A PROFESSIONALS TRAINING CURRICULUM FOR 4D BIM IN CONSTRUCTION CONSULTANCY FIRMS

Graduation Project

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UNIVERSITY OF TWENTE.

COUNT & COOPER

A PROFESSIONALS TRAINING CURRICULUM FOR 4D BIM IN CONSTRUCTION CONSULTANCY FIRMS

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PREFACE

This report is written to summarise the research that has been conducted as the final stage of the master programme of Construction Management and Engineering in University of Twente, the Netherlands. The research has been conducted within Count and Cooper Consultancy B.V. and focuses on 4D BIM and the development of a training curriculum for construction consulting companies.

This project is the last milestone on my student life which was a great journey full of challenges and opportunities. Of course, I could not have made it without the valuable help of several people that were there eager to support me whenever this was necessary.

First, I would like to thank my supervisors from University of Twente, Farid and Leon who were there through the whole process to guide me, bringing me back to the right line with their feedback and helping me look always one step further towards better results. I would also like to thank Hans for keeping an overview with his experienced eye on my work.

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SUMMARY

4D BIM is an emerging technology in the construction sector that does not only require the use of new software tools but also the adoption of a new process for planning the construction activities in 4D. Previous research and professional trainings focus explicitly on the software aspects related to 4D BIM as a tool. The aim of this research was to design a training curriculum for acquiring both software and process related competencies to assist implementation of 4D BIM in construction consulting firms. The design process consisted of three discrete phases. During the first phase eighty – seven (87) 4D BIM competency items were revealed with the help of professionals. These were categorized in competency topics under six competency sets that are the same (competency sets) proposed in research for BIM competencies exploration. In the second phase, educational research outcomes, describing the steps and the process for developing a training curriculum in detail, have been employed to propose a process-oriented, on-the-job training. The training consists of three levels of 4D BIM competency and is organized in nine training modules that combine a training session of 3,5-5 hours with an on-the-job assignment to be completed within the time frame of 1 or 3 months. In the last phase an evaluation step has been taken in order to evaluate the relevance and the perceived validity of the proposed training curriculum by different professionals and training experts. The proposed approach has been considered relevant not only for consulting firms but for a broader audience in the construction sector after some modifications. The evaluation of the perceived validity has a positive outcome as well. However, full implementation would be required to measure the efficiency of the training based on the learning outcomes. The current study aims to assist construction consulting firms develop in-house training activities in order to act as 4D BIM champions in the construction sector. The steps of this design research approach have been explicitly documented in order to provide the base for future research in construction professionals training. The proposed way of coupling professionals experience with educational science, could result in training activities for accelerating the digital transformation of the construction industry.

INTRODUCTION

The latest years, the construction domain is focusing strongly on digitalisation in order to ensure that the benefits for increased productivity will be fully leveraged and that the construction sector will be able to keep pace with innovation. It is estimated that all construction firms will run completely digital within the next 10 years. The main step towards digital construction was the development of Building Information Modeling (BIM), since 2002, that has been referred as the backbone of the industry's digital transformation (World Economic Forum, 2018).

As BIM can be defined a "*digital representation of all the physical and functional characteristics of a facility*" (Ding, Zhou and Akinci, 2014). However, it is important to emphasise that BIM should not be perceived only as a tool for 3D CAD. The BIM approach is based on the modelling of 3D objects, that integrate all information regarding the geometric but also the functional properties, though the entire life cycle of a facility. This makes BIM more than an advanced tool for 3D design as it can assist the communication of information and therefore the decision making, through the entire life of a construction project (planning, design / engineering, construction, operation) (Ding et al., 2014). Therefore, considering the broader character of BIM, this could be better defined as a "*collaborative process*" (World Economic Forum, 2018) and precisely "*the process of generating and managing information about a building during its entire lifecycle*" (Kassem, Brogden and Dawood, 2012).

One of the latest applications of BIM with significant impact on the design and the construction phases of large-scale projects, is the ability to add time as a fourth dimension in the BIM (model), known as 4D BIM. By that is simply meant the animation of the 3D objects in a 3D BIM (model) based on their construction sequence, on the exact time that is defined by the construction schedule. At this point, it is necessary to clarify that there are several ways of producing a 4D visualisation of a construction project, that do not necessary involve the concept of BIM. Already, 10 years ago Allen and Smallwood (2008) proposed the use of 4D planning (without referring to BIM yet) in order to achieve highly efficient construction schedules and clarity in communication. However, when talking about 4D BIM, it is specifically meant the visualisation of the construction tasks' sequence by matching the objects of a 3D BIM (model) with their corresponding activities in a construction schedule. 4D BIM, results in the development of a visualised construction schedule that integrates all assets of a BIM (model). However, the character of 4D BIM doesn't involve only the software tool for visualisation, but a whole new process for developing a construction schedule.

A 4D BIM (model) enables all parties involved in the design-engineering and the construction phase of a project to closely examine through a visualisation the construction process. In this way, better understanding and improved decision making can be achieved (Gledson and Greenwood, 2017). With the visualisation of the construction sequence, practitioners can identify problems, inefficiencies and mistakes of the construction schedule in a virtual setup and proceed with adjustments before these occur in real life. At the same time, the process of developing a construction schedule itself, can be improved when done with 4D BIM. Within the planning process, several activities can benefit from the use of 4D BIM: identification of the construction tasks, recognition of the logical dependencies and collective decision making regarding the construction sequence, gathering of information and evaluation of the duration of the tasks and finally communication of the overall construction plan and different project timelines (Bolshakova, Guerriero, Carvalho and Halin, 2019; Gledson and Greenwood, 2017; Trebbe, Hartmann and Dorée, 2015). Due to the fact that the value of 4D BIM has been widely recognised by practitioners, the last years there is significant effort to reveal the factors that would trigger it's adoption by the construction sector (Gledson, 2015; Gledson and Greenwood, 2017; Sediqi, 2018).

Knowledge and skills as a barrier for 4D BIM adoption

As part of BIM and the broader digital transformation of the construction industry, the adoption of 4D BIM does not come easy. One of the three main action areas for accelerating BIM adoption in the construction sector is the enablement of all stakeholders (World Economic Forum, 2018). Enablement involves actions for improving skills, changing processes along with the use of new technological tools and ensuring long-term commitment and financing. One of the biggest challenges when trying to upskill the construction sector is that the digital transformation should take place, while maintaining a competitive and operational position within the market. Construction consulting firms usually consist of people who have a higher level of education and work within temporary organisations responsible to provide know-how for the delivery of large infrastructure projects (Kreitl and Oberndorfer, 2004). Since the reliability of a construction consulting firm depends on the ability of their professionals to deliver advanced services for on-going projects, the upskilling process is significantly challenging. This becomes clearer when looking at the challenges that occur not only within the organisation (intra-organisational) but also among the different organisations of a project coalition (inter-organisational).

In an intra – organisational level, challenges with the 4D BIM implementation occur on the adoption of software tools but also on the ability of people to adapt within the process. It is obvious that 4D BIM practitioners need some technical knowledge for using multiple digitisation features and various 4D planning software tools (Allen and Smallwood, 2008). But what is also required, similarly to other BIM specialisations, is an amount of discipline specific skills (i.e. creating construction schedules) and soft skills (i.e. collaborating efficiently with different disciplines) in order to be able to overcome challenges that come up in their everyday practice. Davies, McMeel and Wilkinson (2015), pinpointed the need of employees to have advanced personal and interpersonal skills to collaborate efficiently and manage conflicts within the BIM process, and the need for thorough understanding of the project management tasks linked to their roles.

At the same time, in an inter-organisational level the difference on BIM maturity and 4D BIM readiness among the members of the project coalitions, causes several challenges for construction consulting companies that aim to act as early adopters of 4D BIM. This is because the quality of a 4D BIM (model) highly depends on information provided by different members of a project coalition. The 3D BIM (model) is usually provided by members of the design team and the information related to the Work Breakdown Structure (WBS), the sequence and duration of the construction activities is usually provided by the contractor(s) or the different subcontractors. Boton et al., (2015), report that due to lack of BIM readiness of the 3D model and relevant interoperability issues, it is often the case, that the worktime investment for the preparation of 4D BIM can be very high. It is a common issue that the effort required in order to align the level of detail between the different inputs, can be significantly demanding. Often the elements of the WBS are not at the same level of detail with the 3D design, that has been prepared by a different company. Therefore, there is need for additional work by the 4D modelers to prepare detailed tasks that correspond to the 3D objects (Boton et al., 2015). Furthermore, it is possible that the 3D BIM (model) cannot be used directly but only after several modifications or it may not even be possible to be used at all (Disthikar, Jayasena and Ariyachandra, 2016).

Both in an inter-organizational and an intra-organisational content, two components become clear regarding the knowledge and skills required for accelerating the adoption of 4D BIM: the learning of new digital tools (software) and the adoption of a new way of working (process). Adriaanse, Voordijk and Dewulf (2010), identified that knowledge and skills – regarding the use of the technology - as one of the

four mechanisms that influence the adoption of ICT[1] innovations, in the construction sector and therefore the adoption of 4D BIM. In that context, knowledge and skills refer to the ability of the different actors to act within the new ICT procedures (process) and operate the application (software) (Adriaanse et al., 2010). At the same time, Gledson and Greenwood (2017), identified as main factors influencing the adoption of 4D BIM, the compatibility of the new process with the current process and the ability to experiment with the tool (software) before applying it in ongoing projects. Therefore, any attempt to approach 4D BIM related knowledge and skills, it is necessary to consider the process character of 4D BIM.

Aim of the study

There are no previous studies (to our knowledge) that have been exploring 4D BIM abilities in a way to include both software and process related knowledge and skills. However, there is previous research in the broader field of BIM abilities, in which the term competency has been used to address holistically knowledge, skills and personal traits to be acquired for successful BIM implementation (Barison and Santos, 2011; Giel and Issa, 2015; Succar and Sher, 2014; Succar, Sher and Williams, 2013). The term competencies, has being used to describe all the three components of "*personal traits, professional knowledge and technical abilities required by an individual to perform a BIM activity or deliver a BIM-related outcome*" (Succar et al., 2013). This definition is also being used within the scope of this study to describe competencies required to perform 4D BIM activities for delivering 4D BIM outcomes.

The identification of specific 4D BIM competencies and the development of a 4D BIM competency framework was one of the first aims of this study. Succar et al. (2013), have developed a framework for BIM competencies assessment, acquisition and application. This framework consist of competency tiers, sets and topics to assist the classification and the analysis of the competencies. The way that the competencies have been described and classified in the research by Succar et al. (2013) has been used as a base for this project. However, the scope of the competencies' exploration within this project, is narrowed down to only 4D BIM related competencies. Therefore, the framework by Succar et al. (2013) has been adapted by the researcher and an alternative conceptual version has been proposed to make it suitable for the 4D BIM competencies exploration. Specifically, due to the fact that 4D BIM has been considered a process that includes but requires more than just execution, software-related competencies, the exploration of the competencies required for 4D BIM has been focused on the domain tier, as described by Succar et al. (2013).

Additionally, a need has been identified, for the development of a systematic training for professionals in the construction sector, regarding 4D BIM, and the corresponding software and process related competencies. The development of individual competencies of the employees has been recognised as one of the ways for achieving organisational competency (Succar et al., 2013). For accelerating BIM adoption it has been recommended for companies to collaborate with professional providers or academia in order to develop upskilling courses, either on the job or in the classroom (World Economic Forum, 2018). However, the existing trainings for 4D BIM have been significantly overlooking the above-mentioned process aspect of 4D BIM as they have been developed mainly by the software providers and therefore, they focus particularly on the software skills. Furthermore, although there are previous research studies regarding the development of complete BIM training curriculums (Abdirad and Dossick, 2016; Barison and Santos, 2014; Puolitaival and Forsythe, 2016; Succar et al., 2013), these have been only addressing 4D BIM in an introductory level or as a "good to know" visualisation technique. Nonetheless, most of that research for BIM trainings, has been developed with the aim to assist academic education, which differs

[1] ICT: Information Communication Technologies

significantly from practitioner's education.

This study aims to propose a professionals' training curriculum for acquiring both software and process related competencies for 4D BIM in order to build organisational competency and consequently contribute to successful 4D BIM implementation in engineering consulting firms. This project builds on previous work regarding BIM competencies assessment, acquisition and application (Succar et al., 2013) and extends it by proposing a detailed 4D BIM competencies framework. An extensive listing of 4D BIM competencies has been created with the input of professionals working in the 4D BIM process. Based on it, a systematic and holistic training approach has been proposed for acquiring the identified competencies.

The main research objective of this study is to design a training curriculum for acquiring both software and process related competencies for implementing 4D BIM in construction consulting firms. Within this objective, there are two main research questions that will be answered: (1) Which are the specific 4D BIM competencies that practitioners need for successful 4D BIM implementation? (2) Which should be the features (modules, learning and assessment method) of an on-the-job training for acquiring 4D BIM competencies?

Structure of the report

Chapter 2 presents the overall methodology and the study setting and the methodological steps in each of the different phases of this project. Chapter 3 presents the results of the competencies exploration and the detailed design of the training and Chapter 4 presents the results of the validation. Chapter 5 includes a discussion of the results. Finally, chapters 6 and 7 analyse the limitations of this study and summarise some concluding remarks.

