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

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Abstract In order to fully understand and efficiently implement 4D BIM models and methods, we need to develop a precise knowledge of which project digital documents should be used, and also how they influence the decision-making 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 decision-making at collaborative meetings. Through this research we continue to progress towards a new 4D-based collective decision device, thus these elements will contribute to propose 4D BIM as a support for the decision-making on 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), next it introduces a proposition for 4D BIM uses implementation by project development phase, and to conclude it summarizes 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 “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, in order to set a context, it overviews in more details current tendencies of digital era for AEC and a place of 4D BIM diffusion. Third, the article will summaries BIM project complexity in order to understand the current context and its limits. Next, 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.

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2 Research towards a new 4D-based collective decision device

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

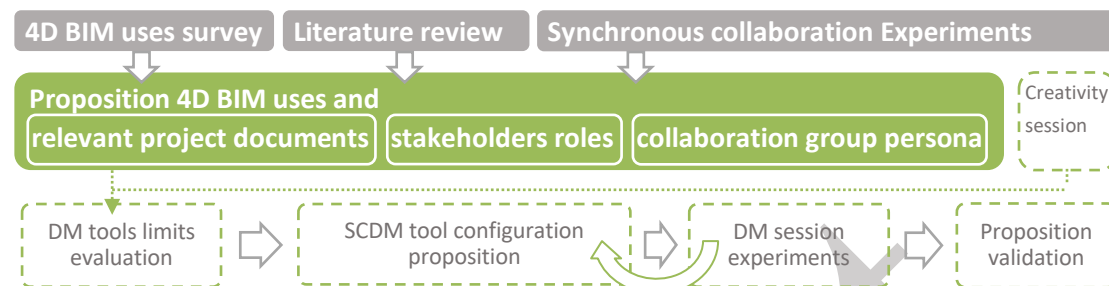


Fig 1. Summary of methodology steps for decision-making support proposition (v.2 extended)

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 <https://www.shariing.com>) 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, for example 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 has conducted a 4D BIM uses survey.

These research steps, aside with a literature review, have resumed current limits of the proposed collaboration solution, also they have revealed users need for more natural and industry adapted interactions during a collaboration session.

2.2 Further research steps

Next research step is a proposal of relations between project phase and 4D BIM use, and 4D BIM uses relation to project documents, as well as the 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 decision-making support design team with field information for the future AEC adapted interface, interactions and collaboration session scenarios.

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

3 BIM context of AEC industry

A BIM model becomes core of shared skills and is encompassed by stakeholders collaboration (NIBS buildingSMART alliance, 2015), which fosters further digitalization for design and for construction. Building Information Modeling and Management brings changes to many aspects of AEC project development to every construction market. This section overviews global tendencies in order to picture the 4D BIM place. It also introduces contexts in France and Luxembourg.

3.1 Recent AEC Market tendencies

AEC industry is no longer so oriented to local conditions as before; recently many countries have more interest in sophisticated technologies and materials for innovative and challenging designs. However, often they do not hold all the necessary skills or resources, therefore the industry becomes more focused on skills share and improvement, aside with a tendency to become more coherent with international standards and practices.

Through the lens of the 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), (EUBIM 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 for others regarding a market context, demands, a location, a project type, etc.

In addition, the current tendency of the market is an increase in the frequency of demands for additional services, as not only for design and construction phases, but also for services related to project maintenance or facility management phases, especially for the newly build projects (Volk et al., 2014). The basic service provisions for a project, which consists of design and construction, and management tasks, are often accompanied by 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, PTNB, IT barometer surveys, etc.). Often BIM research surveys and studies with industry professionals show their high interest in stronger collaboration, or they show a belief in quality improvements due to BIM. It is worth mentioning that BIM is perceived in various ways by AEC industry professionals. (Becerik-Gerber and Rice, 2010)(Vass, 2017). A critical realist description of BIM experiences provide improved standing points (Fox, 2014). Often project stakeholders vision depends on how well they are informed on the subject and on their experiences. Nevertheless, more accurate data comes from feedback on projects from firms with a high-level BIM implementation. The feedback on the subject from a firm having not yet conducted a BIM project would be slightly different from a firm which has already accomplished a pilot BIM project, or even developed a number of projects.

According to AEC market reports, the percentage of contractors with high BIM implementation levels grows intensively, and varies from 40 to almost 80% for the major markets (Japan, New Zealand, South Korea, Canada, the UK, France, Australia, Germany, Brazil, the USA) (McGraw Hill Construction, 2014). The leaders in BIM implementation and practices are the USA and Scandinavian countries (Smith, 2014). Not only buildings and facilities construction projects seek to implement BIM, but also transportation infrastructure projects have been progressively using BIM, with approximate use in half of projects (in 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).

As for the types of construction stakeholders and their benefits from BIM, the contractors generally reach positive return on investment more quickly than design professionals (McGraw Hill Construction, 2014). So maybe contractors will become the leaders in implementation, and will play the major role in fostering competence development of other stakeholders. Also the 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 the market reports, scientific research on BIM adoption and measurement of the BIM maturity has covered 21 countries and analyses the current situation with a maturity matrix, which shows that none of the countries has yet to achieve the high level, and for now the leader is the UK (Kassem

and Succar, 2017), (Succar, 2014). Various levels of granularity may be applied for the analysis, however, together with the objectives, benchmarks and skills the technology infrastructure (software, hardware and networks) are also an important components of the system.

In the spectrum of these global situations our main interest and study fields are France and Luxembourg (since the research project 4D Collab stay attached to the professional context). Luxembourg is developing a national BIM strategy and BIM execution plan (Eurostat, 2018), and has a strong initiative and support at the governmental level. According to an IT-barometer survey the firms were not very familiar with BIM (in 2014), with the highest awareness among architects (about 40 %) (Kubicki and Boton, 2014). This might mean that architecture professionals may eventually take 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, it states that only a little more than 10% of firms have declared using BIM regularly (Eurostat, 2017) and it stays relatively new to the implementation concept and await for national policies further development (Hochscheid and Halin, 2018). The main concern about the future implementation, for about a half of firms, being the cost and complexity of BIM.

French digital initiative has conducted a survey which identified three main advantages of BIM perceived by professionals. The first advantage is stakeholders encouragement for stronger exchanges on a project, the second one is a reduction of design errors and the last is the project quality improvement (Plan Transition Numerique dans le Bâtiment, 2017).

