformational functionalities (Porkka and Kähkönen, 2007). However, interoperable data formats have not integrated the time dimension into a single model with 3D (Kassem et al., 2014). The tools are currently limited to a single window without customization to user profiles (Singh et al., 2011).

First, for the device, a DM is part of a connected project development, which maintains project information in a single document management system and representation interface (Kvan, 1999) and alleviates the abovementioned interference. As an outline, such collaborative and interoperability tools must help avoid information losses, optimize work, avoid redundancy of tasks, and maintain the link to BIM data storage.

Second, the device may provide DM session participants with multi-user collaborative interactions with project documents. Three mechanisms, namely, mutual awareness of other users’ actions, degree of user control over the actions within the system, and availability of background information, complete these successful interactions (Yuill and Rogers, 2012).

This process indicates shared views and shared access to any document interactions. We propose the following interaction families, such as visualization (the model is only reviewed but with additional information level), annotation (the model is not modified but has an additional level of information with annotations), and modification (direct interaction with data and direct modifications). For example, an interaction may annotate a 3D model, which can be performed by more than one user at the same time.

Different discipline users have different usage patterns and may require varying interfaces (Singh et al., 2011). Thus, an interface must provide equal usability to all DM session participants, regardless of their level of understanding of the project. Such ease of access and low training time are accessible with collaborative NUI (Whitney, 2013).

In addition, the device should include different types of touch displays rather than limit one type of equipment. Mahyar et al.’s (2010) case study showed that interactive devices support formal and informal collaborative activities, with a vertical display type for presentation-related activities and tabletop display for many collaborative situations (Mahyar et al., 2010).

For a future 4D-based collaboration device, we implement a multi-touch collaborative table and wall within a NUI as a DM session device. The integration of a device with NUI fosters the convergence of 4D uses with project documents and allows the ease of interactions at DM sessions.

## 6.2 4D BIM uses and project stakeholders' roles

A project does not progress without people. Every role and responsibility have a place and influence on the final result. Davies stated that a clear definition of project roles in global guides and protocols is required to make BIM practice efficient and ambiguous (Davies et al., 2017). The role and involvement of stakeholders are inevitably dependent on a project and contract types on workflow organization.

Project design development, design management, and project management in a BIM project are closely related and guided with BIM management. On the basis of the managing design process roadmap (Gu and London, 2010), various steps are related to the BIM process setup (identification of roles, phases, activities, dependences, tools, etc.) preceding a design stage.

Various disciplines have their roles in project development (architecture, civil engineering, cost management, commissioning engineering, drainage engineering, electrical engineering, mechanical engineering, structural engineering, quality control, project management, time management, design coordination, document management, data security, etc.) (The Chartered Institute of Building, 2018), and a challenge of BIM is the requirement to connect people to project information (Kensek, 2014).

A project is frequently developed by specialists who have not worked together previously. Considering that human resources depend on a project site, every firm develops their part on a common project but does not integrate into a collaborative framework because they are a separate unit (Dodge Data & Analytics, 2017). A project team requires appropriate training and information to be efficient in the work environment (Singh et al., 2011). Thus, the prepared and project customized organization of BIM with a well-adapted framework are essential for efficient design, time, cost, and construction management. At present, for client BIM roles, BIM guides define project team roles well but ignore BIM management from client-side definitions (Davies et al., 2017).

However, a global pattern is predictable to scheme the main workflow components and stakeholder involvement (Kassem et al., 2014). Table 1 presents the proposition of involvement and influences of stakeholders' vis-a-vis 4D BIM uses synthesis.

Stakeholders use 4D BIM and interact with it in various means, which depend on a contract and a project phase. 4D visualization use has a transversal place in project lifecycle, which supports other uses and all stakeholders benefit from it. The table presents the responsibility or participant stakeholders roles, with nuances (responsible validator RV or coordinator RC; participant producer PP, expert PE or reader PR (Halin et al., 2002)).

For example, 4D scheduling is relevant on design and pre-construction phases (followed by 4D monitoring during the construction) and involves project management

and client meeting 3D model creations. A client has RV and PR responsibilities, in which the process is led by experienced architects and engineers, and a BIM manager assists in placing the methodology and collaboration. A contractor has a secondary role on a design phase 4D scheduling and assumes the responsibility of coordination on a pre-construction phase.

