User-Centered Methods Applied to 4D/BIM Collaborative Scheduling

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***Abstract*—4D simulation (linking 3D models with time schedules) allows stakeholders to better understand the construction process of a building. However, 4D tools' recurrent usability issues contribute to its limited adoption. We used user-centered methods to better understand the nature of those issues and identify current practices and users' needs. Based on the gathered data, we framed and then conducted a creativity session with architecture, engineering, construction professionals and researchers, as well as construction software editors. Through the creativity process, users produced 46 ideas that led us to define and develop new functionalities for a new 4D prototype.**

Keywords- User-Centered Design; User needs; 4D BIM; Collaboration; Creativity.

I. INTRODUCTION

The design of a construction building is a complex activity that requires great coordination and a lot of information exchange from different disciplines (architects, engineers, contractors, project managers, etc). Given the fragmented nature of the construction market and information flows, close collaboration between the different stakeholders is essential for the construction process to meet the time, financial and aesthetic requirements of the owner. To that end, the planning and scheduling processes must be carried out in a rigorous and collaborative way. These two processes are complementary, although often confused [1]. Thus, in the construction field, planning consists in defining the objectives, modalities and resources of the project while scheduling makes it possible to allocate resources to tasks as well as to define their sequencing and the time necessary for their completion. [2]. Nowadays, this activity is still carried out manually and requires a large amount of individual and collective work to produce and exchange information [3]. However, a significant amount of information is lost during these exchanges, which results in low quality documents strongly impacting the project's planning and scheduling process [4]. Collaborative scheduling process mainly occurs during the "Design stage" and more precisely in the pre-construction phase. It is during this pre-construction phase that the teams work together on the definition of the construction process. This collaborative activity mainly occurs during coordination meetings, during which plans and diagrams from different disciplines are pooled to resolve design errors. These documents, in 2D or 3D, are digital or paper representations of the physical characteristics of the building and are therefore mediators in the process of collaboration and decision-making [5].

To meet this growing need for collaboration and information sharing, recent decades have seen the emergence of Building Information Modeling (BIM). The Associated General Contractors (AGC) of America defines BIM "as a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users; needs can be extracted and analyzed to generate information that can be used to make decisions and to improve the process of delivering the facility" [2]. BIM is, therefore, both a technology and a new work process requiring a reorganization of workflows. Documents and information centralization allow each actor to have access to all of the information throughout the entire project lifecycle. With the help of BIM tools, each stakeholder produces a 3D digital artifact representing a "business-oriented" vision of the building. These are then regularly updated and merged to form a centralized artifact. When applied to scheduling processes, BIM turns a 3D model into 4D. 4D artifacts are created by linking a 3D model with a planning, resulting in a model that visually simulates the construction process over time. Trough visualization of construction process, 4D offers many benefits such as work process optimization, rework reduction, increased errors detection, construction time reduction, and better communication among stakeholders [4]. Thus, 4D can be crucial to improve collaboration, decision making and reduce misinterpretations among teams.

While BIM's adoption and use in coordination meetings are growing, 4D's remain low. Despite its numerous advantages and potential uses, it is still mainly used as a visualization tool [6]. Researches have identified softwares' visualization issues as a barrier to 4D adoption at the individual level [7].

This paper is organized as follows: Section 2 gives an overview of related works on 4D's flaws and usability issues. Section 3 presents the creativity method, tools used and participants. Section 4 presents and analyzes the results of the creativity session. Section 5 concludes the paper and give an outlook of future work.

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II. RELATED WORK

Some studies have sought to identify the usability issues of 4D softwares that limit their adoption. Guevremont and Hammad [6] and Castronovo, Lee, Nikolic and Messner [7] provide an overview of 4D issues. Through semi-structured interviews of AEC professionals, they found, among other issues, that there is a lack of visualization and interaction standards, such as common color coding, information filtering (i.e obtaining a precise information about a mechanical object), zooming to visualize precise spatial information or modifying the graphical level of detail. Both studies propose guidelines to enhance 3D models and schedule representation of 4D models.

Others researchers have been focusing on observing and analyzing the interaction between stakeholders and artefacts during coordination meetings from an ethnographic point of view [8].