However, within the above advantages, three mains perceived disadvantages of BIM were identified as well, namely, the lack of internal skills (suggested by more than 45% of participants), software costs (suggested by more than 40% of respondents), and finally the lack of standardization (suggested by more than 35% of respondents) (Plan Transition Numerique dans le Bâtiment, 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 stronger communication on the project and bring new roles and relationships to the project (Singh et al., 2011), aside with new opportunities for AEC professionals, for example, with integrated project delivery and LEAN.

3.3 4D BIM on a global scale

Currently, the main use of 4D BIM is for visualization of the planned construction process. However, other uses have not yet been fully integrated into construction practices (Guerriero et al., 2017). In addition, since 4D BIM is inevitably joined to construction time management, which must take in count the 4D benefits and limitations (Mahalingam et al., 2010). As a part of time management 4D can become a valuable source of information for a decision-making. Nevertheless, visualized project information and the BIM model development level correspond to the objectives of the collective decision-making session (Boton et al., 2015).

During the last two decades the various studies have been conducted and often concluded that 4D BIM adoption rate stays relatively low (McGraw Hill Construction, 2014) (Kubicki and Boton, 2014) (Mahalingam et al., 2010) (Boton, 2013). The adoption and implementation of BIM and nD BIM is a dynamic, continuous process, which is highly dependent on local market conditions. The percentage rates of diffusion indicate the market advancement, and potential for studies. Yet the rates change progressively every year.

For example, the experiences 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). And we continue to hear from companies who test 4D in their work. According to the international Smart market report many contractors have committed to the

integration of models with schedule on design and pre-construction phases as one of their top three organization leverages 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 in Luxembourg in 2014 showed that only about a fifth part of respondents were familiar with 4D (Kubicki and Boton, 2014).

4D BIM diffusion dynamics in the UK have been investigated in detail during the last two years, when a survey indicated that more than a half of survey participants currently use 4D in their practices, with a higher level of personal 4D BIM use in organizations with a higher level of BIM maturity; also the adoption was either an authority decision or a collective consortium decision (Gledson, 2015)(Gledson and Greenwood, 2017). Australian research summarizes resumes that the adoption of 4D has stayed at the basic level and that 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 bonding for all the markets. And global tendencies frequently have their reflection on a local market. Along with new benefits and opportunities, AEC professionals are facing new challenges, such as the complexity of project data and of work process organization as a project grows. Therefore, the industry requires efficient management methods in order to increase the efficiency both of construction and project quality.

4 Complexity of a construction project and 4D uses

This section overviews project complexity in order to better understand the project in details. It also defines a 4D relation concept to distinguish information types presented by a 4D. Next, this section looks into time management methods, and resumes with 4D uses relation to a project phase.

4.1 Understanding project complexity and “4D relation” concept

The previously mentioned complexity of BIM encompasses the project complexity (building function and structure, construction method, the 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 also be acknowledged as a part of the information processing approach to task complexity (Campbell, 1988). Figure 2 summarizes these influences.

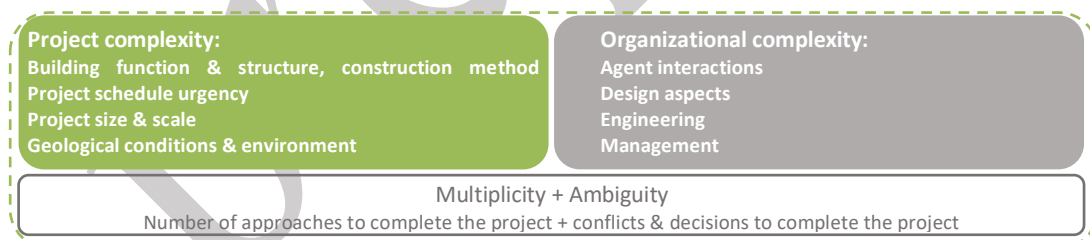


Fig 2. Project complexity influences schema

According to UK standards and classification of BIM maturity levels, such sophisticated models and collaborative BIM start appearing level 2 and assure the full transition to iBIM (level 3) (The British Standards Institution, 2014). Also, the level of development, which is growing through the project development phases, provides the progressive complexity increase to the system. Certainly project document set depends on a type of project, on 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 a data organization is created by a number of project documents. A 3D BIM model is often a core of the 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 whole lifecycle of the project (Lee et al., 2006) (Hartmann et al., 2008). So 3D (x, y, z) + time management models are 4D, an additional to them information on costs stands as 5D, and 6D and 7D stand for other resources.

BIM allies the virtual 3D model of the construction project with a construction schedule, it occurs mostly at the pre-construction phase of project development (Hu and Zhang, 2011). Construction projects with 4D implementation are no longer pilot projects but a common way of proceeding for large construction projects, due to the fact that 4D BIM improves cost control and eliminates errors, whilst also making scheduling and coordination more efficient.

Through the evolution of the project its BIM model evolves as well, gaining new data, new connections, new actors. Since “conceptually 4D CAD represents a type of graphic simulation of a process” (McKinney et al., 1996), it is important to understand what is actually represented in 4D.

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

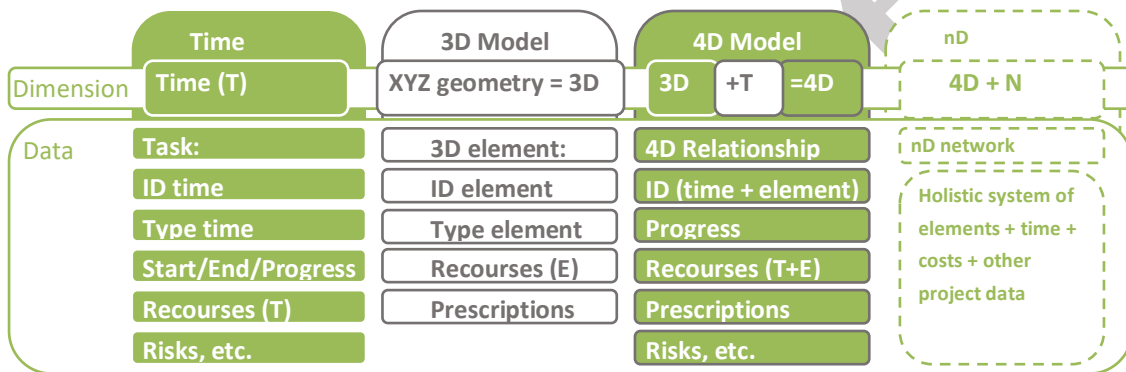


Fig 3. Dimensions and Data concepts as parts of 4D model

4.2 Time management and project development relation

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

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

The time management can be approached with different methods (Boton, 2013): classic - Critical Pass Method (CPM), and Program Evaluation and Review Technique (PERT), which have been in use for numerous decades but did not seem to show the highest efficiency due to the lack of resources taken in to account or because of prediction inaccuracies; linear projects - Linear Scheduling Method (LSM), and Line of Balance (LOB); recent approaches - Last Planner System (LPS), Critical Chain Method (CCM), Virtual Construction (VC).