Multiple competence involvement into DM on a 4D BIM use must be beneficial in terms of error detection and communication to increase construction efficiency. An important team role is held by a construction manager and contractor, who assemble many responsibilities on pre-construction and construction phases. 3D model creators have many responsibilities and influences; they have many responsibilities in the beginning of the project and have to update their models through all the phases (RV and PP roles). The client has more influence on input data (time- and cost-related) rather than on the construction processes.

## 6.3 4D BIM uses and relevant project documents

When the responsibilities and involvement links are summarized, we may search for project data that are relevant to the DM session and offer actors with sufficient and complete information on a project. Inevitably, documents still depend on project and contract types, but a global pattern is predictable.

The core of session support documents is a 4D relationship of 3D model and time management data. For example, with an approximate LOD at a design phase, the 3D models (architecture, structural, MEP, and civil) from early design to design development are associated with the time management data about the program or the main planning with an estimation of time and required construction resources (general stages). Further, at the pre-construction phase with a precise LOD, the 3D models (architecture, structural, MEP, and civil) are well established and detailed, and they are bonded to the time management data in terms of planning with estimation of time and required construction resources, which are transformed into a precise construction schedule (tasks, elements, dates; construction firm, equipment, and material requirements). Finally, at the construction phase, detailed initial and ongoing 3D models are correlated with a precise dynamic construction schedule (on-going tracking, risks, milestones, and logs).

At a DM session, project stakeholders must have access to other project documents apart from the 4D model and simulations. For example, DM session participants with 4D as a support for scheduling during the design phase may require information and documents, such as a state of terrain (plans, permits, environment, and soils study), a program and budget from the client, project volume, specifications (generic numbers, and plans), project principal stakeholders (generic list), a construction methodology option, general requirements on project

**Table 1** 4D BIM uses and stakeholders operating roles and influences

4D BIM use	Stakeholders													
	Client	Construction manager	BIM manager	Architect	Civil structural engineer	MEP engineer	Contractor	Safety manager	Workers	Manufacture supplies	Building surveyor	Quantity surveyor	Facility manager	
Design phase—approximate LOD														
Scheduling														
Forecast construction phases & sequencing	RV	-	RC	-	RV	-	RV	-	RV	-	RV	-	-	-
Optimize the construction schedule	-	-	PE	-	PP	-	PP	-	PE	-	PE	-	PE	-
Clash detection														
Detect spatio-temporal conflicts	-	-	RC	-	RV	-	RV	-	RV	-	RV	-	-	-
Detect static and dynamic conflicts	-	-	PE	-	PP	-	PP	-	PE	-	PE	-	-	-
	-	-	RC	-	RV	-	RV	-	RV	-	RV	-	-	-
	-	-	PE	-	PP	-	PP	-	PE	-	PE	-	-	-
Pre-construction phase—precise LOD														
Scheduling														
Forecast construction phases & sequencing	RV	RC	-	RC	-	RV	-	RV	RC	-	-	-	-	-
Optimize the construction schedule	-	PP	-	PP	-	PP	-	PP	RC	-	PR	-	PE	-
Clash detection														
Detect spatio-temporal conflicts	-	PP	-	PP	-	PP	-	PP	RC	-	PR	-	PE	-
Detect static and dynamic conflicts	-	PP	-	PP	-	PP	-	PP	RC	-	PR	-	PE	-

(Continued)

4D BIM use	Stakeholders												
	Client	Construction manager	BIM manager	Architect	Civil structural engineer	MEP engineer	Contractor	Safety manager	Workers	Manufacture supplies	Building surveyor	Quantity surveyor	Facility manager
Safety management													
Analyze structural safety issues	-	RV	-	RC	-	-	-	RV	RC	-	-	-	-
Identify safety issues	-	PP	PE	PP	PE	PP	PP	PE	PP	PR	RV	RC	-
Constructability management													
Design temporary works	-	RC	-	RC	-	-	-	RV	RC	-	-	-	-
Test different construction alternatives	-	RC	-	RC	-	RV	RV	RV	RV	PE	PE	PE	-
Optimize interfaces management	-	RC	-	RC	-	RV	RV	RV	RV	PE	PE	PE	-
Site lay-out & environment management													
Anticipate environment conflicts	-	RC	-	RC	-	-	-	RV	RC	-	-	-	-
Forecast onsite conflicts & coordinate	-	RC	-	RC	-	RV	RV	RV	RV	PE	PE	PE	-
Adjust the schedule during the construction	-	PP	PE	PP	PE	PP	PP	PP	PP	PR	PR	PR	-
Construction phase—detailed LOD													
Safety management													
Analyze structural safety issues	-	RV	-	RC	-	-	-	RV	RC	-	-	-	-
Identify safety issues	-	PP	PE	PP	PE	PP	PP	PP	PP	PR	PR	PR	PR