In their study on the use of 3D and 2D digital, or paper, artifacts during coordination meetings, Mehrbod, Tory and Staub-French [8] identified the navigation between artifacts as the major problem. When solving a problem, actors spend a large part of their time navigating between 2D and 3D artifacts searching for more detailed 2D views, trying to obtain measurements and trade-specific information or even annotating documents. These navigation difficulties, as well as the lack of visualization and interaction standards, greatly slow down the collaboration and decision-making process during coordination meetings.

In summary, few studies have attempted to determine the AEC professionals needs about the use of 4D for scheduling purpose through the use of user-centered methods on all stages of the design process. Among them, none have described how users' needs have been used to generate and provide professionals with adapted solutions. In this paper, we present a collective creativity method used to generate functionalities that meet users' requirements.

III. SCOPE OF PROJECT AND METHODS

This paper describes part of a research project, 4DCollab [9], which involves the use of a collective creativity method to produce new 4D features. The project objective is to develop, through a user-centered methodology, a synchronous and co-located collaborative tool to help AEC professionals with site planning in the pre-construction phase. Using BIM and 4D technologies, the tool should improve communication, decision-making and information sharing between the various stakeholders. To tackle the identified issues, user needs were determined through a user-centered approach by first conducting semi-structured interviews with professionals in order to collect data on their individual and collective practice with 4D tools. Then, a multimodal analysis of speech gestures, exchanges and interactions around 2D, 3D and 4D documents during coordination meetings was performed. The data collected highlighted the main obstacles to the adoption of these technologies, as well as their main advantages. These data were then used to define the framework of a creativity session.

A. Means of the creativity process

In accordance with Parjanen [10], we define collective creativity as an approach of creative activity that emerges from the collaboration and contribution of many individuals so that new ideas are produced collectively by individuals connected by the common concern. Once the subject is defined (in our case, it is centered on user needs), the course of a collective creativity session is designed around an alternation of divergence-convergence. Thus, the creative process is structured in 4 main phases: an analysis phase, a divergent phase, a convergent phase and post workshop, a synthesis phase (Figure 1).

The objective of the divergent phase is to move away from the subject by diverging through exploratory reasoning. Its purpose is to produce new, unexpected, even crazy ideas. They can be lifted in this way, as their potential links with the subject have not yet been highlighted. The role of the convergence phase is then to bring the subject (user needs) and these ideas together in order to be able to respond to the problem at hand. Once this rapprochement is achieved, the term "crazy" ideas may then disappear and give way to "interesting" ideas to solve user needs. Our collective creativity action (during 2 continuous half-days of work) aimed to explore the theme of "new functionalities to share knowledge with others" and to formalize as many idea sheets as possible.

B. Participants

The working group was made up of 13 people (3 women and 10 men) from different professions: 2 architects, 2 computer scientists, 1 building construction professional, 1 researcher in architecture, 1 researcher in psychology, 2 mecanical engineers, 2 programmers in BIM, 2 software editors.

IV. RESULTS

The creative process was structured in 4 main phases : an analysis phase, a divergent phase, a convergent phase and a synthesis phase. The analysis phase was carried out using a purge tool (in our case, we used the mindmapping tool [11]. The purpose of the purge is to define the scope of the group's understanding of the initial subject. The purge resulted in a representation of ideas and concepts in the form of a Mind map which allowed the emergence of generic work themes. 14 thematic areas comprising a total of 68 items emerged.

The divergent phase opened up the initial topic by drawing from other areas concepts, notions and ideas that could later feed into the initial topic. Three tools were used: "Hot Potato" [12], Brainstorming [13], and then Analogy [12]. The initial questions were "What evokes for you the words : Compare, Appreciate, Confront, Bring together,...?" and "How to facilitate an instructive discovery in a city abroad ?". The convergent phases focus on returning to the initial subject by integrating the elements found in the divergent phase. It is during these phases, provoked at different moments of the creativity session, that the creativity group collectively brings out 38 embryos of ideas. An "idea embryo" is the first step of an idea explained by a member of the creativity group to the

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other members in the form of a drawing. "Idea embryos" are most often generated during the phases of divergence and convergence.