Adaptive dynamic time management may combine these approaches to find the best fit for each section of the project (The Chartered Institute of Building, 2018). The program and the early planning start at the same time as the concepts and design, once the project shape is defined the time aspect is introduced and developed, and resources follow. An efficient dynamic schedule assures review, revision, monitoring, updates and impacts. For a complex BIM project, a single approach would not be efficient, thus early anticipation and a holistic, systematic approach should be implemented.



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

4.3 4D BIM uses and project development

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

Guerriero et al. (Guerriero et al., 2017) propose following 4D BIM uses: 4D Scheduling, 4D Clash Detection, 4D Safety Management, 4D Site Lay-out & 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, of course when the 3D and time dimensions and accompanying data are available, sometimes it even may be helpful on the negotiation stage. In practice, for some complex projects the 4D models are also useful in a dialogue with authorities. (Fischer and Kunz, 2004). Curiously, a survey respondents with less BIM experience tend to identify visualization as a major benefit from BIM, and more experienced respondents tend to 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 yet been put in a wide practice. It is also often seen as a complementary scheduling instrument (Rolfsen and Merschbrock, 2016), also used as one for a review the sequence of work, improve the constructability. (Fischer and Kunz, 2004).

One of 4D BIM major benefits is information accessibility and clear visualization - all actors have access to a 3D model and to an attached schedule, to 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 LOD is summarized in Fig 5. The operation and maintenance phase is not in a scope of this research due to the phase specifics and main relevance in a domain of facility management.

Project phase	Program	Pre-design, Schematic design D. Development	Pre-construction, Construction documentation	Construction Fabrication	Delivery O&M
Model LOD	Conceptual	Approximate	Precise	Detailed	Recorded
Time management		Scheduling			
4D BIM use		Clash Detection	Safety Management	Site Lay-out & Env. Management	Constructability Management
				Monitoring	

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

5 Synchronous collaboration and software solutions

BIM is the current philosophy of digital project development tools and methods, where the project data is mostly digital. Project stakeholders collaborate on a shared virtual 3D model of the project which is enriched by virtual simulations and estimations. First, this part describes BIM socio-technical system

to understand the place of collaboration and synchronization in BIM work context. Next, we overview software types and decision-making session interactions.

5.1 Describing socio-technical system of BIM

In particular, with BIM, the project stakeholders use the single virtual model as a source of information, and as a design and modelling support. In BIM workflow the project development process relies on a *sociotechnical system* (Fig.6) (WPS Group & Kaoris Future, 2018)(Sackey, 2014). Where the intelligent models and information management represent the *technical core* of the system. Of course, these elements are created and operated with specific software tools.

The core is enclosed by *social elements*: synchronous collaboration, coordinated work practices, institutional and cultural frameworks. The institution has its own intersocial order, which is nevertheless created by the interactions and influences among the institutional professionals (Jacobsson et al., 2017). These elements are framed by design and management methods, which are highly relying on the technical core. When BIM enables a more integrated collaboration among actors, it makes transformational effects on work processes (Jacobsson et al., 2017).

Often, the actors are focused on a project quality as the central priority. A BIM project itself, as a system, is non-linear and adaptive, it is also very interdependent with a significant number of influences involved, thus it must be approached with an adaptive management.

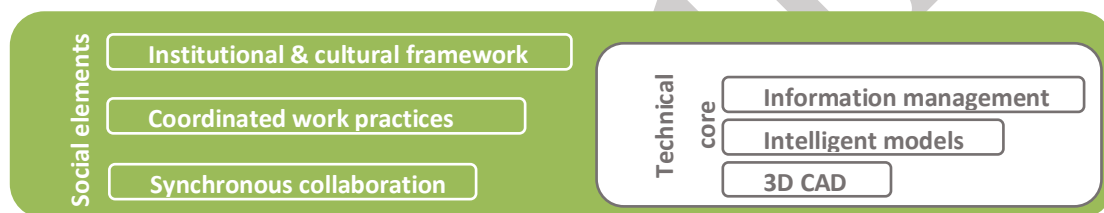


Fig 6. BIM socio-technical system (according to (Kennerley, B, 2017))

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), more than 80% of respondents expect an increase in collaboration of an owner and a contractor (KPMG, 2015). These aspects point out the value of more intense collaboration and professionals attention to workflow organization.

Often digital workflow is interfered after preparation to stakeholders meetings. At this moment a synchronization occurs, which means that meeting objective(s) is set, thus relevant project stakeholders will be invited to meet. They prepare an up to date project information and extract documents which seem the most relevant to meeting objective.

The meeting is further referred as decision-making (DM) session. Our study focus is a DM for a session for design development or value engineering within synchronous co-located (same place, same time) collaboration. According to Himmelman: “Collaborating - exchanging information, altering activities, sharing resources, and enhancing the capacity of another for mutual benefit and to achieve a common purpose (Himmelman, 2004).

During a collaboration all the users share the same environment, to bring the shared vocabulary to a work process and to shared project information (Achten, 2002) (Wilkinson, 2005). Collaboration technology, aside with real-time exchanging opinions, requires information on work awareness and on teamwork progress (Wilkinson, 2005). Collaboration efficiency is reduced if project stakeholders do not share the same organization and don't have an equal access to information, also if a decision-making weight is not mutual as well. (Dossick and Neff, 2009). A study of Lee and Jeong suggests implementation of domain-specific, intelligent filters in order to facilitate users interactions of selection

and interpretation of the task relevant information during the a work with BIM model viewers, also shared filters improve understanding between disciplines (Lee and Jeong, 2012).

To sustain the connection to digital documents and document management systems, it is possible to integrate a collective decision device (hardware and software) into DM sessions. Moreover, with a digital technology integration a project keeps design integrity, also project team members benefit from a distributed access to project documents (Fischer and Kunz, 2004).