METHODOLOGY

In order to approach the above-mentioned research objective, a design research methodology has been followed. Specifically, the Integrative Learning Design (ILD) approach, developed by Bannan-Ritland (2007), has been applied. The ILD framework differs from any traditional design research methodology since it does not focus specifically on answering questions about how the technology could be improved. The main aim of an ILD research is to emphasize on generating knowledge about cognition, context and culture of use of the technology through the design process of a training curriculum (Bannan-Ritland, 2007). Therefore, ILD can be considered a suitable approach in the context of this study, that has the aim to design a training for professionals, that covers 4D BIM competencies that have been revealed through the design process itself.

The ILD framework consists of multiple phases and cycles of integrated research and design. Through these cycles knowledge is generated about factors related to learning, context, culture and technology that influence the design process (Bannan-Ritland, 2007). Within the scope of this project, three discrete phases have been covered: an informed exploration of the 4D BIM competencies, an enactment of these competencies into a curriculum design and an evaluation of the overall design (Figure 1). The research integrates exploratory, construction and empirical methods and it consists of at least one complete design cycle. The method for collecting, analysing data and making design choices based on the results, is described in more detail in each the following sub-chapters.

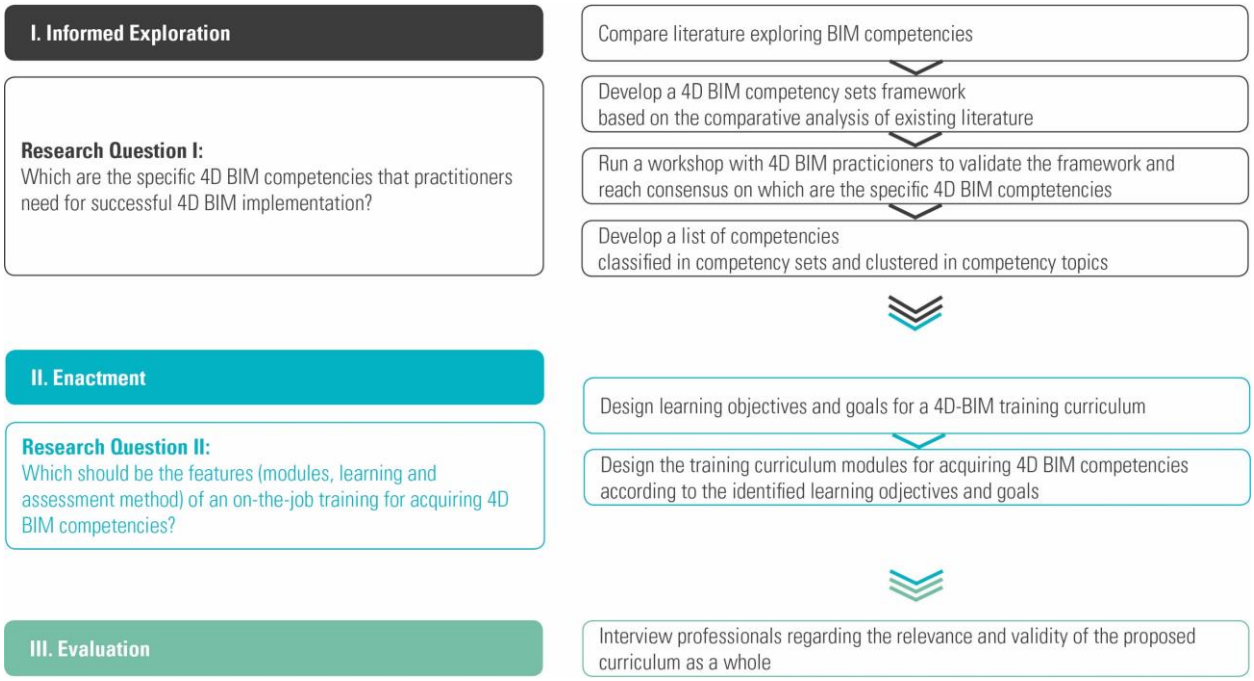


Figure 1. Detailed methodology

Study Setting

As it has already been discussed, when it comes to the successful implementation of the 4D BIM process, the problem of bridging the skills gap should not only be examined in an inter-organisational level but also in an inter-organisational level. This study focuses on building 4D- BIM competency in an intra-organisational level, due to the potential this could have for solving inter-organisational challenges of 4D BIM implementation at the same time. Companies that have already realised the value of 4D BIM and act as early adopters have benefits by the development of 4D BIM competency. Firstly, they can ensure competitive advantage within the construction market, for providing high quality digital project management services, when at the same time they can maintain flexibility to work with partners who are not familiar with 4D BIM yet. Secondly, acquiring solid 4D BIM competency, can bring the company to a power position taking the lead and envision, coach or educate partners and suppliers regarding the adoption of 4D BIM in future projects.

Count&Cooper Consulting bv, has been used as a study setting, where the 4D BIM competencies have been explored and a training has been developed for acquiring them. Count & Cooper is a company with about 35 employees, providing services for winning tenders and realizing successfully large-scale infrastructure projects (megaprojects). When it comes to the realization of megaprojects, these are characterized by a wide scope and a high-risk profile. The mission of the company is to ensure on time and within budget delivery of the projects, advancing the use of 4D BIM applications. Count&Cooper projects are fully developed virtually before the work starts on site. The aim of the company is to develop a complete and accurate 4D BIM (model) for every project, in order to maximise the benefits of 4D BIM for:

- minimizing risks by discovering early mistakes before the construction starts
- making realistic estimations regarding tasks duration, cost and risk, based on model data
- making the construction schedule tangible and optimising decision making
- improving communication and minimizing the room for interpretation of the planning among internal or external parties (both during the design and the construction phase)

The company acts as an early adopter of 4D BIM, therefore all the current company projects have been developed in 4D BIM. As a construction consultancy, the role of the company within project coalitions is to provide services that cannot be covered by the in-house capabilities of the rest of the project partners. Development of the digital construction, part of which is 4D BIM, is one of these knowledge and expertise gaps that the company fills in. However, at the same time 4D BIM can only be developed based on the information that is provided by other partners (designers, contractors and subcontractors). Consequently, it becomes clear that the role of Count&Cooper within project coalitions is very dynamic and requires continuous interaction along the process of 4D BIM.

Methodology for informed exploration

During the first phase of the informed exploration, four discrete steps (Figure 2) have been followed to approach an answer to the first research question: "Which are the specific 4D BIM competencies that practitioners need for successful 4D BIM implementation?" The first two steps were a theoretical exploration during which relevant literature was reviewed and a theoretical framework for the 4D BIM competencies has been developed. The theoretical framework was then validated through a 4D BIM competencies exploration workshop with practitioners. Based on the input of the professionals during the workshop, a detailed list of competencies classified in competency topics has been created as the final deliverable of this phase.

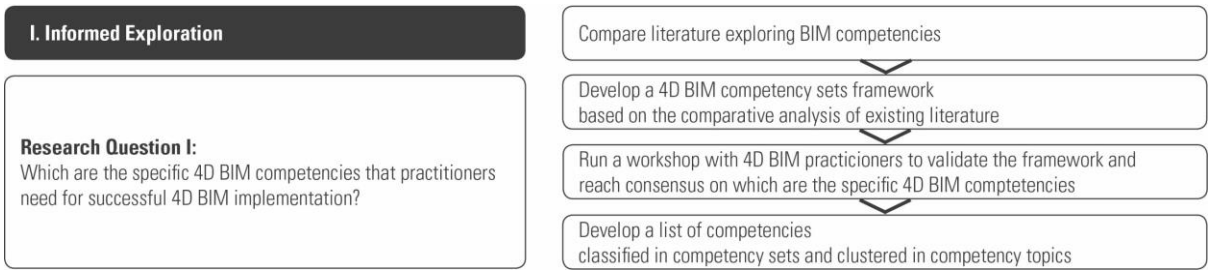


Figure 2. Phase I: Informed exploration

1.1.1 Theoretical exploration

Literature review

Initially, four different studies, exploring BIM competencies, have been compared in terms of the targeted BIM user group, the sources of the competencies, the focus of the competencies' identification (overall / specific role / specific skills) and the structure of the classification categories. These studies had the significantly broader scope of BIM competencies identification and they are barely referring to specific 4D BIM competencies. However, they have been considered sufficiently suitable for setting a conceptual framework for exploring 4D BIM competencies. The conceptual framework adopts the level of competency sets from the BIM competencies identification and has been adapted to assist a more focused exploration of 4D BIM competencies. The main results from the literature review have been summarised in the table below (Table 1).

Table 1. Literature comparison

Parameter		Framework for Evaluating the BIM Competencies of Building Owners (Giel and Issa, 2015)	Soft skills requirements in a BIM project team (Davies et al., 2015)	An integrated approach to BIM competency assessment, acquisition and application (Succar et al., 2013)	The Competencies of BIM Specialists: A Comparative Analysis of the Literature Review and Job Ad Descriptions (Barison and Santos, 2011)
Year of research		2015	2015	2013	2011
Targeted BIM user group		Facility owners	BIM Project Teams	BIM individuals within project teams	BIM Managers in AEC
Sources of competencies		Academic Literature Review Delphi Expert Panel	Interviews with 45 BIM Specialists	Job Advertisement Descriptions, Documents describing BIM-Roles, Academic Literature, Formal Skill Inventories, Interviews with Experts	22 Job Ads 24 Academic Literature Articles
Focus of identification		Relevant for Facility Management	Soft Skills	Overall BIM Competencies	Overall BIM Competencies
Classification of competencies	**Competency Tiers**	--	--	• Core Competencies • Domain Competencies • Execution Competencies	--
	Competency Sets	• Operational Competencies • Strategic Competencies • Administrative • Competencies	• Soft Skills • BIM Technical Skills • Discipline Specific Skills	• Technical • Operation • Functional • Implementation • Administration • Supportive • Research and Development • Managerial	--
	Competency Topics	(for each set) Such as: BIM Deliverable Evaluation - Data Richness, BIM Deliverable Evaluation - Geometry, Documentation, Project Procedures etc.	(for soft skills only:) • Communication • Negotiation and conflict management • Authority and leadership • Attitude	(for each set) Such as: Documentation and detailing, Capturing and Representing, Collaboration, Standardization templates Risk Management, General IT Support, Change Management, Leadership etc.	• Aptitudes • Education • Skills and abilities • Experience • Attitudes
	Competency Items	(for each topic)	(for each topic)	(for each topic)	(for each topic)
Number of Topics		14 BIM Competency Topics	4 BIM Competency Topics	55 Competency Topics	5 Competency Topics
Number of Competencies		59 BIM Competency Items	5-6 Mentioned (not listed)	55 Competency Items	57 Competency Items
Specific 4D BIM competency items		--	--	Presentation and Animation: Generate professional-quality renderings or 3D animations using Specialized Software Tools; Simulating and Quantifying: Use software tools to conduct various types of model-based simulations and estimations	Skills and abilities: Using scheduling tools, clash detection, 4D simulation, logistics, safety planning

As it can be noticed in Table 1 the amount of studies that have been carried out on the topic of BIM competencies is relatively limited. The most elaborate analysis has been performed by Succar et al., (2013) and it includes the identification of 55 competency items classified in competency sets and topics. What is interesting to mention, is that from the four studies, only two (Barison and Santos, 2011; Succar et al., 2013) have approached the topic of BIM competencies in a holistic way. These are the only two studies that have been exploring competencies of employees working with BIM in all the three aspects of knowledge, skills and competency traits. The study by Giel and Issa (2015) is targeted on competencies relevant for facility owners and the study by Davies, McMeel and Wilkinson (2015) is only exploring soft skill requirements for BIM project teams. The study by Succar et al. (2013) uses several means for the identification of these competencies while Barison and Santos (2011) are listing only competencies that could be found in job descriptions and academic articles.

Only two of the studies mention competencies specifically related to 4D BIM, and these are described in a rather general statement. For example Succar et al. (2013) under the competency topic of "Presentation and animation" mention as a competency item: "Generate professional-quality renderings or 3D animations using Specialized Software Tools". This description does not mention specifically 4D BIM besides the fact that 4D BIM can probably be considered as a "Specialised Software Tool". At the same time, Barison and Santos (2011), under the term of skills and abilities mention the competency of a 4D simulation. This is way more specific description and it clearly indicates one of the specific 4D BIM tasks.

However, not all studies have been classifying BIM competencies in a similar comprehensive way. The development of a competency classification framework for 4D BIM, has been important towards the next step of the 4D BIM competencies exploration. The classification framework of (Succar et al., 2013) has been considered the most complete and extensive one. It includes four levels of classification in which the competency items can be found under competency topics, competency sets and tiers (from bottom to top). As it can be observed in Table 1 the identification of the competencies in the other three studies can fall under the same levels proposed by Succar et al. (2013). However, the identified elements in the other three studies only cover partly the levels of competency sets and topics and non-of them mention competency tiers. Therefore, the classification framework introduced by Succar et al. (2013) has also been used for the exploration of the 4D BIM competencies in this project after it has been adapted to address the more narrow scope of 4D BIM competencies.

Theoretical competencies framework

The framework of Succar et al. (2013), uses three competency tiers: core, domain and execution. The core competency tier refers to the personal abilities of individuals that enable them to perform a task or activity (speciality, overall experience, market exposure, and project experience). The domain competency tier refers to the specific professional abilities of individuals for delivering complex outcomes. Lastly, the execution competency tier refers to specific tools and techniques that individuals use to deliver their work. Within the domain tier there are 8 competency sets. Four primary competency sets: technical, functional, supportive, managerial and four secondary competency sets that appear on the overlapping of the core sets (Figure 3).