The selection (by voting) and classification of ideas allowed the identification of 12 embryos of ideas that most caught the attention of the members of the working group. The drafting of 8 of the 12 idea sheets was carried out in groups of 2 or 3 people (Figure 2). A total of 46 idea sheets were produced, 8 of which were produced directly by the group during the creativity session.

For the 4DCollab project, idea generation (one of the results of collective creativity) is not an end in itself. A synthesis of the results was presented visually in a CK (Concept-Knowledge) Tree [14][15] (Figure 3). The classification "by families of Idea sheets" was carried out (after the session by the facilitator) with the formalization of C tree (concepts). This is intended to provide a vision of the links between the sheets produced as well as an overview of the fields explored (and not explored) by the group's production.

V. CONCLUSION AND FUTURE WORK

In this paper, we have discused 4D's issues that limits its use by AEC profesionnals and how user-centered methods can be used to resolve those issues. We have presented and defined a user-centered method, based on the principles of the collective creativity, that we used to generate new 4D functionnalities adapted to users' needs. From a quantitative point of view, 14 thematic areas (including 70 items) emerged during the analysis phase and were presented in a Mindmap. During the creative production phase, 38 ideas were generated. They open up new ways of solutions, complementary to existing "main stream" solutions. The collective creativity session was centered on user needs and its conception was organized around successions of divergence/convergence. The group of professionals participating in the session generated a total of 38 ideas. 12 of them were evaluated by them as the most interesting to meet the user needs of "new functionalities to share knowledge with others". Following this collective creativity session, some of these new functionalities were also evaluated as relevant from a business point of view. These were developed and implemented on the first version prototype, whose usabilility is being iteratively evaluated with the user testing method.

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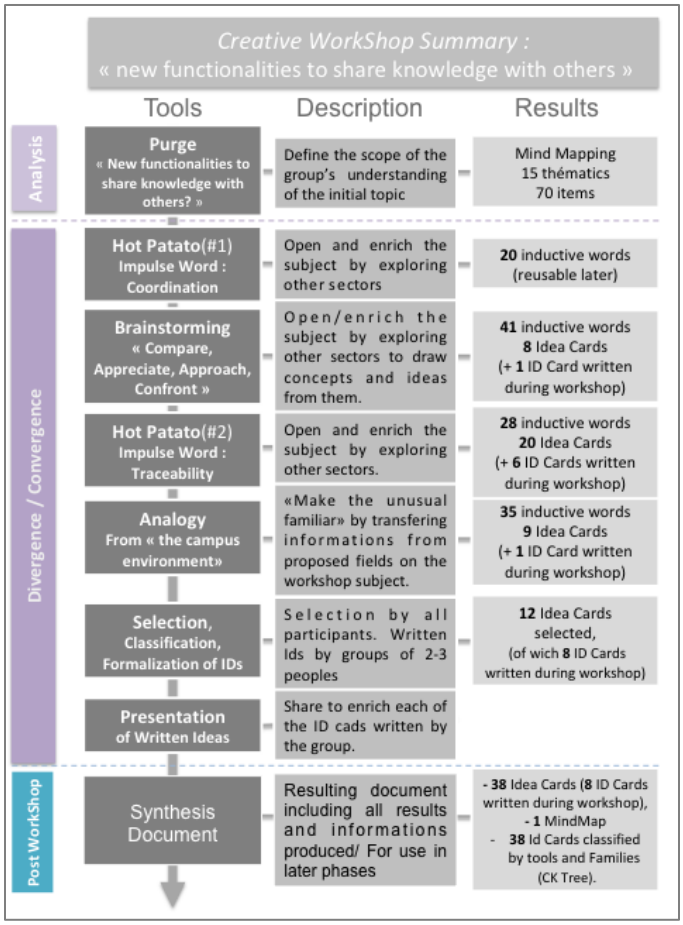