5.3 Document management systems

The complexity increases through a project lifecycle, and it places 3D into a center of collaboration and exchanges. So, it gathers and connects numerous types of documents, some of them are originally digital and some are digitalized in order to get integrated into document management systems.

Nowadays, distant collaboration solutions like document management systems (like 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 propose various collaborative modeling features. (Boton, 2018). Real project case studies prove that cloud-based synchronization and project design information exchanges indeed are possible, yet they lack improved AEC and BIM better adapted tools (Munkley et al., 2014). Moreover, studies report BIM users facing intra-organizational challenges, mostly in piloting documents for internal work practices, and in following the managers requirements (Vass and Gustavsson, 2017). Thus cloud-based solutions are a part of a usual practice, however they must integrate more customized task management in addition to document management.

Yet, according to Munkley, cloud computing platforms and services are still lacking the wide range of functionalities adapted specifically to BIM project development. (Munkley et al., 2014). Also such solutions are not specifically targeting synchronous collaboration for DM sessions. Still, even if they lack democratic interactions and discipline filters. Future document management systems must keep a connection to DM session tools to maintain 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, utilities (Wallner and Von Both, 2017). For 4D software “4D CAD” and “Integrative applications” types (Porkka and Kähkönen, 2007) are the most relevant to viewer-modeler-checker classes and allow BIM based collaboration situations.

There are various types of examples 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 offer various instruments such as animations and simulations, planning and scheduling, scenarios comparison, 4D clashes detection, reports and tracking, also exports and imports options, and even a distant collaboration for some cases. Aside with these tools, there is a number of 4D tracking automation approaches (Kropp et al., 2018). (Park et al., 2017) and new planning systems (Ivson et al., 2018).

Malsane summaries that 4D must be created and modified in alliance with project planning activities (Malsane et al., 2015), thus a collaborative decision making is a way to benefit from the 4D BIM uses potential. The tools main focus on is 4D simulations, quantities or costs management, and not necessary on co-located synchronous collaboration. In addition, even with some offering touch gestures support the interface is designed for a single user interactions with the 4D model information.

The VR-based collaborative propositions, like collaborative 4D simulation environment (Boton, 2018), iRoom (Fischer et al., 2002) and VCE (Waly and Thabet, 2003) offer interactive and collaborative solutions indeed. However, they are limited to the VR technology. As an alternative, we seek to propose a real physical environment with a touch table to keep a collaboration situation close to a classic “around

the table” discussion type of a meeting. Synchronous collaboration environments for BIM must provide own view of the project model for each discipline, it must assure all the updates and show them to all in real time (Isikdag and Underwood, 2010).

6 Identifying elements for 4D collaboration

6.1 Parameters for a new collaboration device and user interactions

According to cases studies (Haymaker and Fischer, 2001), after the sessions with 4D an implication of the different members of the project team increased and they have been more committed into collaboration and resolution of project problems. 4D may bring a benefit as it outlines settled parts of a project within the points to develop or rethink as well (Haymaker and Fischer, 2001). Experiments with portable distant collaboration devices on site show very positive feedback from the construction professionals (Svalestuen et al., 2017), furthermore, a 4D construction simulation improved a project understanding and a work flow for a construction team.

With a future 4D-based collaboration device proposition, a number of features must be considered. For example, 4D visualization as a decision making support requires a development of new appropriate ways for reporting. (Porkka and Kähkönen, 2007). A feature of adjustable level-of-detail relevant to different disciplines needs must be integrated into the future 4D simulation solutions, with more user-oriented transformational functionalities (Porkka and Kähkönen, 2007). Also, the interoperability data formats have not yet integrated the time dimension into a single model with 3D (Kassem et al., 2014). The tools are currently single window limited, without customisation to user profiles. (Singh et al., 2011).

First, with the device a DM would be a part of a connected project development, which keeps a project information in a single document management system and representation interface (Kvan, 1998), thus it would nivellate the above-mentioned interference. As an outline, such collaborative and interoperability tools must help to avoid information losses, to optimize work, to avoid redundancy of tasks, to keep the link to BIM data storage.

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

It means not only shared views, but shared access to any document interactions. We first propose following interaction families: visualization (the model is only reviewed, but there is an additional information level), annotation (the model is not modified, but has an additional level of information with annotations), modification (direct interaction with data and direct modifications). For example, an interaction may be to annotate a 3D model, but it will be possible to do that at the same time by more than one user.

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

In addition, the device is not limited to a one type of equipment, but may include for example different types of touch-displays. Mahyar et al. case study shows that interactive devices have a potential for supporting formal and informal collaborative activities, with a vertical display type for presentation related activities on one hand, and tabletop display for more collaborative situations (Mahyar et al., 2010).

For a future 4D-based collaboration device we propose to implement a multi-touch collaborative table and wall within a NUI as a decision-making session device. The integration of a device with NUI fosters the convergence of 4D uses with project documents and gives the ease of interactions at decision-making session.

6.2 4D BIM uses and project stakeholders roles

The project does not progress without people. Every role and responsibility have a place and influence on a final result. Davies states that a clear project roles definition in global guides and protocols is necessary to make BIM practice more 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.

Projects' design development and design management, and project management in the case of a BIM project, would be closely related and guided with BIM management as well. According to the Managing design process roadmap (Gu and London, 2010), there are a number of steps related to the BIM process setup (identification of roles, phases, activities, dependences, tools, etc.) preceding a design stage.

Also various disciplines have their role 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 one of the challenges of BIM will be a requirement to connect people to project information (Kensek, 2014).

Often a project is developed by specialists who have not been working together previously, since the human resources depend on a project site, thus every firm develops their part of the common project, but since being a separate unit does not integrate into a collaborative framework (Dodge Data & Analytics, 2017). The project team need appropriate training and information in order to be efficient in the work environment. (Singh et al., 2011). Thus, the prepared and project customized organization of the BIM process with a well-adapted framework are essential for efficient design, time and cost, and construction management. With attention to client BIM roles, thus nowadays BIM guides define well a project team roles but neglect a BIM management from a 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 a proposition of involvement and influences of stakeholders vis-à-vis 4D BIM uses synthesis.

Stakeholders use 4D BIM and interact with it in various ways, it depends on a contract and a project phase. 4D visualization use has a transversal place in project lifecycle, it supports every other use, all the stakeholders benefit from it. The table proposes 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 a Design and Pre-construction phases (it is followed by 4D Monitoring during the construction), and involves firstly the project management and a client meeting 3D model creations. Client has RV and PR responsibilities, the process is led by experience of architects and engineers, BIM manager assists to place the methodology and collaboration. Contractor has a secondary role on a design phase 4D scheduling but takes a responsibility of coordination on a pre-construction phase.