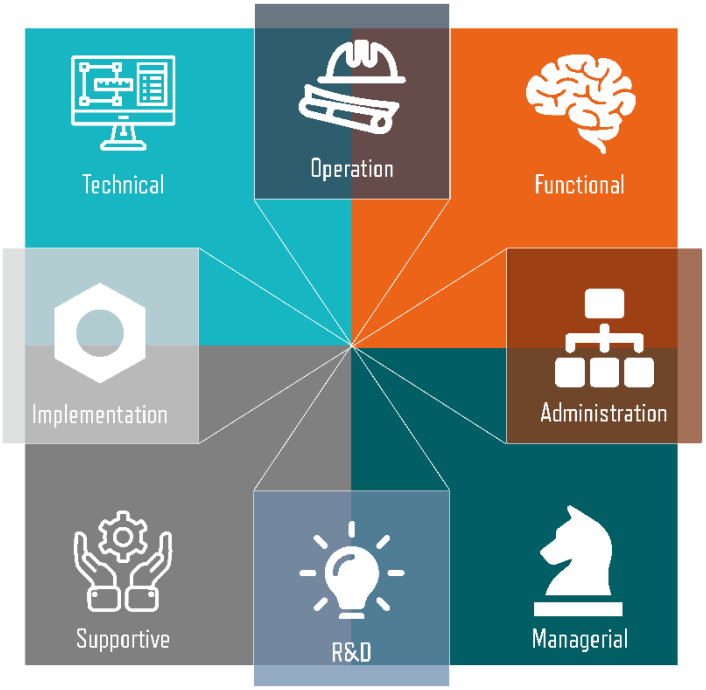
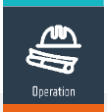
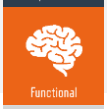


Figure 3. Domain competency tier [Redesigned: Succar, Sher, and Williams 2013]

1.1.2 Conceptual 4D BIM competencies framework

The above eight competency sets, by the definition of Succar, Sher, and Williams (2013), refer to BIM competencies only. However, they have been adapted by the researcher to assist a more focused exploration of 4D BIM competencies. The adapted description for each of the competency sets can be found in the Table 2. This has been the conceptual framework used for the classification of the 4D BIM competencies that have been identified during the next step of this project. By the end of the exploration phase, the conceptual framework has been validated in order to define up to which extend these competency sets can be used not only for identifying BIM competencies but also more specific 4D BIM competencies.

Table 2. Conceptual Framework: Domain Competency Sets for 4D BIM

Icon	Competency Set	Description	Example
	**Technical**	individual abilities needed to generate 4D BIM project deliverables across disciplines and specialties	4D BIM software related abilities
	**Operation**	daily, hands-on individual efforts required to deliver a project or part/aspect of a project in 4D BIM	project-based use of the 4D BIM software outcomes
	**Functional**	non-technical, overall abilities needed to initiate, manage and deliver projects with the requirement for 4D BIM	non-software related abilities and soft skills
	**Implementation**	activities required to introduce transformative 4D BIM concepts and tools into an organization	knowledge sharing abilities
	**Administration**	day-to-day organizational 4D BIM activities as required to meet and maintain strategic objectives	organizational and documentation abilities
	**Supportive**	abilities needed to maintain information and communication technology (ICT) systems supporting 4D BIM	IT abilities
	**Research & Development**	abilities needed to evaluate existing 4D BIM processes, investigate new solutions and facilitate their adoption - within the organization or by the larger industry	new applications of 4D BIM
	**Managerial**	decision-making abilities which drive the selection/adoption of long-term strategies and initiatives regarding 4D BIM	leadership and partnering abilities

1.1.3 Practical exploration

After the theoretical exploration, a practical exploration of the individual competencies was necessary. In a workshop with 4D BIM professionals, the required 4D BIM competencies were revealed and the conceptual framework was also validated.

The workshop was inspired by the "DesignLab co-creation toolkit" that is based on an empirical method (namely: "Science2Design4Society") (Kresin and Karreman, 2017) that enhances multidisciplinary collaboration. The method is focused on the relationships between the technology and the society and the way these can be managed or improved (Kresin and Karreman, 2017). A workshop based on this empirical method, can be applied in every step of the design process and in this case, it was used during the exploration phase with the aim to reveal the solution space. Although a brainstorming workshop set-up has been used, participants were asked not to come up with new ideas but to reflect on their personal experience and provide examples from past projects regarding the given questions. The workshop lasted 90 min in total and it had two parts with a 5 min break in between. It took place in the practitioners' office, within their normal working hours. The detailed workshop protocol can be found in *Appendix II. 4D BIM competencies* exploration workshop.

The goal of the workshop was to assist workshop participants, identify 4D BIM competences and roles. For that reason, the techniques used during the workshop are similar, to the ones used in ethnographic research and aim to help practitioners recall and reflect on their experience instead of creating new ideas. In each of the two workshop phases a different question was introduced to the participants. The first question was: "*Which are the roles that 4D planners should fulfil within the 4D BIM process in order to respond to their everyday tasks?*". It can be described as a "mini-tour" question (Gee and Ullman, 1998), as participants were asked to give a general overview and describe their experience through the 4D BIM

process based on a 4D BIM process flowchart. The 4D BIM process flowchart (*Appendix I. 4D BIM process flowchart*) has also been developed within the scope of this project and it maps the steps of the 4D BIM process within the different company projects. The development of the flowchart has been based on observations during day-to-day tasks, participation in meetings and one-to-one discussions with the company employees. The second question was: "*Which are the specific competencies that a 4D planner needs in order to overcome challenges or ensure a smoother process?"*. This can be characterised as an "example question" (Gee and Ullman, 1998) because during the group discussion, participants were encouraged to recall and provide tangible examples from previous or current projects when explaining the competencies.

To analyse the sample of participants, a short questionnaire has been created and distributed electronically (Microsoft Forms) prior to the workshop. The questionnaire was not serving only as a data collection tool for analysing the profile of the workshop participants but also as a preparatory step for the participants of the workshop (Isaksen, 2005). The answers to these open questions, have been used as a preparatory step to help participants relate with the topic of interest and recall some personal examples that they would share during the workshop. At the same time the input regarding challenges with 4D BIM has also been used to derive related competencies that may have not been revealed during the workshop.

The sample of the participants for the workshop, has been a diverse mix of 9 company employees from different disciplines, working in various company projects. The level of 4D BIM competency for each of them is different (not all the participants had hands on experience in 4D BIM models) but all of them have been involved in projects on which 4D BIM has been used. Therefore, they were able to share their experience regarding the part of the 4D BIM process that they have been involved. The analysis of the sample of participants is presented on the Table 3.

Table 3. Sample of participants for the 4D BIM competencies workshop

	N	Frequency	%
Gender	9		
Male		6	67%
Female		3	33%
Discipline	9		
Marketing		1	11%
Construction Management & Engineering		5	56%
General project management		2	22%
Civil engineering		1	11%
Job level	9		
Upper management (strategy responsibility)		0	0%
Middle management (tactical responsibility)		3	33%
Lower management (Day to day running)		6	67%
Previous 4D BIM experience	9		
One project		4	100%
Two projects		1	56%
Three projects		3	44%
Four projects		1	11%
Phase of 4D BIM projects working on currently	9		
In tendering		5	56%
Under construction		6	67%

In the workshop participated company employees that were not all highly experienced with the 4D BIM software themselves, but they were involved in the 4D BIM process before. They have been involved because if the intention of the researcher to identify skills required for the interaction among different specialists during the 4D BIM process as a whole, and beyond the software tool related skills. Specifically, the parts of the process that require interaction among different internal or external parties. Additionally, the formulation of multidisciplinary teams, was aiming to assist participants to reach consensus regarding the boundary conditions of the question and also to provide insights regarding the way their team produces knowledge and interacts in the working environment (Adams, Mann, Jordan and Daly, 2009). The above insights have been used indirectly, as input for designing a training that would fit in the company mindset.

1.1.4 Competencies listing

During the workshop, the participants' input was collected in post-it notes and different canvases for each team and each phase of the workshop. At the same time the session was being recorded in order to give the possibility to retrieve extra information from the group discussions during the results documentation. The conversations have not been transcribed but they have been used to enrich the workshop results that were documented in the form of structured minutes taken by the researcher. The same process has been followed for some extra individual meetings that were necessary before and after the workshop session with the managers and the planners that were not able to join the group session. Furthermore, the results of the questionnaires were also documented in the form of a report in order to be able to use the input retrieved with the open-ended questions.

For the analysis of the results the software Atlas.ti has been used, in which all the result-related documents from the practical exploration were imported, and every quote was coded with one of the codes: 4D BIM roles or 4D BIM competencies. Under each of these codes, sub-codes were added for the main roles identified during the workshop and for each of the competency sets of the theoretical framework. It was necessary to remove redundant results and re-allocate them in sub-codes. During the workshop some competencies were initially identified as part of different competency sets than the ones, they belong to due to the limited time that participants had for classifying them. Lastly, it was necessary to re-write some of the competency items in a way that similar quotes could be combined under a single competency definition. In this way it was also made possible to reformulate some competency items in statements that continue the sentence: "The 4D BIM practitioners should have the ability to…" in order to ensure a coherency in the 4D BIM competencies listing.

1.2 Methodology for enactment

During the second, enactment phase, the competencies that were identified in the previous phase have been used to design a 4D BIM training curriculum for professionals. During this phase three steps of action upon the previous results have been made (Figure 4) in order to an answer to the second research question: "Which should be the features (modules, learning and assessment method) of an on-the-job training for acquiring 4D BIM competencies?". The first step was to define the learning objectives and organise them into modules that would help practitioners to acquire the 4D BIM competencies. The modules and the learning objectives were internally discussed with the company management, and training methods that have been used in the past were explored. The next step was to design each of the training modules in detail. Previous research regarding the methodology for developing a training curriculum and for evaluating the training outcomes has been studied in order to proceed with the detailed design of the training. The last step was a Group A/B testing for selecting the most appropriate instructional method.

1.2.1 Preliminary design

The competencies listing, as a result from the previous phase, has been the basis for developing

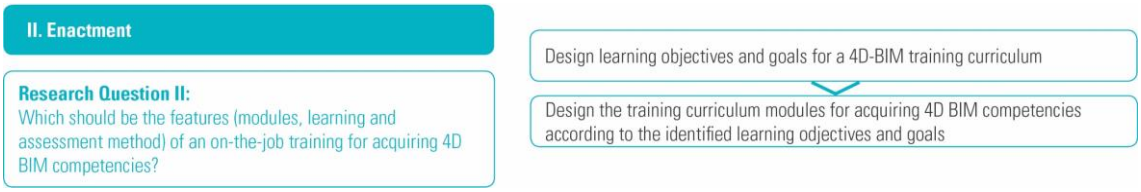


Figure 4. Phase II: Enactment

learning objectives. Each of the identified competency items has been considered a learning objective since it was not possible to be further broken-down in smaller learning outcomes. Also, only one competency item has been addressed under each learning objective to ensure that the learning outcomes could be evaluated in a binary way: achieved / not achieved. However, several learning objectives have been combined under the single learning goal of each module.

Each of the learning goals has been addressed in a different module of the training curriculum. The modules in total have been organised in a sequence of increased complexity. To achieve this all the learning goals have been categorised in three meta-levels (Table 4), as these are described in the application of Boom's taxonomy in computer science learning objectives (Starr, Manaris and Stalvey, 2008). According to Starr et al. (2008) there are three meta levels that can be identified in this adjusted bloom's taxonomy. The beginner's level emphasises memorisation and basic understanding, the intermediate level focuses on the use of the process and on the development of competencies related to the application and the expert level aims to design / create of new knowledge or criticising the current approach. Based on the three meta-levels the learning goals for each of the modules have been organised in three different levels of 4D BIM competency. The main learning tasks in each of the modules have been designed in order to address the corresponding tasks of "produce" and explain" of the specific level.

Table 4. Meta-level structure by Starr et al., (2008)

Meta-level	Produce	Explain	Aim
Beginner	Recall	Comprehension	Memorization and basic understanding
Intermediate	Application	Analysis	Use or competent application
Expert	Synthesis	Evaluation	Design or creation and critique

The preliminary design that occurred from the above step (learning objectives – goals – modules - levels) has gone through one more design iteration, during which the company management (Digital Construction Manager and Human Resources Manager) reviewed it in terms of clarity and completeness and proposed improvements. At the same time similar competencies trained in the past among the company employees were identified and the training methods that have been previously used. A pre-existing, in-house training for new employees has been reviewed and assessed by the researcher regarding its 4D BIM readiness in order to derive insights for the detailed design. The proposal of the new training has been aligned with the existing in-house training program of the company for new employees so that the results can be easily and directly applicable.

1.2.2 Detailed design

The detailed design of the training curriculum was aiming to a holistic approach that avoids compartmentalization and fragmentation of the learning and ensures higher transfer of knowledge. In order to meet these three requirements, the four-component instructional design (4D-ID) approach (Kirschner and van Merriënboer, 2008), has been followed. Within this approach, four components are described as necessary for the design of a training curriculum: learning tasks, supportive information, procedural information and part-task practise. The characteristics of each component can be found on Table 5. Each of the four components has been included in the detailed design of the modules.