(Continued)

4D BIM use	Stakeholders												
	Client	Construction manager	BIM manager	Architect	Civil structural engineer	MEP engineer	Contractor	Safety manager	Workers	Manufacture supplies	Building surveyor	Quantity surveyor	Facility manager
<b>Constructability management</b>													
Design temporary works	-	RC	RC	-	-	-	RC	RV	-	-	-	-	-
Test different construction alternatives	-	PP	-	PP	PE	PP	PP	-	PE	PE	-	-	PR
Optimize interfaces management	-	PE	PP	PP	PE	PP	PP	PE	-	-	-	PE	-
Site lay-out & environment management	-	RC	-	PP	-	PP	RC	RV	-	-	-	-	-
Anticipate environment conflicts	-	RC	RC	-	-	-	RC	-	-	-	-	-	-
Forecast onsite conflicts & coordinate	-	RC	RC	PP	PP	PP	PP	PE	PR	PE	-	PE	PR
Adjust the schedule during the construction	-	PP	PP	PP	PP	PP	PP	PE	PR	PR	-	-	-
Monitoring	-	PR	PP	PP	PE	PP	PP	PE	PR	PR	-	-	-
Give short term goals to construction team	-	RV	RC	-	-	-	RC	-	-	-	-	-	-
Record progress & compare to schedule	-	PE	PP	PP	PE	PP	PP	PE	PR	PR	PE	-	-
Adjust the schedule during the construction	-	RV	RC	PP	PE	PP	PP	PR	PR	PR	PR	PE	PR
	-	PE	PP	PP	PP	PP	PP	PR	PR	PR	PR	-	-

Note: R: RV—responsible validator, RC—responsible coordinator; P: PP—participant production, PE—participant reader. Italic words represent background influence

delivery, program, calendar events intersecting with construction, and a collaboration protocol. This list may be completed during preconstruction with detailed terrain preparation (construction technology techniques, tools, competence), plans and technical details of the project, detailed requirements on project delivery, project stakeholders' roles and intervention limits, stakeholders' calendars and resources, collaboration charts, and economic and management risks and quantifications.

Similarly, at the design phase, DM sessions for 4D clash detection and solutions are supported by discipline models assembled, rules of conflict detection, and estimations of charges. They are then further completed with a collaboration protocol, roles, charts, and construction methodology details at pre-construction.

For 4D site and environment, safety, and construction management, a DM session participant may need to refer to the same additional documents for planning and clash detection completed with security protocols, contracts, insurances, and controls; requirements on project delivery; safety control protocols; economic and management risks and quantifications; project diary (log, reports, photos, scans, and exchanges); and requirement lists (e.g., responsible construction firm, and materials). 4D monitoring shares the same list of required documents as project diary (log, reports, photos, scans, and exchanges), requirements list (e.g., responsible construction firm, materials), collaboration protocols, contracts, and economic and management risks.

These document lists vary depending on the type of session and interaction demands, and they must be approved with further interviews of professionals. Relevant document lists and information types are required to design an interface for a 4D-based collaboration device, which will be adapted to a collaboration scenario.

## 7 Conclusions

4D BIM is a part of common practice and offers other uses besides the improvement in project visualization. The implementation of 4D BIM uses must be customized to a project development phase. Some of the uses are already available on the design phase, but the principal field of implementation is on pre-construction. The uses are not limited to planning activities and clash detection but offer access to construction management and monitoring.

Stakeholders' roles and responsibilities evolve through the project lifecycle. Their role in 4D BIM use and DM change as well. Every DM session, with a 4D BIM use as an approach, has a specific objective. This objective requires stakeholders' interventions and relevant information on a project. However, even with a full information 3D model and time management 4D relation, there is still a constant need for additional project documents. Such documents vary depending on the 4D BIM use and project

phase.

The 4D and a set of other digital documents at a DM session provide information support. However, the session participants must have access to relevant interactions with the project information to maintain fluidity of collaboration and develop a clear understanding of the project. Therefore, with this research project, we continue to progress to develop a configuration for relevant synchronous collective DM support, which is optimized for AEC specific requirements and 4D BIM uses.

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