Figure 1. Visual summary of the creative process used for the workshop

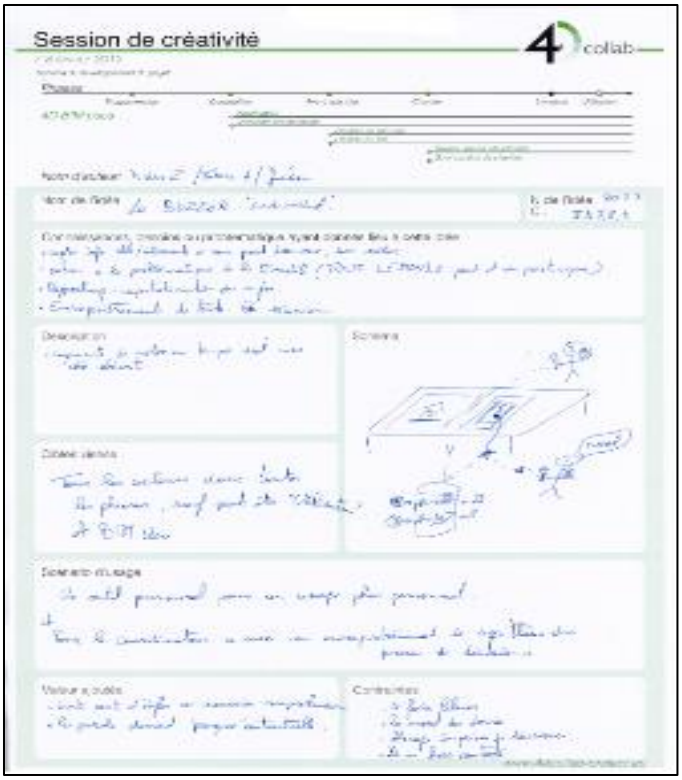

Figure 2. Example of Idea sheet (PAT 7-8-9) written by a group during the workshop (see d) in Fig.2)

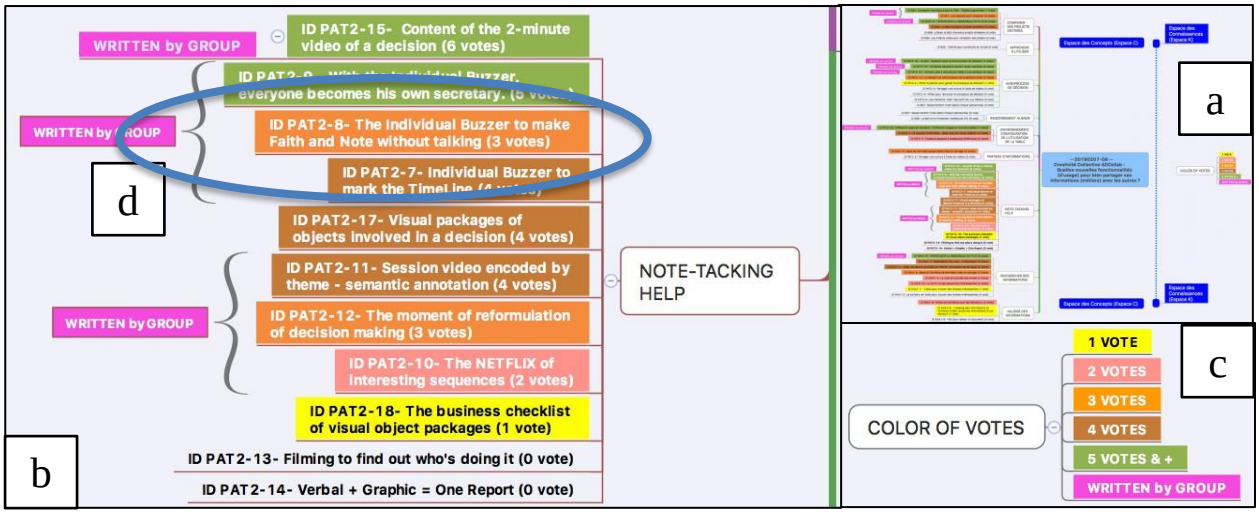

Figure 3. CK Tree : Classification "by families of Idea sheets" :
a) Global view of CK tree, b) Detail of a family, c) Caption, d) Example of Idea sheet written (detail in Figure 2)

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