Table 5. Blueprint components of the 4D-ID approach (Kirschner and van Merriënboer, 2008)

Blueprint components of 4C - ID	
Learning Tasks	• aim at integration of (nonrecurrent and recurrent) skills, knowledge, and attitudes • provide authentic, whole-task experiences based on real-life tasks • are organized in easy-to-difficult task classes • have diminishing support in each task class (scaffolding) • show high variability of practice
Supportive Information	• supports the learning and performance of nonrecurrent aspects of learning tasks • explains how to approach problems in a domain (cognitive strategies) and how this domain is organized (mental models) • is specified per task class and always available to the learners
Procedural Information	• is prerequisite to the learning and performance of recurrent aspects of learning tasks (or, practice items) • precisely specifies how to perform routine aspects of the task, e.g., through step-by-step instruction • is presented just in time during the work on the learning tasks and quickly fades away as learners acquire more expertise
Part-Task Practice	• provides additional practice for selected recurrent aspects in order to reach a very high level of automaticity • provides a huge amount of repetition • only starts after the recurrent aspect has been introduced in the context of the whole task (i.e., in a fruitful cognitive context)

The first of the four components in this approach is the formulation of learning tasks. All learning objectives have been classified in categories and learning constructs (Table 6), to ensure that it would be possible to create learning tasks that approach competencies in an integrated and holistic way. According to the classification scheme proposed by Kraiger, Ford and Salas (1993), there are thirteen different learning constructs that help to identify not only the type of the learning objectives (specific knowledge, compilation or automaticity skills, attitudinal or motivation abilities) but also the mechanisms that can be appropriate for facilitating the learning process for each objective. The learning objectives used under each of the proposed learning goals, are from more than one competency sets and they correspond to different learning constructs. Therefore, it was possible to design learning tasks that integrate declarative, procedural and affective learning and they simulate real life conditions.

After the formulation of the learning tasks, it was necessary to set the performance objectives for each leaning task. As it has already been mentioned, the learning objectives were classified in learning constructs. In that way the type of the expected learning outcomes for each learning objective was specified. The learning outcomes were firstly categorised as cognitive, skill-based or affective and then the focus of the outcome measurement has been specified for each of them (Kraiger et al., 1993). It was then necessary to select from the potential evaluation methods the most suitable for each of the learning objectives. This process of selecting the appropriate assessment methods, has been done during the detailed design of the training in order to ensure that the assessment would fit the design of the specific learning task.

Table 6. Classification scheme for learning outcomes for training evaluation (Kraiger et al., 1993)

Category	**Learning Construct(s)**	
Verbal knowledge	Declarative knowledge	Cognitive Outcomes
Knowledge organization	Mental models	
Cognitive strategies	Self-insight	
	Metacognitive skills	
Compilation	Composition	Skill-based Outcomes
	Proceduralization	
Automaticity	Automatic processing	
	Tuning	
Attitudinal	Target object	Affective Outcomes
	Attitude strength	
Motivation	Motivational disposition	
	Self-efficacy	
	Goal setting	

Supportive information has been designed based on the specific learning goals of each module. In some of the modules the supportive information covers partly some of the learning objectives of the module, the ones that are related to theoretical knowledge. Procedural information, within the scope of this project cover both information regarding the software use but also information regarding the 4D BIM process. Procedural information regarding the software, has been designed by rearranging the information that can be found in the software manuals and trainings provided by the software supplier. Procedural information regarding the 4D BIM process has been derived from the experience of professionals and it has been designed to be provided during the training in presentations and short workshops, during which participants try out the new working process.

At last, one of the most important components oh the proposed design is the part-task practice. Part-task practice has been designed as a component in each of the training sessions by the design of different assignments that correspond to the different learning tasks. Moreover, after the completion of each training session an on the job assignment has been designed in which participants have the time to practice and repeat the acquired competencies to achieve a higher level of automacity.

1.3 Methodology for validation

As the last phase of this research there is an attempt to evaluate the proposed design and propose improvements to be considered in future implementation of this training curriculum. This phase was aiming to evaluate to what extent is the proposed design valid and relevant. The ideal way to approach this research question would be to implement the training and measure the results. However, this evaluation process requires significant amount of time especially when we are talking about a training curriculum and not a single course. As an alternative an interview approach was selected. Different professionals, experienced in 4D BIM or in the development of professional trainings, were asked to provide their feedback on the detailed curriculum design in terms of perceived validity and relevance.

1.3.1 Validation Interviews

Figure 5. Phase III: Evaluation of the local impact

The detailed design of the training has been validated with the assistance of six professionals. The overall design of the training curriculum was presented to professionals with expertise either in 4D BIM or in BIM related software training. The goal of the series of interviews was to validate to what extent the design of the on-the-job training curriculum, is relevant and valid for practitioners in the construction sector that are recently involved in the 4D BIM process. Therefore, practitioners were asked to provide their feedback on two main questions:

1. To what extent do the proposed learning objectives and modules reflect needs of professionals working with 4D BIM?
2. To what extent could the proposed features (modules, learning and evaluation method) assist the practitioners acquire and apply the above competencies in a company project after the completion of each module?

Semi-structured interviews have been used for the collection of data, during this validation part of the design. An interview guide has been developed (Appendix V. Evaluation interview protocol) but it was only including the basic open-ended questions to be used as topics to be covered during the interview. The guide was not followed to the letter and different follow-up questions have been used based on the informant responses. The participants were interviewed in their own office and the interviews have been recorded. The interviews have not been precisely transcribed, but minutes have been kept by the researcher after the interview and based on the recording. Due to the degree of the structure, the resulted text of each semi-structured interview was a collaboration of the interviewer and the informant (Ayres, 2012).

The duration of the interviews was restricted to one hour due to limited availability of the participants. It was significantly challenging to ensure that the participants would be able to coherently understand

the detailed design of the training in order to be able to provide their feedback within an hour. Therefore, each participant received as an input the complete list of competencies, the overall training design and the detailed design for only three of the training modules (one from each level). Different participants received different modules to ensure that all the modules have been validated. The supportive material and the leading interview questions was shared with the participants prior to the interview.

Participants in the interviews have been selected based on their expertise in BIM software training or their experience in coordination of 4D BIM projects within their organization. In total six professionals participated in the interviews. Two of them were training experts (Participants No 5 and No 10) and four of them were responsible 4D BIM managers within their organization (Participants 1,2,3 and 4). The participants should have at least 4 years of experience on their field, they should have worked in at least 3 projects with 4D BIM (excl. the training experts) and have some hands-on experience in 4D BIM software themselves. Unfortunately, the sample of participants had only men representatives as it has been significantly difficult to find women representatives within the available time. All the details regarding the sample of participants can be found in the table below (Table 7).

Table 7. Sample of participants in the validation interviews

	N	Frequency	%	Min	Max	Mean	SD
Gender	**6**						
Male		6	100%				
Female		0	0%				
Age	6			26	52	35,2	8,5
Level of Education	6						
Vocational Education		1	17%				
University of Applied Sciences BSc		4	67%				
University MSc		1	17%				
Job Function	6						
Technical Specialist		4	67%				
Management Professional		2	33%				
Company size	6						
Small (1-49)		1	17%				
Medium (50-249)		3	50%				
Large (250+)		2	33%				
Years of experience	6			4	30	10,2	8,7
Expertise	6						
4D BIM Coordination in Projects		4	67%				
Training Expert		2	33%				

The interview notes were coded by using the software Atlas.ti, and the different quotations were categorized in three main topics of the interview discussion: comments related to validly, comments related to relevance and general comments. For each of the topics a list of quotations was prepared, from which the main result topics have been derived.

RESULTS

1.4 Results of informed exploration

The outcome of the exploration phase was an extensive listing of ninety-three (93) individual domain competencies related to the 4D BIM process. Eighty-seven (87) of these competency items, that have been identified from the data collected during the practitioners' workshop, were successfully categorized under six out of the eight competency sets of the conceptual framework, as domain competencies. However, six of the competencies that came up during the workshop were broader and not related only to the 4D BIM process itself. These include some foundational traits in the topics of: time management, digital affinity, problem solving aptitude, effective teamwork; and one situational enabler: creativity. Therefore, these competencies have been better categorized as core competencies instead of domain competencies. The core competencies have not been analyzed further as they were out of the scope of this study. After selecting the relevant competencies, the 4D BIM competencies framework had eighty-seven (87) domain competencies. The extensive list of the domain competencies classified under competency sets and competency topics can be found in *Appendix III. Competencies list*.

All the identified domain competencies have been classified (Table 8) under the two primary competency sets of technical and functional competencies and all the four secondary competency sets of operation, implementation, administration and research and development. However, there are no competencies identified related to 4D BIM, under the competency sets of Supportive and Managerial competencies. This observation can be explained because 4D BIM is part of the general BIM process of organizations and is not currently a separate core activity. This has also been confirmed during by professionals in different firms during the validation phase (see: chapter 4.1.1 last paragraph). Therefore, long-term strategy and decision-making regarding 4D BIM is usually addressed within the BIM strategy and initiatives. The same goes for the supportive competencies. Abilities to maintain and support information and communication technology systems are necessary anyway within the BIM processes of a firm, therefore it wouldn't be reasonable to be defined separately for 4D BIM. That is also the reason why these categories have been removed in the final 4D BIM competency framework.

Although no managerial or supportive competencies have been identified by the practitioners within the 4D BIM framework, some competencies have been recognized in the research and development overlap of these two competency sets (such as: write simple code lines, explore new concepts and innovative ideas regarding 4D BIM implementation). In this case, the research and development competencies of 4D BIM, can be considered as the overlap of the supportive BIM competencies (writing simple code lines for 4D BIM purposes) and managerial BIM competencies (explore new concepts and innovative ideas for 4D BIM) with the 4D BIM process. They provide a direction for the general BIM research and development competencies towards 4D BIM.

The identified competencies have also been organized in twenty-five different topics (Table 8) to cluster similar competencies and organize them in common learning themes. The competency topics for 4D BIM are not the same with the competency topics for BIM (introduced by Succar et al. (2013). Each of the 4D BIM competency topics includes more than one competency items and several competency topics can be found under the same set. The competency topics have not been used to formulate the learning goals, (during the next step) to avoid as it has been explained, compartmentalization and fragmentation of the training curriculum. Therefore, competencies of one competency topic can be found within different learning goals in the final design of the training.

Table 8. 4D BIM Competencies Identification

Tier	Set	Topic	Item (examples)
Domain Competencies	**Technical***	Software data import / export	Such as: Export schedule from different software
		3D Design Software	Such as: Draw simple 3D elements and polyline paths in various 3D software
		Basic 4D BIM Software Use	Such as: Use 3D model user fields for smart filtering
		Advanced 4D BIM Software Use	Such as: Create 3D paths in 4D BIM Software
	Operation	Data evaluation and processing (Input)	Such as: Understand the 3D elements in the model and request clarifications
		Model output use	Such as: Use 4D BIModel during meetings to provide information
		Construction engineering basics	Such as: Identify the steps and the logical sequence of the construction
		Project planning	Such as: Organize sessions to acquire more information from multiple specialists
		Construction monitoring	Such as: Keep track of the progress and time constraints
		Model updating	Such as: Access and use a changes management platform
	Functional*	Validation and verification	Such as: Facilitate and guide the validation meetings
		Interdisciplinary collaboration	Such as: Set and coordinate a network of different specialists
		Effective communication	Such as: Understand the technical terminology and jargon
		Data visualization	Such as: Translate data into workable information (presenting)
		Working flexibility	Such as: Find out alternative solutions when there is lack of information
	Implementation	Standardization	Standardize the way of working and prepare templates
		Knowledge sharing	Such as: Create manuals, roadmaps and flowcharts for 4D BIM
		Coaching	Explain the way of working and coach new colleagues
	Administration	Initial agreements	Such as: Analyze the contract and develop a 4D BIM requirements list
		Process management	Such as: Make agreements of the information exchange and format
		Information mining	Such as: Understand the project hierarchy
		Balance effort and impact	Such as: Evaluate the need and the effort for updating the model
	Supportive*	Broader BIM Set - Could not be identified for specific 4D BIM competencies	
	Research & Development	General research and development	Such as: Find out ways to optimize the way of working with 4D BIM
		Continuous learning	Adopt and learn from scratch new digital tools
		Scripting	Write simple code lines / Know a programming language
	Managerial*	Broader BIM Set - Could not be identified for specific 4D BIM competencies	

* Primary BIM competency sets according to Succar et al. (2013)

As a secondary result of this phase and as a conclusion after the validation of the conceptual framework, the adapted 4D BIM competencies framework can be found in Figure 6. It includes only six out of the eight competency sets that have been described in the initial conceptual framework, as it has not been possible to identify competencies in the managerial and supportive competency sets. Also, the description of each set has been adapted to target specifically 4D BIM competencies.

Figure 6. 4D BIM competency sets framework (Adapted from Succar et al., 2013 *)*

1.5 Results of enactment

As a result of the enactment phase, the detailed design can be found in the *Appendix IV. Detailed design on the training*. The detailed design addresses all the 87 identified competencies resulted from the informed exploration phase.

1.5.1 Three levels of 4D BIM development

The overall training curriculum has been constructed of three different levels of 4D BIM competency.