Multiple competence involvement into decision-making 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 as well, they have more responsibilities in the beginning of the project, and then have to update their models through all the phases (RV & PP roles). Finally, the client has more of an influence on input data (time and costs related), rather than on construction processes itself.

Table 1. 4D BIM uses and Stakeholders operating roles & influences

Phase LOD	4D BIM use	Stakeholders													
		Role type	Client	Construction man.	BIM manager	Architect	Civil/Structural eng.	MEP Engineer	Contractor	Safety manager	Workers	Manufactures suppl.	Building surveyor	Quantity surveyor	Facility Manager
Design-Approximate	<i>4D Scheduling</i>														
	Forecast construction phases & sequencing	R	<i>RV</i>	RC	RV	RV	RV	RV	PE		PE		PE		
		P		<i>PE</i>	PP	PP	PP	PP							
	Optimize the construction schedule	R		RC	RV	RV	RV	RV							
		P	PR	<i>PE</i>	PP	PP	PP	PP	PE						
	<i>4D Clash Detection</i>														
Detect spatio-temporal conflicts	R		<i>PE</i>	RC	RV	RV	RV	RV							
	P				PP	PP	PP	PP	PE						
Detect static and dynamic conflicts	R		<i>PE</i>	RC	RV	RV	RV	RV							
	P				PP	PP	PP	PP	PE						
Pre-construction phase - Precise	<i>4D Scheduling</i>														
	Forecast construction phases and sequencing	R	<i>RV</i>	RC	RC	RV	RV	RV	RC	RC	PR	PR	PR	PR	PE
		P		PP	PP	PP	PP	PP	PP	PP					
	Optimize the construction schedule	R		RC	RC	RV	RV	RV	RC						
		P		PP	PP	PE	PE	PE	PP	PR	PR	PR	PR	PR	PE
	<i>4D Clash Detection</i>														
	Detect spatio-temporal conflicts	R		<i>PE</i>	RC	RV	RV	RV	PP						
		P		PP		PP	PP	PP	PE	PR				PE	
	Detect static and dynamic conflicts	R		<i>PE</i>	RC	RV	RV	RV	PP	PR					
		P		PP	PP	PP	PP	PP	PE					PE	
	<i>4D Safety Management</i>														
	Analyze structural safety issues	R	<i>RV</i>	<i>PE</i>	RC	<i>PE</i>	<i>PE</i>	<i>PE</i>	RV	RC					
		P		PP	PP	PP	PP	PP	PP	PP	PR				
	Identify safety issues	R	<i>RV</i>	<i>PE</i>	RC	PR	PR	PR	RV	RC					
		P		PP	PP	PP	PP	PP	PP	PE	PR	PE			
	<i>4D Constructability Management</i>														
	Design temporary works	R		RC	RC	PE	PE	PE	RV	<i>RV</i>					
		P		PP	PP	PP	PP	PP	PP	PE		PE		PE	
Test different construction alternatives	R	<i>PE</i>	RC	RC	RV	RV	RV	RV	<i>PE</i>					PE	
	P		PP	PP	PE	PE	PE	PP							
Optimize interfaces management	R		RC	RC	PP	PP	PP	RV	<i>RV</i>						
	P		PP	PP				PP	PE		PE				
<i>4D Site Lay-out & Environment Management</i>															
Anticipate environment conflicts	R		RC	RC	PE	PE	PE	RV							
	P		PP	PP	PP	PP	PP	PP	PR		PE		PE		
Forecast onsite conflicts & coordination	R		RC	RC	PE	PE	PE	RV							
	P		PP	PP	PP	PP	PP	PP	PR	PR	PE				
Adjust the schedule during the construction	R	<i>PR</i>	RC	PC	PE	PE	PE	RV		<i>PR</i>					
	P		PP	PP	PP	PP	PP	PP			PE				
<i>4D Safety Management</i>															
Analyze structural safety issues	R	<i>RV</i>	<i>PE</i>	RC		<i>PE</i>	<i>PE</i>	<i>RV</i>	RC	<i>PR</i>					
	P		PP	PP	PP	PP	PP	PP	PP					<i>PR</i>	
Identify safety issues	R	<i>RV</i>	<i>PE</i>	RC		<i>PE</i>	<i>PE</i>	<i>RV</i>	RC	<i>PR</i>					
	P		PP	PP		PP	PP	PP	PP					<i>PR</i>	
<i>4D Constructability Management</i>															
Design temporary works	R		RC	RC	PE	PE	PE	RC	<i>RV</i>						
	P		PP	PP	PP	PP	PP	PP	PE		PE			<i>PR</i>	
Test different construction alternatives	R	<i>PE</i>	RC	RC	PE	PE	PE	RC						PE	
	P		PP	PP	PP	PP	PP	PP	PE						
Optimize interfaces management	R		RC	RC				RC	RV						
	P		PP	PP	PP	PP	PP	PP	PE		PE				
<i>4D Site Lay-out & Environment Management</i>															
Anticipate environment conflicts	R		RC	RC	PP	PP		RC							
	P		PP	PP			PP	PP	PE	PR	PE		PE	<i>PR</i>	
Forecast onsite conflicts & coordination	R		RC	RC				RC							
	P		PP	PP	PP	PP	PP	PP	PE	PR	PR				
Adjust the schedule during the construction	R	<i>PR</i>	RC	RC	PE	PE	PE	RC							
	P		PP	PP	PP	PP	PP	PP	PE	PR	PR				
<i>4D Monitoring</i>															
Give short term goals to construction team	R	<i>RV</i>	RC	RC	PE	PE	PE	RC							
	P	PE	PP	PE	PP	PP	PP	PP	PE	PR	PR	PE			
Record real progress & compare to schedule	R	PC	RC	RC	PE	PE	PE	RC							
	P	PE	PP	PE	PP	PP	PP	PP	PR	PR	PR	PR	PE	<i>PR</i>	
Adjust the schedule during the construction	R	PC	RC	RE				RC							
	P	PE	PP	PE	PP	PP	PP	PP	PR	PR	PE	PR			

R : RV – Responsible Validator, RC – Responsible Coordinator,
P: PP – Participant Production, PE – Participant Expert, PR – Participant Reader, *Italic – background influence*

6.3 4D BIM uses and relevant project documents

Once responsibilities and involvement links are summarized, we may look for a project data which would be relevant at the decision-making session, and will offer actors sufficient and complete information on a project. Inevitably, documents are still depend on project and contract types, however a global pattern is predictable.