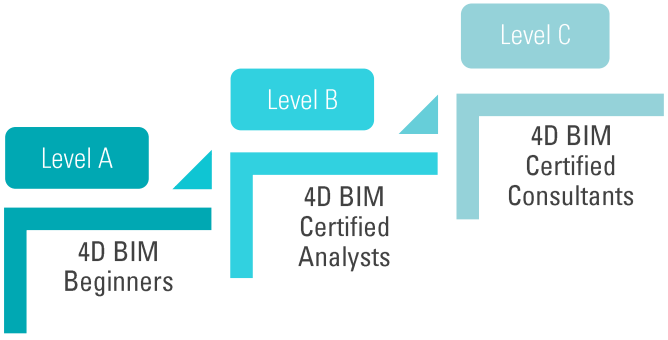


Figure 7. Three levels of 4D BIM development

Each level has been designed as a form of certification that ensures consistency in the way that the trained participants can work with 4D BIM. The levels have been aligned with the roles of a 4D BIM planner within a construction consultancy firm: beginner – analyst – consultant. The roles are mainly related to the focus of the daily job requirements. Usually people in the starting level are mainly oriented in performing and executing specific tasks and therefore the goal of the "4D BIM certified beginners" is to be able to understand the 4D BIM tools and processes and manage information that matters for 4D

BIM. Employees in the second level (analysts), are usually responsible for delivering requirements in a process level. Therefore, the goal for the "certified 4D BIM analysts" is to be able prepare and use different 4D BIM deliverables through the design and construction phase of a project. Lastly, employees in the third level (consultants) are mainly responsible to implement a shared mission and ensure successful implementation of the requirements among different parties. Consequently, the goal for the "4D BIM certified consultants" is to be able to outline the 4D BIM process and needs, solve any related problems and coach employees on their 4D BIM related developments.

The three-levels-design has two more characteristics that should be mentioned. Participants of the last level should have already acquired successfully the competencies in the other two levels. For that reason, within each level there are evaluation activities to ensure that all the required learning objectives have been met before continuing to the next. Secondly, the training design adopts a "zero-to-hero" approach. The first level does not require any previous knowledge regarding 4D BIM and by the completion of the last level it ensures that 4D BIM practitioners can facilitate the learning process of 4D BIM for employees that just start in level A. This has been considered of significant importance to ensure that practitioners will be able to work in the current transition phase of the construction industry. During this transition period the 4D BIM process is not precisely specified in terms of roles and requirements. By educating practitioners to work in an agile way within the 4D BIM process, there is the aim to ensure that they would be able to work under the unfavorable conditions that they have to face in the current learning state of their organization and of other organizations.

1.5.2 Module learning components

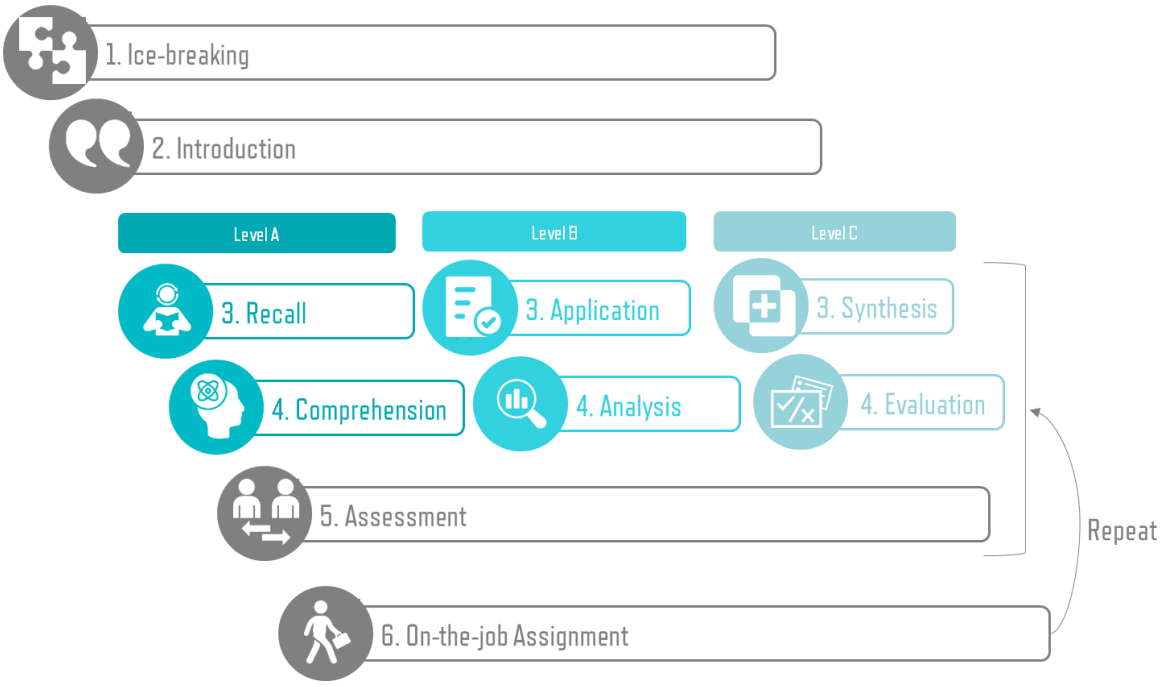


Figure 8. Module learning components

Each of the training modules has six main learning components (Figure 8). The first component is an ice-breaking activity relevant to the topic of interest that indirectly (often with a metaphor) introduces the participants to the core theme of the day. An introductory presentation follows, with the aim to provide all the necessary supportive information relevant to the task and the way it is performed, the process that it is part of and the importance of the task. The introductory presentation aims to answer four questions:

- What are the tasks are being addressed during this training session?
- Which part of the process do these tasks support?
- How are the tasks performed within the process?
- Why are these tasks particularly important?

In some of the modules (1, 2 and 3) the introductory presentation targets also some of the 4D BIM learning objectives of that modules, mainly the ones related to the process character of 4D BIM. For the rest of the modules, the introductory presentation works only as a mean for providing supportive information for the module.

After the introduction the two components of the main learning tasks are taking place. These two learning components (numbers 3 and 4 in Figure 8) involve different tasks that are related to the level of the module. As it has been explained these two components refer to the meta-levels of bloom's taxonomy (Starr et al., 2008). Therefore, in the first level, these components include tasks related to recall and comprehension, when for the second level the tasks are related to application and analysis and for the third level the tasks are related to synthesis and evaluation. The design of the tasks follows the principles of project-based learning and several types of instructional methods have been used:

- Presentation: typical lecture activity with maximum duration of 20 min in which participants watch the trainer explain a specific topic
- Workshop: mini-workshops with duration between 30-80 min have been used in this training curriculum in which participants learn to produce a product, solve a problem or apply a technique under the guidance of their trainer
- Role Play: participants gain new skills and apply knowledge by acting according to specific roles in realistic situation simulation
- Practice exercise: Individual or group assignments in which participants have to apply the skills demonstrated by the trainers using a checklist of requirements
- Demonstration: participants observe the facilitator of the session performing a task or procedure, facilitators give examples and information about alternative ways of working according to the participants questions
- Case Study: individual assignment in which participants are asked to analyses a real case and present their findings and their recommendations
- Simulation: group assignments in which participants are asked to perform a task or apply their competencies under "real life" conditions (assignment material, available means, working environment, time)
- Peer tutoring workshop: participants are asked to prepare in advance a workshop on a specified topic and act with the role of facilitator of the workshop for their peers during the session
- InterVision Session: session in which participants share a specific problem that they have encountered, get feedback from their peers and analyze the way they could treat similar problems

In all the learning tasks, participants are asked to apply and practice the acquired competencies. Therefore, the instructional methods of a presentation or a demonstration, are always combined with a practice exercise, a simulation or a role play under the same learning task. It is important to mention that the three different meta-levels refer mainly to the character of the acquired competencies and not on the type of the assignments. For example, a workshop in the first level during the recall learning task is different than a workshop in the third level during the synthesis learning task. Although they are both workshops, in the recall workshop the competencies addressed are related to learning and memorizing a sequence of steps to perform a task (e.g. visualizing data) when in the synthesis workshop the competencies aim to combine knowledge, skills and attitudes to synthesize a customized way of working.

By the end of the two main learning components, in each module there is the fifth component with is an assessment. This is the last part of a training session in which participants present the outcomes of their learning task and they receive feedback from peers and feedback from the trainers. They also receive a personal assessment matrix filled in by the trainers based on their performance on the criteria described in the evaluation scheme of each module. These criteria are based on the research of Kraiger et al., (1993), that specifies in which way cognitive, skill-based or affective outcomes can be evaluated. For the skilled-based outcomes, the hands-on testing evaluation criteria can directly be applied to evaluate the performance of the participants in the learning tasks. For the cognitive and affective outcomes, evaluation criteria have been specified that should be checked twice in the start and the end of each training session via a short questionnaire. However, more research should be required to analyze the cognitive strategies and the mental models in order to derive the right questions that address correctly each of the learning objectives.

By the completion of each training session the training module has not been completed. It is significantly important to repeat the acquired knowledge and skills in order to eliminate the percentage of it that gets lost by forgetting (Ebbinghaus, 2013). The sixth component of the on-the-job assignment is usually a case study during which participants must apply their skills in real life conditions. They are given a period of one or three months to perform their extra learning task either as a regular task within their daily work or next to their daily tasks. For the on-the-job assignment there is the same assessment matrix that should filled in by the direct supervisors of the trainees.

1.5.3 The nine modules

The nine modules (Figure 9) have been developed based on the different parts of the 4D BIM workflow. Each module includes a mix of competencies from different sets and topics that are necessary to facilitate the overall 4D BIM process and all its separate components.

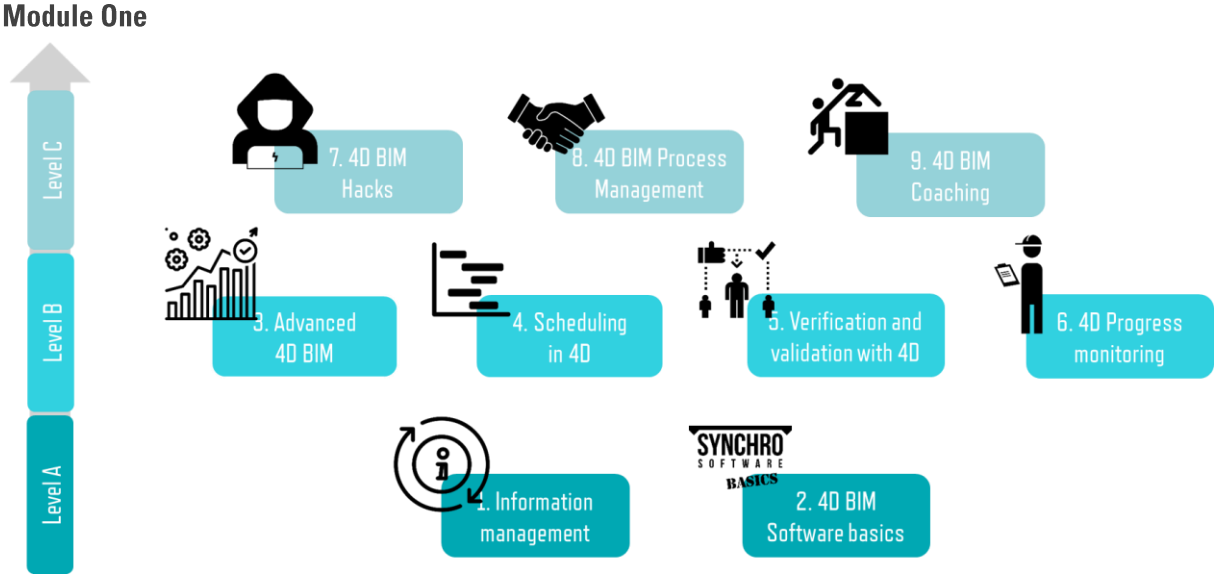


Figure 9. Detailed training design (modules)

Level A starts with the module one of information management that addresses thirteen competencies under the operation, functional and administration competency sets (Table 9). The learning goal by the completion of the first module of information management is for the participants to be able to reach, refine, and visualize information necessary for the development of 4D BIM. The training session for

module one lasts about five hours. Already from the introductory presentation, participants learn how to reach the necessary for 4D BIM information within a project coalition. During the recall part there are three different mini-workshops in which participants learn how to reach and evaluate the information in a 3D model, how they can visualize data in order to present them as information and how they can reach better understanding of complex technical structure by making sketches. During the comprehension part they work on a group assignment, in which by role playing they learn how to collect from different stakeholders all the necessary data to get a better understanding and make a simplified schedule for the construction of a complex technical structure. After the completion of the training session there is an on-the-job assignment in which participants are asked to apply the competencies gained during the session on their job within one month and discuss their progress with their supervisors.

Table 9. Module 1: Information Management

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation method
Introduction	Presentation	23	Collect information regarding the initial schedule	Skill-based Outcomes	Hands-on testing
			Identify the information needs and their sources	Cognitive Outcomes	Structural assessment
			Understand the project hierarchy and reach the right people for information	Cognitive Outcomes	Structural assessment
Recall	Workshop: 3D BIM Readiness	21	Understand the 3D elements in the model and request clarifications	Cognitive Outcomes	Power tests
		22	Evaluate the 3D models in terms of completeness based on the initial agreements	Skill-based Outcomes	Hands-on testing
	Workshop: Data Visualization		Validate data, filter the key information and distinguish the "signal" from "noise" (checking)	Skill-based Outcomes	Hands-on testing
			Translate data into workable information (presenting)	Skill-based Outcomes	Hands-on testing
	Workshop: Technical Drawing		Visualize technical structures	Skill-based Outcomes	Hands-on testing
		30	Identify the structure of complex technical systems (break them down)	Skill-based Outcomes	Hands-on testing
Comprehension	Role Play: Information Mining	24	Identify major phases that may be missing in the initial schedule	Skill-based Outcomes	Hands-on testing
		31	Identify the steps and the logical sequence of the construction process	Cognitive Outcomes	Speed tests
			Understand the technical terminology and jargon	Cognitive Outcomes	Recognition and recall tests
			Understand the work of different specializations, address everybody's expertise and contribution in the team goal	Cognitive Outcomes	Self-report measures

Module Two

Module two has the learning goal for the participants to be able to perform simple 4D BIM software tasks, understand the software logic and learn fast new software tools, buttons and procedures. Therefore, it includes mainly technical competencies (Table 10). During the introduction of module two participants also learn how to adopt a learning mindset. During the recall part there is a mix of demonstration and practice exercise activities to help participants learn the basic functions of 4D BIM software (navigation through the software, creating and linking tasks, creating appearance profiles and allocating resources). During the comprehension part, participants are asked to apply filtering based on used fields within a simulation assignment during which they are asked to work produce a 4D BIM model

for a real company project. After the training session an on-the-job assignment follows, in which participants should practice their competencies and discuss on their progress on-the-job within a period of one month after the training session.

Table 10. Module 2: 4D BIM Software Basics

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Introduction	Presentation		Find out alternative solutions when there is lack of information	Affective Outcomes	Self-report measures
			Discuss with managers about the lessons learned after the completion of a project	Affective Outcomes	Self-report measures
			Adopt and learn from scratch new digital tools	Affective Outcomes	Self-report measures
Recall	Demonstration: Introduction to 4D Software		Navigate through the 4D BIM Software views	Skill-based Outcomes	Hands-on testing
			Set and modify relationships among the project tasks	Skill-based Outcomes	Hands-on testing
			Create and use cutting planes	Skill-based Outcomes	Hands-on testing
			Create and assign clear appearance profiles	Skill-based Outcomes	Hands-on testing
	Practice Exercise: Tasks from 3D objects		Create a schedule from scratch based on the 3D elements (baseline 0)	Skill-based Outcomes	Hands-on testing
	Demonstration: Introduction to user fields		Recognize properties and user fields exist in a 3D model	Skill-based Outcomes	Hands-on testing
Comprehension	Simulation: From 3D to 4D		Use 3D model user fields for smart filtering	Skill-based Outcomes	Hands-on testing
			Allocate 3D resources on tasks in 4D BIM Software	Skill-based Outcomes	Hands-on testing
			Create and export reports (animations + frames)	Skill-based Outcomes	Hands-on testing
			Ensure that all the components are included in the schedule and they are correctly linked with a task	Skill-based Outcomes	Hands-on testing

The second level of modules focuses more on the optimization of way of working within the 4D BIM process. Therefore, four different modules have been developed they assist practitioners, to expertise their 4D BIM way of working.

Module Three

Starting with advanced software competencies, the third module has the learning goal to ensure that participants will be able to perform advanced software tasks and standardize their way of working. Module three addresses technical, implementation and research and development competencies (Table 11). In the introductory presentation participants learn how to ensure working in the most efficient way with 4D BIM and adopting a mindset of seeking the most optimal way of working with 4D BIM. In the application component through a learning task that combines demonstration and a practice exercise, participants apply scripting in 4D BIM software and learn to use baselines. During the analysis component through a learning tasks that combines demonstration and simulation participants are introduced to the use of workspace and 3D paths in the 4D BIM software. After the completion of the training session

participants must complete an on-the-job assignment within three months after the training session. In that assignment they don't only practice their acquired competencies, but they also learn about standardizing their way of working with 4D BIM.

Table 11. Module 3: Advanced 4D BIM

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Introduction	Presentation		Ensure "smart" visualizations that follow and explain precisely the construction process	Skill-based Outcomes	Hands-on testing
			Ensure "smart" activity coding able to provide information for levels, suppliers, etc.	Cognitive Outcomes	Structural assessment
			Find out ways to optimize the process and the way of working with 4D BIM	Affective Outcomes	Self-report measures
			Explore new concepts and innovative ideas regarding 4D BIM implementation	Affective Outcomes	Self-report measures
Application	Demonstration & Practice Exercise: Task Durations and Baselines		Use scripts within the 4D BIM software to improve working efficiency	Skill-based Outcomes	Hands-on testing
			Compare schedule alternatives or progress in 4D BIM Software (baselines)	Skill-based Outcomes	Hands-on testing
Analysis	Demonstration & Simulation: Workspaces and 3D Paths		Create and use workspaces in 4D BIM Software	Skill-based Outcomes	Hands-on testing
			Create 3D paths in 4D BIM Software	Skill-based Outcomes	Hands-on testing
On-the-job assignment	Case Study		Standardize the way of working and prepare templates	Cognitive Outcomes	Probed protocol analysis
			Create manuals, roadmaps and flowcharts regarding the way of working with 4D BIM	Skill-based Outcomes	Hands-on testing

Module Four

Module 4 aims to certify the ability of participants to develop a detailed construction schedule in 4D BIM and therefore integrates operation and functional competencies (Table 12). During the application component of this module, participants follow two mini-workshops in which they learn about two main techniques used in construction planning and therefore in 4D BIM scheduling. They also receive a demonstration about identifying hard classes that they are asked to use during the analysis component. In that, participants get a simulation assignment in which they should find a solution for an impossible planning. After the completion of the training session, participants should apply their skills in one of the on-going company projects as an on the job assignment to be completed within three months.

Module Five

The last two modules of this level aim to ensure the use of the 4D BIM outcomes for the validation and the verification of the construction planning in (Module 5) and for the progress monitoring of the construction works (Module 6). Again, in these modules mostly operation and a few functional competencies have been addressed. A combination of a workshop and a demonstration activity are used in module 5 during the application component to provide insights regarding the way of working by using 4D BIM products during verification and validation meetings (Table 13). In the analysis phase of module 5 a simulation assignment is provided to the participants and they have to prepare a verification and validation meeting in "real-life" conditions.

Table 12. Module 4: Scheduling in 4D

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Application	Workshop: MECE Approach		Think on an analytical way: be able to switch between detailed information and headlines	Cognitive outcomes	Probed protocol analysis
	Workshop: Sprint Approach		Develop the project planning in more detail. From overall task description to detailed tasks, step-by-step (LoD 2 --> LoD 3)	Cognitive outcomes	Recognition and recall tests
			Organize sessions to acquire more information from multiple specialists	Cognitive outcomes	Probed protocol analysis
	Demonstration: Clashes		Report on hard clashes	Cognitive outcomes	Recognition and recall tests
			Identify time depended clashes - constructability reports	Cognitive outcomes	Recognition and recall tests
Analysis	Simulation: Impossible Planning		Interview specialists about the project planning	Cognitive outcomes	Recognition and recall tests
			Identify inaccuracies, missing elements or impossible planning and raise early awareness	Cognitive outcomes	Speed tests
			Coordinate work among different disciplines, provide all the necessary information and eliminate irrelevant matter	Cognitive outcomes	Recognition and recall tests

Table 13. Module 5: Verification and Validation with 4D

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Application	Workshop: Way of Working - Meetings Coordination		Initiate and run the validation loops (plan, organize and prepare meetings / sessions etc.)	Cognitive outcomes	Probed protocol analysis
			Ask the right questions in order to ensure accuracy and validity of the planning and the information in the model	Cognitive Outcomes	Free sorts
			Connect information, draw meaningful conclusions and present them in order to rationalize the decision making	Skill-based Outcomes	Hands-on testing
			Facilitate and guide the meetings (keep order and time, coordinate, draw conclusions, summarize discussions)	Skill-based Outcomes	Hands-on testing
			Adjust the way of talking to address all different layers of the project organization	Affective Outcomes	Self-report measures
	Demonstration: Way of Working - 4D BIM During Meetings	26	Use 4D BIModel during meetings to provide information and stimulate decision making (based on data)	Skill-based Outcomes	Hands-on testing
		27	Use 4D BIModel during meetings to stimulate understanding of the project elements (navigate through the visualization)	Skill-based Outcomes	Hands-on testing
		28	Use multiple 4D BIM outcomes during meetings (to keep notes, make adjustments, etc.)	Skill-based Outcomes	Hands-on testing
Analysis	Simulation: V&V Meeting with 4D	25	Prepare and generate multiple types of 4D BIM Deliverables	Skill-based Outcomes	Hands-on testing
			Prepare for the meetings and think of the interaction with the model during them	Cognitive outcomes	Probed protocol analysis
		29	Present information with the help of the 4D BIModel in an understandable way for non-software users (clashes, design mistakes, etc.)	Skill-based Outcomes	Hands-on testing

Module Six

In module 6, through a presentation and a simulation assignment, participants learn how to identify when a schedule starts differentiating from the optimal and how to use 4DBIM to update the stakeholders on the current situation (Table 14). During the analysis component participants have a workshop during which they "shadow" for an hour an employee surveying the progress of the tasks on site and then they are asked to update the progress of the tasks in the 4D BIM model as an individual practice exercise. Of course, an on-the-job assignment follows each of the modules 5 and 6 so there is a period of three months between them for the completion of the on-the-job assignment. By the completion of the second level, participants are expected to have adopted an optimal way of working with 4D BIM.

Table 14. Module 6: 4D Progress Monitoring

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Application	Presentation: Way of Working - Progress Monitoring		Recognize when the construction starts differentiating from the planning	Skill-based Outcomes	Hands-on testing
			Confirm early any inconsistency between the planning and the actual construction with the people in charge	Cognitive Outcomes	Probed protocol analysis
	Simulation: Update the Stakeholders		Use the model to prepare client and team updates regarding the progress	Skill-based Outcomes	Hands-on testing
Analysis	Workshop: On-site Progress Surveying		Be alert and identify changes and progress in a construction site	Skill-based Outcomes	Hands-on testing
			Keep track of the progress and time constraints and changes in the construction site	Skill-based Outcomes	Hands-on testing
	Practice Exercise: Up-to-date model		Update the model whenever there are schedule/design changes or inconsistencies	Cognitive Outcomes	Probed protocol analysis

Module Seven

The third level of 4D BIM competency refers to broader competencies for overviewing, managing and coaching others within the 4D BIM process. Therefore, in module 7 (Table 15) the learning goal is that participants can use multiple software tools in order to solve issues between 3D models, schedules and 4D BIM and that they can code simple lines (for example in python) for data manipulation and future development purposes. Therefore, mainly technical and research and development competencies have been addressed in this first module. The module is slightly differently organized than the rest of the modules. During the synthesis phase, participants in three small groups have to prepare and present one of the mini workshops (about coding, 4D BIM data graphs or basic 3D modeling) to their peers. In the evaluation component they have receive an individual assignment to prepare a 4D BIM model by importing from scratch the 3D model and project task lines. An on-the-job assignment follows the completion of the training session of module seven and participants have a period of one month to complete it.

Table 15. Module 7: 4D BIM Hacks

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Synthesis	Peer tutoring workshop		Check if the file format of the 3D model can be used	Skill-based Outcomes	Hands-on testing
			Write simple code lines / Know a programming language	Skill-based Outcomes	Hands-on testing
	Peer tutoring workshop		Use excel to export, manipulate and re-import data	Skill-based Outcomes	Hands-on testing
	Peer tutoring workshop		Draw simple 3D elements and polyline paths in various 3D software	Skill-based Outcomes	Hands-on testing
			Subdivide 3D elements in external 3D software	Skill-based Outcomes	Hands-on testing
Evaluation	Practice Exercise: Importing in 4D BIM		Export schedule from different software	Skill-based Outcomes	Hands-on testing

Module Eight

Module 8 has the goal to ensure that participants would be able to outline an action plan regarding the 4D BIM process for new projects, make agreements and influence all parties involved regarding the adoption of 4D BIM (Table 16). In this module functional, implementation and administration competencies are being addressed. During the synthesis component of this module participants participate in two workshops the first regarding company role and the way of working within a new project with 4D BIM and the second about motivational speaking and storytelling about 4D BIM. At last, in the evaluation component there is a simulation assignment in which participants get the information for a new project and have to set a 4D BIM action plan with all the different process steps and requirements. An on-the-job assignment of one month follows the completion of the training session.