The core of the 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 (Archi, Structural, MEP, Civil) from early design to design development associate to the time management data about the program or the main planning with estimation of time and required construction resources (general stages). Further, at pre-construction phase with a precise LOD the 3D models (Archi, Structural, MEP, Civic) are well established and detailed, and they are bonded to the time management data about planning with estimation of time and required construction resources which are transformed into a precise construction scheduling (tasks, elements, dates; construction firm, equipment and material requirements). Finally, at the construction phase detailed 3D models initial and ongoing, as-build correlate with a precise dynamic construction scheduling (on-going tracking, risks, milestones, logs).

At a DM session project at stakeholders must have access to other project documents, in addition to the 4D model and simulations. For example, DM session participants with 4D as a support for scheduling during design phase may require an information and documents as: a state of terrain (plans, permits, environment, soils study); a program and a budget from client; a project volume, specifications (generic numbers, plans); project principal stakeholders (generic list); a construction methodology choice; general requirements on project delivery, program; a calendar events intersecting with construction; and a collaboration protocol. This list may be completed during preconstruction with: terrain preparations; details (constructing 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 with economic and management risks and quantifications.

Likewise, at a design phase DM session for 4D Clash detection and solutions is supported by discipline models assembled; by the rules of conflict detection and by the estimations of charges; and further completed with a collaboration protocol, roles, charts, and then construction methodology details at pre-construction.

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

These document lists vary on a session type and interactions demands, and must be approved with further professionals interviews. Relevant documents 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 Conclusion

4D BIM becomes a part of common practice, and besides the improvements of project visualization it offers other uses. 4D BIM uses implementation 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 nor 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 decision-making change as well. Every decision-making session, with a 4D BIM use as an approach, has a specific objective and this objective requires a stakeholders' intervention 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. The set of these documents alters depending on the 4D BIM use and on the project phase.

The 4D and a set of other digital documents, at a decision-making session, provide the information support. However, the session participants must have access to relevant interactions with the project information in order to keep fluidity of collaboration and better understanding of the project. Therefore, with this research project, we continue to progress to develop a configuration for a relevant synchronous collective decision-making support, optimized for AEC specific requirements and for 4D BIM uses in particular.

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8 References

Achten H H (2002). Requirements for Collaborative Design in Architecture. in: Sixth Design and Decision Support Systems in Architecture and Urban Planning. eds. Timmermans. Ellecom, 1, doi:<http://papers.cumincad.org/data/works/att/ddssar0201.content.pdf>

Becerik-Gerber B, Rice S (2010). The perceived value of building information modeling in the U.S. building industry. *Electronic Journal of Information Technology in Construction*. 15: 185–201

Bolshakova V, Guerriero A, Carvalho H, Halin G (2019). Collective Decision-Making with 4D BIM: Collaboration Group Persona Study. in: *Advances in Informatics and Computing in Civil and Construction Engineering*. Cham: Springer International Publishing. Cham: Springer International Publishing, pp. 455–462, doi:10.1007/978-3-030-00220-6_54

Bolshakova V, Guerriero A, Halin G (2018). Identification of relevant project documents to 4D BIM uses for a synchronous collaborative decision support. in: *Proceedings Creative Construction Conference 2018*. eds. Hajdu, Skibniewski. Budapest: Diamond Congress Ltd., 1036–1043, ISBN 978-615-5270-45-1

Bolshakova V, Halin G, Humbert P, Botton C (2017). Digital Synchronous Collaboration Workspace and 3D Interactions for an AEC Project. Decision-Making Scenario Evaluation. in: *Cooperative Design, Visualization, and Engineering: 14th International Conference, Cooperative Design, Visualization, and Engineering, CDVE 2017. Lecture Notes in Computer Science*. eds. Luo. Cham: Springer International Publishing, 10451: 168–176, doi:10.1007/978-3-319-66805-5978-3-319-66804-8

Botton C (2018). Supporting constructability analysis meetings with Immersive Virtual Reality-based collaborative BIM 4D simulation. *Automation in Construction*. Elsevier, 96: 1–15, doi:10.1016/j.autcon.2018.08.020

Botton C (2013). Conception de vues métiers dans les collecticiels orientés service. Vers des multi-vues adaptées pour la simulation collaborative 4D/nD de la construction. Université de Lorraine, Université de Lorraine,

Botton C, Kubicki S, Halin G (2015). 4D / BIM simulation for pre-construction and construction scheduling. Multiple levels of development within a single case study. in: *Proceedings Creative Construction Conference 2015*. eds. Hajdu, Skibniewski. Budapest: Dimond Congress Ltd., 500–

505, doi:10.13140/RG.2.1.1941.3603978-963-269-491-7

Braun V, Clarke V (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*. 3: 77–101, doi:10.1191/1478088706qp063oa

Campbell D J (1988). Task Complexity: A Review and Analysis. *Academy of Management Review*. 13: 40–52, doi:10.5465/amr.1988.430677503637425

Davies K, Wilkinson S, McMeel D (2017). A review of specialist role definitions in bim guides and standards. *Journal of Information Technology in Construction*. 22: 185–203

Dodge Data & Analytics (2017). The Business Value of BIM for Infrastructure. , SmartMarket Report. eds. Jones, Laquidara-Carr. Bedford, USA: Dodge Data & Analytics, Research & Analytics,. Bedford, USA: Dodge Data & Analytics, Research & Analytics,

Dossick C S, Neff G (2009). Organizational Divisions in BIM-Enabled Commercial Construction. *Journal of Construction Engineering and Management*. 136: 459–467, doi:10.1061/(asce)co.1943-7862.00001090733-9364

EUBIM Task Group (2017). Handbook for the introduction of Building Information Modelling by the European Public Sector. [WWW Document]eds. Taskgroup. EU: , URL http://www.eubim.eu/downloads/EU_BIM_Task_Group_Handbook_FINAL.PDF (accessed 2.28.19).

Eurostat (2018). European Construction Sector Observatory Country profile Luxembourg. , European Construction Sector Observatory Country Fact Sheets. Luxembourg: . Luxembourg:

Eurostat (2017). European Construction Sector Observatory Country profile France. , European Construction Sector Observatory Country Fact Sheets. France: . France:

Fischer M, Kunz J (2004). The scope and role of information technology in construction. *Doboku Gakkai Ronbunshu*. 1–31, doi:10.2208/jscej.2004.763_1

Fischer M, Stone M, Liston K, Kunz J (2002). Multi-stakeholder collaboration : The CIFE iRoom. *Proceedings CIB W78 Conference*. 6–13

Fox S (2014). Getting real about BIM. *International Journal of Managing Projects in Business*. eds. Sankaran, Nilgün Okay and Gerhard C. 7: 405–422, doi:10.1108/IJMPB-12-2013-0073

Gledson B (2015). Investigating the diffusion of 4D BIM Innovation. in: *Proceedings 31st Annual ARCOM Conference*. eds. Raidén, Aboagye- Nimo. Lincoln, UK: Association of Researchers in Construction Management, 641–650, doi:10.13140/RG.2.1.4669.01659780955239090

Gledson B J, Greenwood D (2017). The adoption of 4D BIM in the UK construction industry: an innovation diffusion approach. *Engineering, Construction and Architectural Management*. 24: 950–967, doi:10.1108/ECAM-03-2016-0066

Gu N, London K (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*. Elsevier B.V., 19: 988–999, doi:10.1016/j.autcon.2010.09.00209265805

Guerriero A, Kubicki S, Berroir F, Lemaire C (2017). BIM-enhanced collaborative smart technologies for LEAN construction processes. in: *2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. IEEE, 1023–1030, doi:10.1109/ICE.2017.8279994978-1-5386-0774-9

Halin G, Hanser D, Malcurat O, Bignon J C (2002). A relational approach of cooperation in building design. in: *The 8th International Conference on Concurrent Enterprising*. eds. Klaus-Dieter, Pawar, Weber, Thoben. Rome, Italy: Centre for Concurrent Enterprising, 978-0853581130

Hartmann T, Gao J, Fischer M (2008). Areas of Application for 3D and 4D Models on Construction Projects. *Journal of Construction Engineering and Management*. 134: 776–785, doi:10.1061/(ASCE)0733-9364(2008)134:10(776)

Haymaker J, Fischer M (2001). Challenges and Benefits of 4D Modeling on the Walt Disney Concert Hall Project. , CIFE TWorking Paper: WP 64, Stanford University.

Hillebrandt P M (2000). *Economic Theory and the Construction Industry*. , Third edit. edLondon: MACMILLAN PRESS LTD, UK,. London: MACMILLAN PRESS LTD, UK, doi:10.1057/9780230372481978-0-333-77479-3

Himmelman A T (2004). Collaboration for a Change: Definitions, Decision-making models, Roles, Collaborative Process Guide, Collaborative Leadership. in: *Fourth International Conference on Multi-Organizational Partnerships and Cooperative Strategy*,. Minneapolis, USA: Himmelman Consulting, <null>

Hochscheid É, Halin G (2018). L'adoption du BIM dans les agences d'architecture en France. SHS Web of Conferences. eds. Leduc, Miguet. 47: 01009, doi:10.1051/shsconf/20184701009

Hu Z, Zhang J (2011). BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 2. Development and site trials. *Automation in Construction*. 20: 155–166, doi:10.1016/j.autcon.2010.09.0130926-5805

International Organization for Standardization (2010). ISO DIS 9241-210. Ergonomics of human system interaction - part 210: Human-centred design for interactive systems. Switzerland: Geneva: ISO,

Isikdag U, Underwood J (2010). Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction*. Elsevier B.V., 19: 544–553, doi:10.1016/j.autcon.2009.11.006

Ivson P, Nascimento D, Celes W, Barbosa S D J (2018). CasCADE: A Novel 4D Visualization System for Virtual Construction Planning. *IEEE Transactions on Visualization and Computer Graphics*. 24: 687–697, doi:10.1109/TVCG.2017.27451051077-2626 VO - PP

Jacobsson M, Linderöth H C J, Rowlinson S (2017). The role of industry: an analytical framework to understand ICT transformation within the AEC industry. *Construction Management and Economics*. 35: 611–626, doi:10.1080/01446193.2017.131514801446193 (ISSN)

Kassem M, Iqbal N, Kelly G, Lockley S, Dawood N (2014). Building Information Modelling : Protocols for Collaborative Design Processes. *ITcon*. 19: 126–149

Kassem M, Succar B (2017). Macro BIM adoption: Comparative market analysis. *Automation in Construction*. 81: 286–299, doi:10.1016/j.autcon.2017.04.005

Kennerley, B W G plc (2017). BIM is a Sociotechnical System. [WWW Document], URL <http://www.wsp-pb.com/en/Who-we-are/In-the-media/News/2013/What-is-BIM/> (accessed 2.28.19).

Kensek K M (2014). *Building Information Modeling*. , First edit. edAbingdon: Routledge,. Abingdon: Routledge, 10: 0415717744

KPMG (2015). Climbing the curve, 2015 Global Construction Project Owner's Survey. , KPMG Int. , 132253-G.

Kreider R G, Messner J I (2013). *The Uses of BIM: Classifying and Selecting BIM Uses*. , The Pennsy. ed, The Pennsylvania State University. The Pennsylvania State University, University Park, PA, USA,. The Pennsylvania State University, University Park, PA, USA,

Kropp C, Koch C, König M (2018). Interior construction state recognition with 4D BIM registered

image sequences. *Automation in Construction*. Elsevier, 86: 11–32, doi:10.1016/j.autcon.2017.10.02709265805

Kubicki S, Boton C (2014). IT Barometer Survey in Luxembourg: First results to understand IT innovation in Construction sector. in: *Computing in Civil and Building Engineering (2014)*. eds. Park, Kang, Lee, Seo. Reston, VA: American Society of Civil Engineers, 423–430, doi:10.1061/9780784413616.0539780784413616

Kvan T (1998). *Designing Together Apart Computer Supported Collaborative Design in Architecture*. Design. Milton Keynes, England: The Open University,. Milton Keynes, England: The Open University,

Lee A, Wu S, Marshall-Ponting A, Aouad G, Tah J, Cooper R, Fu C (2006). nD modelling - a driver or enabler for construction improvement ? RICS Research paper series. RICS Research. 5: 16

Lee J, Jeong Y (2012). User-centric knowledge representations based on ontology for AEC design collaboration. *CAD Computer Aided Design*. Elsevier Ltd, 44: 735–748, doi:10.1016/j.cad.2012.03.0110010-4485