Table 16. Module 8: 4D BIM Process Management

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Synthesis	Workshop: Way of Working - The 4D BIM Process		Outline the 4D BIM process for a project and describe precisely the needs for each of the process steps	Skill-based Outcomes	Hands-on testing
			Define and agree with all parties the LoD appropriate for each of the different phases of the project	Skill-based Outcomes	Hands-on testing
			Make agreements on the information exchange tasks and format in each of the process phases	Cognitive Outcomes	Structural assessment
	Workshop: Motivational Speaking / Storytelling		Storytelling regarding 4D BIM use and benefits in a tangible way to colleagues' and partners	Skill-based Outcomes	Hands-on testing
			Adopt persuasive and convincing techniques to talk about the 4D BIM tools to various management stakeholders	Skill-based Outcomes	Hands-on testing
			Initiate proactively the 4D BIM (Digital Construction) way of working instead of the "traditional planning"	Affective Outcomes	Self-report measures
Evaluation	Simulation: 4D BIM Process Plan for New Contract		Set and coordinate a network of different specialists	Cognitive Outcomes	Probed protocol analysis
			Understand the project scope and rationalize decisions based on it	Cognitive Outcomes	Hands-on testing
			Analyze the contract and develop a 4D BIM requirements list	Skill-based Outcomes	Hands-on testing
			Negotiate and agree upon the 4D BIM deliverables with the involved parties	Affective Outcomes	Self-report measures

Module Nine

The last module refers to coaching within the 4D BIM process and therefore participants completing module 9 should be able to overview the 4D BIM process, coach others on the way of working with 4D BIM and balance between effort and impact when updating 4D BIM (models). Operation, functional, implementation and administrational competencies are addressed (Table 17). During the synthesis component of this module participants follow three different mini-workshops regarding influencing techniques regarding the adoption of 4D BIM by a new project coalition, managing changes in 4D BIM and coaching of new employees involved in the 4D BIM process. During the evaluation component participants participate in an InterVision session in which they discuss and get feedback on different management approaches for 4D BIM teams. By the completion of level C participants are expected to be able facilitate the 4D BIM learning process within their organization but also the 4D BIM learning process required for the collaboration with partner organizations.

Table 17. Module 9: 4D BIM Coaching

Training Component	Instructional Methods	Set	Learning Objectives	Measurable Outcomes	Evaluation methods
Synthesis	Workshop: Influencing		Gain credibility and build trust among the project stakeholders	Skill-based Outcomes	Hands-on testing
			Explain the way of working and coach new colleagues	Skill-based Outcomes	Hands-on testing
	Workshop: Change Management and Response to Changes		Acquire detailed information regarding changes, their urgency and priority	Cognitive Outcomes	Structural assessment
			Access and use a changes management platform (Software: Autodesk glue, etc.)	Skill-based Outcomes	Hands-on testing
			Evaluate time-wise the desired LoD and define accordingly the 4D BIM deliverables	Skill-based Outcomes	Hands-on testing
			Evaluate the need and the effort for updating the model	Cognitive Outcomes	Readiness for testing
			Monitor regularly the level of detail and decide on adding more activities or keeping less based on the initially agreed LoD	Skill-based Outcomes	Hands-on testing
	Workshop: Coaching		Explain "why" (for each decision, change, action …)	Skill-based Outcomes	Hands-on testing
Evaluation	InterVision Session		Select the proper team management approach, for the team and the task to be performed	Cognitive Outcomes	Probed protocol analysis

From the above, it becomes clear that overall training that is being proposed, involves a long-term experience with 4D BIM (Figure 10). In total 2 months working experience with 4D BIM software are required for the completion of the first level, 12 months of working experience within a 4D BIM project is required for the second level and 9 months managerial experience within the 4D BIM process is required for the completion of the third level. However, it is important to mention here again that somebody can start working within the 4D BIM process already after the completion of the first two modules (Level A). The total of 17 months is required for participants who start without any knowledge of 4D BIM and aim to become "certified consultants" which means that they can facilitate the 4D BIM learning process of other employees and solve managerial issues regarding the implementation of 4D BIM.

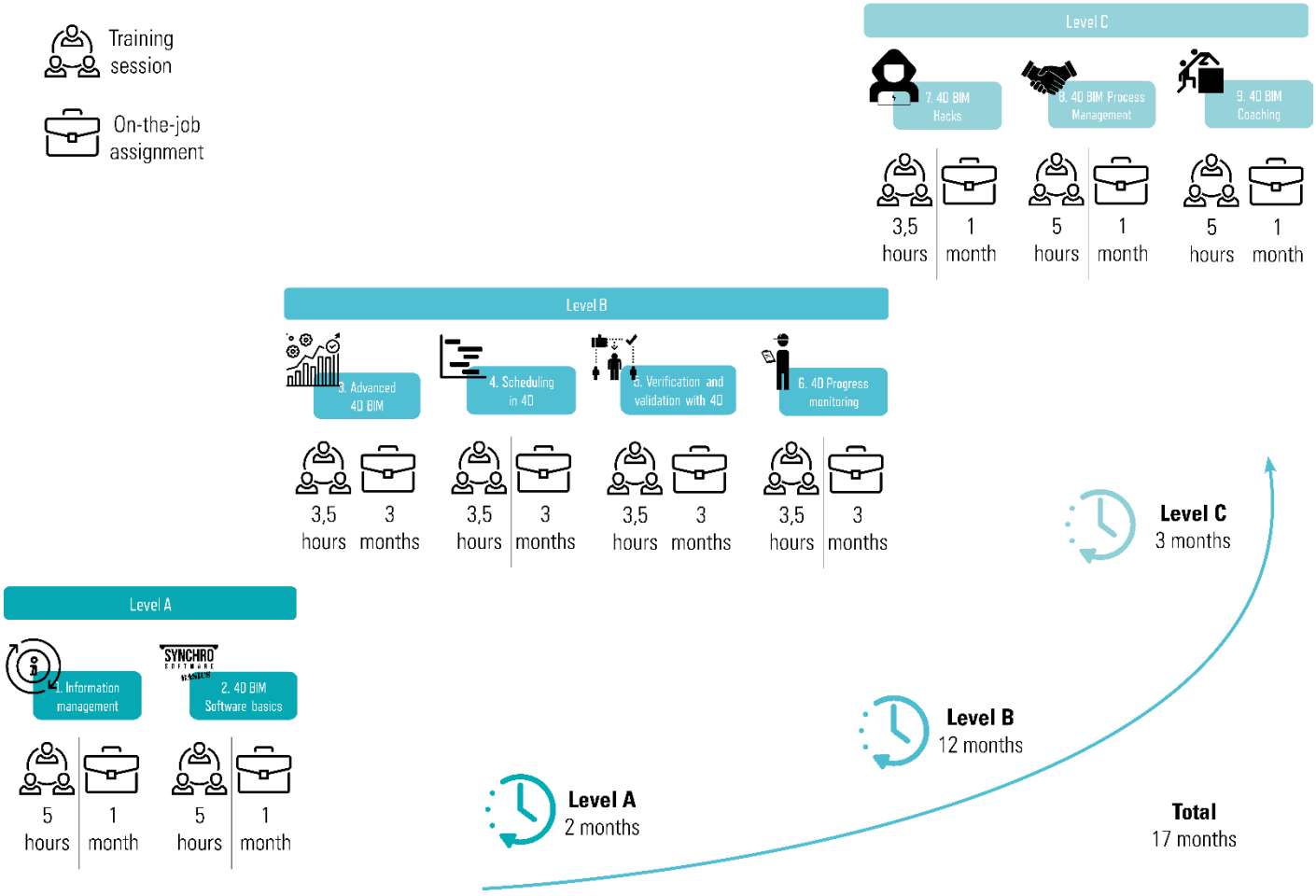


Figure 10. 4D BIM Training curriculum duration

VALIDATION

All the detailed tables with the evaluation results and the corresponding quotations can be found in *Appendix VI. Evaluation outcome.* The quotations have been coded starting on the number of the participants in the interview (1,2,3,4,5 and 10) and followed with the sequence number of the quotation of that participant (for example 5.23 refers to the 23rd quotation from the interview with participant 5). Once again participants with the numbers 1,2,3 and 4 are professionals experiences in 4D BIM and participants with the numbers 5 and 10 are professionals in BIM training.

1.5.4 Relevance

In terms of relevance, it is agreed among all the 4D BIM practitioners that participated in the interviews that the list of the identified competencies is very extensive and that it holistically maps competencies relevant for 4D BIM planners and crucial for a 4D BIM training. Additionally, a very interesting outcome of this validation phase is that participants indicated the relevance of the proposed 4D BIM competencies identification not only for consulting firms but also for contractor firms. It was recognised that the proposed curriculum could address the needs of more roles involved in the 4D BIM process in general. Specifically, it was mentioned that most of the contractor companies are developing similar in-house training programs, with the aim to train the role of work preparators for developing 4D BIM models and delivering 4D BIM outcomes. At the same time, it was pinpointed that competencies related to progress monitoring with 4D BIM should be required by the site managers or the site superintendents. Ideally in the future, the responsibility of updating the 4D BIM model in terms of progress for the construction tasks should be outsourced to these roles. Overall, it was agreed that the list of competencies could be relevant for several roles involved in the 4D BIM process among a project coalition. Participants could even see a consulting firm taking the lead and delivering a 4D BIM training for upskilling not only their personnel but also partners within a project coalition: "you could take this training a bring it to a tender team to teach them about 4D BIM and bring everyone on the same level of 4D BIM understanding"

However, according to the validation feedback, there are some additional competencies that should be considered for implementing successfully the proposed 4D BIM training curriculum among a broader target group of participants. Professionals indicted the need to include more construction scheduling related competencies in module 4 (use of scheduling techniques: critical path method, network diagram, float calculations) when it comes to the training of work preparators for 4D BIM. Also, the interviewees indicated the need to include additional advanced competencies in module 7 that would ensure a broader spectrum of 4D BIM uses in the future. Three main items were identified in this direction: the use of a server-based application for facilitating collaboration within the 4D BIM process (software such as SWP by Bentley); the use of 4D BIM outcomes for managing projects in a company level and not only in a project level (deriving insights for business development and more efficient resource allocation among different projects of the company); the use of 4D BIM for construction site logistics. Although, these topics are recognised important for the future implementation of 4D BIM, they cannot be considered current practises in which practitioners should be trained. This is because 4D BIM is still an emerging practice in the construction sector and therefore, these advanced 4D BIM uses would first require the establishment of 4D BIM as a common practice within the procedures of the company as a whole.

Specifically, participants in their general comments agreed that several of the addressed competencies of the training, are linked to an optimal way of working with 4D BIM which is not the current way of working. This is because 4D BIM for most of the firms is not a core activity yet and the effort allocated for 4D BIM training, highly depends on the current and future technological developments. However, it

seems that the market is pushing towards 4D BIM and it is believed that technology will establish 4D BIM as a core activity of the companies in the construction sector soon. Consequently, there is the aim to reach that higher level of 4D BIM competency. A training activity of this kind would be very much aligned with the interest of firms to invest further on implementing and advancing 4D BIM. For some firms the complete training design that has been proposed may be ideal but for some others only a small part of the proposed training could cover their needs.

1.5.5 Validity

When the interviewees were asked about the perceived validity of the training curriculum, they firstly expressed their positive reaction regarding the structure in which the knowledge is provided. Most of them agreed that the content of the different levels is the appropriate, and that a structured approach in 4D BIM education could have successful results. However, they proposed minor improvements that could be considered such as including module four in modules of level A. More precisely, one of the interviewees indicated that although module one has been approached correctly in terms of the basic software competencies, there is need for teaching planning related competencies already from the first level: "*Although you can easily get a "push the buttons" training this is clueless if you don't have knowledge about how planning management works*". At the same time there were two contradictory statements regarding the first module of information planning. One of the 4D BIM practitioners doubted the need for this module in the first level, when the training experts indicated the importance of this specific module for speeding the learning process regarding object-oriented software competencies. A couple of other practitioners also indicated that module one is crucial for everyone involved in the process and it could probably be enriched with more knowledge regarding BIM in general. Modules of Level B have been recognised as the most important in terms of upgrading the 4D BIM process within a firm. Furthermore, modules of Level C have been identified as an innovative component of the 4D BIM training that has the potential, to establish knowledge within an organisation in more stable ground.

In terms of the specific training features, most of participants, and among them both the training experts, indicated that the learning components could successfully help participants to acquire and apply the competencies. Specifically, they recognised a good mix of training methods, that makes the training interactive, and clear learning goals and deliverables that help practitioners learn. The training experts pointed out that although the training material for the software is the appropriate one (step-by-step guide) the time allocation for each module should be adjusted: "if you say this is a 3,5-hour session [ref. to module 3], this is a lot to do within 3,5-hours". Extra time should be considered, in all the modules, for answering questions and explaining concepts and evaluating the trainees' work.

As two of the most important features of the training have been recognised the evaluation and the on-the-job assignment. Regarding the assessment, it has been recommended to define more accurately which is the process for a participant who doesn't meet the performance requirements of a module. As far as for the on-the-job assignment, it has been considered the most crucial component of the proposed design. Professionals indicated that participants in the training is necessary to apply their competencies in real conditions to secure that they will be able to use 4D BIM successfully in company projects.

Overall, the proposed design has been characterised as a very complete and detailed approach that is aligned with similar efforts of different companies in the construction sector. The interviewees suggested that the training (or at least parts of it) should be recommended as necessary for all practitioners involved in the 4D BIM process. They have also confirmed, that their in-house training efforts regarding 4D BIM are similar but cover only in a very small part of the proposed design, and specifically the software related competencies. Lastly the visualisation of the training design was got positive feedback as it is believed

that it helps for the better understanding of the training activities.