Mahalingam A, Kashyap R, Mahajan C (2010). An evaluation of the applicability of 4D CAD on construction projects. *Automation in Construction*. Elsevier B.V., 19: 148–159, doi:10.1016/j.autcon.2009.11.0150926-5805

Malsane S M, Amey D, Sheth Z (2015). Simulate Construction Schedules Using Bim 4D Application To Track Progress. *International Journal of Mechanical And Production Engineering*. 3: 978–93, 9789382702979

McGraw Hill Construction (2014). *SmartMarket Report The business value of BIM for construction in major global markets: How Contractors Around the World Are Driving Innovation With Building Information Modeling*. , SmartMarket Report. Bedford: . Bedford: , 1800591446

McKinney K, Kim J, Fischer M, Howard C (1996). Interactive 4D-CAD. *Proceedings of the third Congress on Computing in Civil Engineering*. 135: 1261, doi:10.1061/(ASCE)CO.1943-7862.0000101

Munkley J, Kassem M, Dawood N (2014). Synchronous Building Information Model-Based Collaboration in the Cloud: A Proposed Low Cost IT Platform and a Case Study. in: *Computing in Civil and Building Engineering (2014)*. Reston, VA: American Society of Civil Engineers, 89–96, doi:10.1061/9780784413616.0129780784413616

NIBS buildingSMART alliance (2015). *National BIM Standard - United States® Version 3*. [WWW Document]USA: , URL <https://www.nationalbimstandard.org> (accessed 2.28.19).

Park J, Cai H, Perissin D (2017). Bringing Information to the Field: Automated Photo Registration and 4D BIM. *Journal of Computing in Civil Engineering*. 32: 04017084, doi:10.1061/(asce)cp.1943-5487.0000740

Plan Transition Numerique dans le Bâtiment (2017). *Plan Transition Numérique dans le Bâtiment - Rapport d'étape*. , BIM-France. France: . France:

Porkka J, Kähkönen K (2007). Software Development Approaches and Challenges of 4D Product Models. in: *W78:2007 - Bringing ITC Knowledge to Work*. 85–90

Pyung K, Lecturer K, Ma T, Lecturer S, Baryah A S, Zhang C, Hui K M (2016). Investigation of Readiness for 4D and 5D BIM Adoption in the Australian Construction Industry. *Management Review: An International Journal* □. 11: 43–65

Rolfen C N, Merschbrock C (2016). Acceptance of Construction Scheduling Visualizations: Bar-charts, Flowline-charts, or Perhaps BIM? *Procedia Engineering*. 164: 558–566,

doi:10.1016/j.proeng.2016.11.6581877-7058

Sackey E (2014). A Sociotechnical Systems Analysis of Building Information Modelling (STSaBIM) Implementation in Construction Organisations. Loughborough, UK: Loughborough University Institutional Repository., Loughborough, UK: Loughborough University Institutional Repository,

Sacks R, Gurevich U, Shrestha P (2016). A review of Building Information Modeling Protocols, Guides and Standards for Large Construction Clients. *Journal of Information Technology in Construction (ITcon)*. 21: 479–503

Singh V, Gu N, Wang X (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in Construction*. Elsevier B.V., 20: 134–144, doi:10.1016/j.autcon.2010.09.0110926-5805

Smith P (2014). BIM implementation - Global strategies. *Procedia Engineering*. 85: 482–492, doi:10.1016/j.proeng.2014.10.57518777058

Succar B (2014). Building Information Modelling Maturity Matrix. , doi:10.4018/978-1-60566-928-1.ch0049781605669281

Svalestuen F, Knotten V, Laedre O (2017). Using Building Information Model (Bim) Devices To Improve Information Flow and Collaboration on Construction Sites. *Journal of Information Technology in Construction (ITcon)*. 22: 204–219

The British Standards Institution (2014). PAS 1192-3:2014 SpecificationSpecification for information management for the operational phase of assets using building information modelling. UK: . UK: , 978 0 580 83910 8

The Chartered Institute of Building (2018). Guide to good practice in the management of time in major projects. *Dynamic time modelling*. , Second edi. edHoboken, HJ, USA: Wiley-Blackwell., Hoboken, HJ, USA: Wiley-Blackwell, 9781119428435

Vass S (2017). The Business Value of BIM - Elaborating on Content and Perspective. Stockholm, Sweeden: Royal Institute of Technology., Stockholm, Sweeden: Royal Institute of Technology, 9789185783816

Vass S, Gustavsson T K (2017). Challenges when implementing BIM for industry change. *Construction Management and Economics*. Routledge, 35: 597–610, doi:10.1080/01446193.2017.1314519

Volk R, Stengel J, Schultmann F (2014). Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in Construction*. Elsevier B.V., 38: 109–127, doi:10.1016/j.autcon.2013.10.0230926-5805

Wallner S, Von Both P (2017). BIM Tools Overview Target group-and process-oriented examination of free BIM tools. *eCAADe* 35. 1: 137–146, 978-94-91207-12-9

Waly A F, Thabet W Y (2003). A Virtual Construction Environment for preconstruction planning. *Automation in Construction*. 12: 139–154, doi:10.1016/S0926-5805(02)00047-X

Whitney H (2013). Views You Can Use. in: *Data Insights*. Elsevier., Elsevier, pp. 191–229, doi:10.1016/B978-0-12-387793-2.00005-X

Wilkinson P (2005). *Construction collaboration technologies : the extranet evolution*. London ; New York: Taylor & Francis., London ; New York: Taylor & Francis,

Wood H L, Piroozfar P, Farr E R P (2014). Understanding complexity in the AEC industry. in: *Proceedings 29th Annual Association of Researchers in Construction Management Conference, ARCOM 2013*. eds. Smith, Ahiaga-Dagbui. Reading, UK: Association Of Researchers in

Construction Management, Reading, UK: Association Of Researchers in Construction Management, pp. 859–869, 978-0-9552390-7-6

WPS Group & Kaoris Future (2018). Truths about BIM. London, UK: . London, UK:

Yuill N, Rogers Y (2012). Mechanisms for collaboration. ACM Transactions on Computer-Human Interaction. 19: 1–25, doi:10.1145/2147783.21477841073-0516

Zou Y, Kiviniemi A, Jones S W (2017). A review of risk management through BIM and BIM-related technologies. Safety Science. Elsevier Ltd, 97: 88–98, doi:10.1016/j.ssci.2015.12.0270925-7535

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