1.5.6 Feedback on implementation of the training curriculum

Interviewers have also provided feedback in terms of the potential implementation challenges of the training curriculum. One of the points raised regards the overall duration of the training. The duration of the complete program is considered by the interviewees to be very long (17 months). Accordingly, participants recommended, that splitting the training in three different courses (one course including the modules of one level) could improve the feasibility of the program. In this way, it would become clear to the trainees that after completing the first course (level A) they can already start working with 4D BIM tools. The second course (level B) can help them expertise their knowledge regarding the 4D BIM process and in the third course (level C), they can learn how to manage the 4D BIM activities within a company or within a project. Among other ideas, proposed for reducing the duration of the training program, was the ability to customise the learning path based on the trainee needs. It was indicated that the quality of the training can be affected by the previous experience of the participants and that different roles may require a different training approach. Consequently, an initial assessment should be proposed for all the employees, during which the learning path for each trainee is defined based on their previous experience and their specific personal and role needs.

Additionally, during the evaluation, it was clearly mentioned that the proposed training could also address the training needs of participants from construction firms in terms of 4D BIM. However, most of the participants in the interviews indicated the need to select specific competencies to be linked with employees in different roles in a construction project to make the training relevant for a greater audience that includes contractor companies. This is because the 4D BIM process between consulting firms and contractor companies is very different. Consultancy firms mainly focus on infrastructural megaprojects, on which the 4D BIM process involves the management of complex interfaces, within a project coalition with several stakeholders. Consequently, trained employees from a consultancy firm should be able to cover all the knowledge and expertise gaps that occur during the 4D BIM transformation among the several partners of a project coalition and the proposed training covers that need. However, for contractor firms, especially in the case of buildings or smaller complexity assets, the whole 4D BIM process has been reported centralised in one and only experienced planner who is responsible to develop the model in 4D BIM and has minimum interaction with other parties. But also, in bigger infrastructural projects, interviewees pinpointed that contractor employees are only being involved in the 4D BIM process from their specific company / project role. It would only be only relevant from them to invest in acquiring the specific competencies that are relevant and directly applicable to their role.

According to the recommendations from practitioners, at least four roles within a project, should be trained in some of the modules that have been included in the proposed design. The 4D BIM planners or the work preparators should follow all the modules in the first and the second level (1-6). However, it is not relevant for them to follow the levels in the third level, as this should be the responsibility either of the BIM coordinator or BIM managers in a project coalition. BIM coordinators should be responsible to overview the technical and implementation aspects of the 4D BIM process within a project and therefore modules 1,5, 7 and 8 are more relevant for them. At the same time BIM managers should have the ability to manage and implement the 4D BIM process internally in a company setting and therefore modules 8 and 9 are indicated as necessary for them. Lastly, it was mentioned that employees with the role of the site / field management or project superintendents should be responsible to report on the progress management in the 4D BIM model and therefore should follow modules 1 and 6. In an attempt to summarise the above results a matrix was created for the suggested modules for different employees in consultancy and contractor firms (Table 18).

Table 18. Comparison matrix for modules that are relevant for different roles in construction firms

Modules	Consulting firms	Contractor firms			
	4D BIM Planner	BIM Manager	BIM Coordinator	4D BIM Planner / Work preparator	Field / site manager
1. Information Management	x		x	x	x
2. 4D BIM Software basics	x			x	
3. Advanced 4D BIM Software	x			x	
4. Scheduling in 4D	x			x	
5. Verification and validation in 4D	x		x	x	
6. 4D Progress monitoring	x			x	x
7. 4D BIM Hacks	x		x		
8. 4D BIM Process management	x	x	x		
9. 4D BIM Coaching	x	x			

As a last point during this evaluation round, the interviewed experts, indicated that with minor modifications, the proposed training curriculum, could also be used as a separate training product. Although the training has been initially designed to be implemented as an inhouse upskilling training program, several experts indicated that it could have potential in the market as a separate training product. In that case, there are a couple of issues that should be improved before discussing the proposed design as a training product. It should be ensured that the training can be adjusted to the specific company needs, the duration of the training sessions should be standardised and the trainers for each of the modules should be defined. A separate feasibility study would be needed in order to identify the actual interest of different firms to outsource these training activities based on the cost of such a training program.

DISCUSSION

The focus of this assignment was to develop a training curriculum for 4D BIM in construction consulting firms. There is no relevant literature describing either the 4D BIM competencies that should be addressed in such a training or how the training components of a 4D BIM training should be. Relevant literature could only be found on the BIM competencies and the development of BIM training activities. Based on the literature regarding BIM competencies, the 4D BIM competencies framework has been constructed (as presented in Chapter 3.1). Literature regarding BIM education reports as the most challenging issues of a BIM related training the balance between (1) theoretical knowledge and practice, (2) technological and process aspects and (3) traditional and emerging construction project management approaches (Puolitaival and Forsythe, 2016). The proposed training curriculum seems to tackle all these three aspects sufficiently.

Specifically, according to the feedback of the practitioners the mix of the training methods and the combination of an on-the-job assignment are the strong characteristics of the training features, as they incorporate both theory and practice in a good balance. Furthermore, the training integrates some modules related to the use of the technological tools (software) but at the same time process related aspects of 4D BIM have been carefully designed. The third level of the training has been recognised as an innovative approach of 4D BIM training that addresses all the process related challenges and establishes 4D BIM competencies beyond the use of technology. Lastly, regarding the challenge to balance between traditional and emerging construction management techniques; 4D BIM has been approached as a complete emerging construction management process itself; and the proposed design has received positive comments on the way that it is addressing an optimal way of working. However, it has been recommended to include more competencies related to the traditional construction planning techniques.

Moreover, the evaluation of the training regarding the perceived validity had a generally positive outcome. Interviewees agreed that this should be the way that a 4D BIM training should be approached and they indicated that they would adopt at least parts of the proposed design for upskilling their employees in terms of 4D BIM. This project suggests that acquiring 4D BIM competency in the proposed holistic approach, increases the chances for consulting companies to become 4D BIM champions. By reaching the higher level (level C) of 4D BIM competency, consultants should be able to facilitate the learning process of their peers or partners, who just start with 4D BIM. Being able to run the process of 4D BIM from the beginning to the end, both internally and inter-organisationally gives the potential to consulting firms to step up and lead the 4D BIM implementation within project coalitions. In this way consulting firms not only maintain competitive advantage by delivering high quality 4D BIM outcomes, but also manage successfully challenging interfaces with partners during the 4D BIM transition process.

It has also been proposed that construction consulting firms can use the proposed training not only for upskilling their own personnel but also for upskilling the members / partners of the different project coalitions that they are involved. However, the proposed design required some significant adjustments to be able target a broader group of practitioners within the construction sector. Firstly, the module of scheduling in 4D should be enriched further with traditional scheduling techniques (critical path method, network diagram, float calculations) and included in the first level of 4D BIM competency in order to address lower skilled in terms of planning professionals. Furthermore, the three levels should be separated and organised as three different courses (with three modules each) that do not require the completion of any the other courses. For this scheme to work an initial assessment should be introduced, during which the trainees' current role, previous experience and needs are considered in order to design

a personal learning path that consists from a compilation of different modules. The above modifications have been summarised and a potential redesign of the training curriculum has been proposed (Figure 11) for addressing a broader audience than practitioners in construction consulting firms.

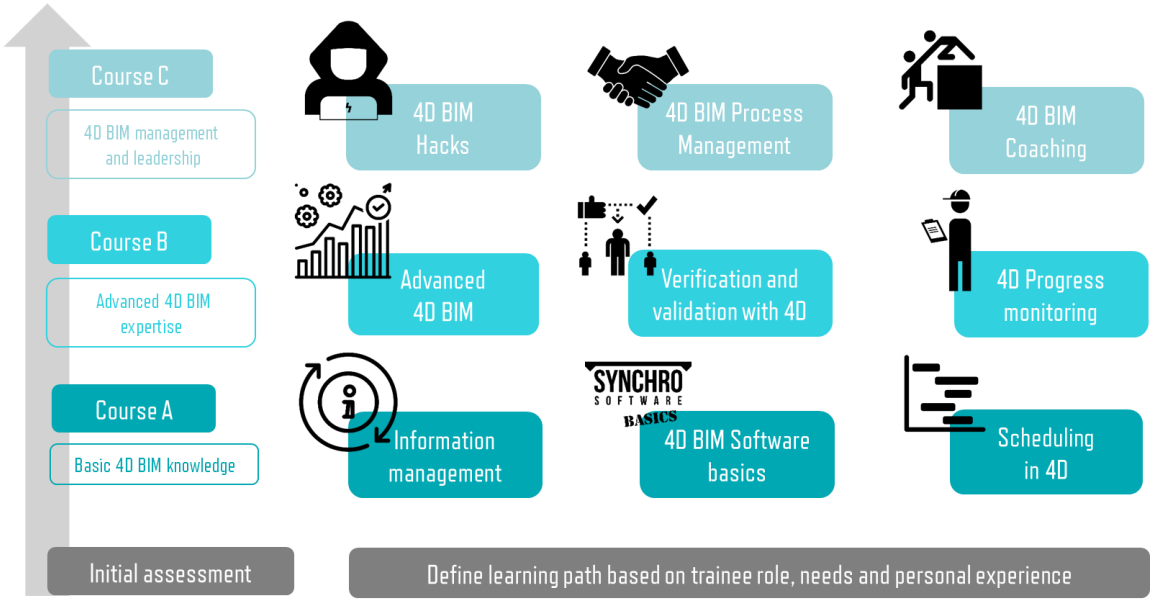


Figure 11. Proposed re-design of the training for contractor firms

LIMITATIONS

Since this research consists single design cycle approach has specific limitations, that should be pointed out. These should be considered as topics for further research that could result in a second design cycle before the implementation of the final training result. First, for the competencies with cognitive or affective outcomes, extensive analysis of the the cognitive strategies and the mental models has not been performed within the scope of this project. In order to design the supportive information for these learning objectives in detail (presentations, quizzes), further research is required on these learning patterns (Kirschner and van Merriënboer, 2008). This project provides examples for both the supportive and the instructional information but mainly for the skills-based learning objectives. Diving into the mental models and the cognitive strategies, in order to develop accordingly training material for specific 4D BIM learning objectives should be the subject of future research in the overlap of the disciplines of construction management and educational science.

Second, the evaluation of this training during the local impact phase, only addresses the perceived validity of the training features. To measure the actual effectiveness of a training program, the training should be fully implemented on a trial setup. An idea about how this setup could look like is provided in *Appendix VII. Implementing module 2 for deciding on the instructional method* in which an example of an A/B testing has been designed for deciding on the instructional method of Module 2. However, for evaluation purposes a more thorough set up should be developed. In case of an A/B testing setup, at least six participants should be acquired per group in order to have statistically significant results and a quantitative analysis of the results to be possible. Also, a clear hypothesis should be formulated that address the effectiveness of the training and the experiments should measure cognitive and affective outcomes, as well and the performance of participants in an on-the-job assignment after the training session. Due to the amount of time required for that kind of thorough testing, within the present project it was only possible to evaluate the perceived validity of the design by interviewing different experts.

This research has been conducted within a Dutch construction consulting firm and the research outcomes have been validated with professionals from different construction contractor firms and software training experts. However, the 4D BIM competencies framework should also be validated the content of suppliers, clients and other stakeholders that are involved in the 4D BIM process among other to ensure external validity of the 4D BIM competencies identification. Also, the proposed design, should also be validated among several construction consulting firms that develop similar kind of activities in order to confirm that the proposed training approach addresses sufficiently the needs of construction consultancy companies.

CONCLUSIONS

The main purpose of this paper was to establish a 4D BIM competencies framework and design a professionals training curriculum for acquiring these competencies. The 4D BIM competencies framework is developed based on the generic BIM framework of Succar et al. (2013), and it is customised to address a more targeted exploration of one specific new process within the BIM practice: 4D BIM. The training curriculum translates these identified competencies in levels of competency and specific learning modules and activities by using educational and instructional research develop a design.

This is the first attempt for identifying in a structured way, competencies for a specific software-centred process in the content of BIM: 4D BIM. The results of this study (development of the 4D BIM competencies framework) can be used in research to approach the identification of competencies related to other software-centred processes with the aim to expand the exploration beyond the software skills. At the same time, in the industry BIM is an emerging field and more technology and software-centred applications are expected to be employed in everyday use the next years (VR, HoloLens, etc). The ability to identify domain competencies that are required for the process change and are not described in the instruction manuals of the technology supplier can be crucial for keeping up with the technological transformation of the construction industry.

Regarding 4D BIM itself, this project proposes a complete training curriculum that can be used by the industry to evaluate 4D BIM competency among practitioners and industry. The current study aims to assist firms in the construction sector in the development of in-house training activities in order to apply the training and measure the learning outcomes. The training design proposes the way that practitioners, on-the-job knowledge can be coupled with educational and instructional research outcomes to develop professional training activities. When it comes to research, in the existing body of knowledge there is limited work regarding the development of training activities for upskilling construction professionals on-the-job. The proposed training can be used for further researching the efficiency of these kind on-the-job training efforts and for defining up to which extend can bring the industry to a higher level of 4D BIM competency.

This project claims that developing professionals as technology champions, who know how to manage the process required for the use of new technology and coach others in their learning process, can accelerate digital transformation in the construction industry. However, more research is required measure precisely the learning outcomes of the proposed modules. A trial application of the proposed training approach would lead to an optimised and fine-tuned version of the training, that can be used by consulting companies to upskill in terms of 4D BIM, their employees and their partners in different project coalitions. Then it would be possible to say with confidence up to which extend the development of 4D BIM champions within consulting companies is possible to accelerate 4D BIM adoption by the construction sector.

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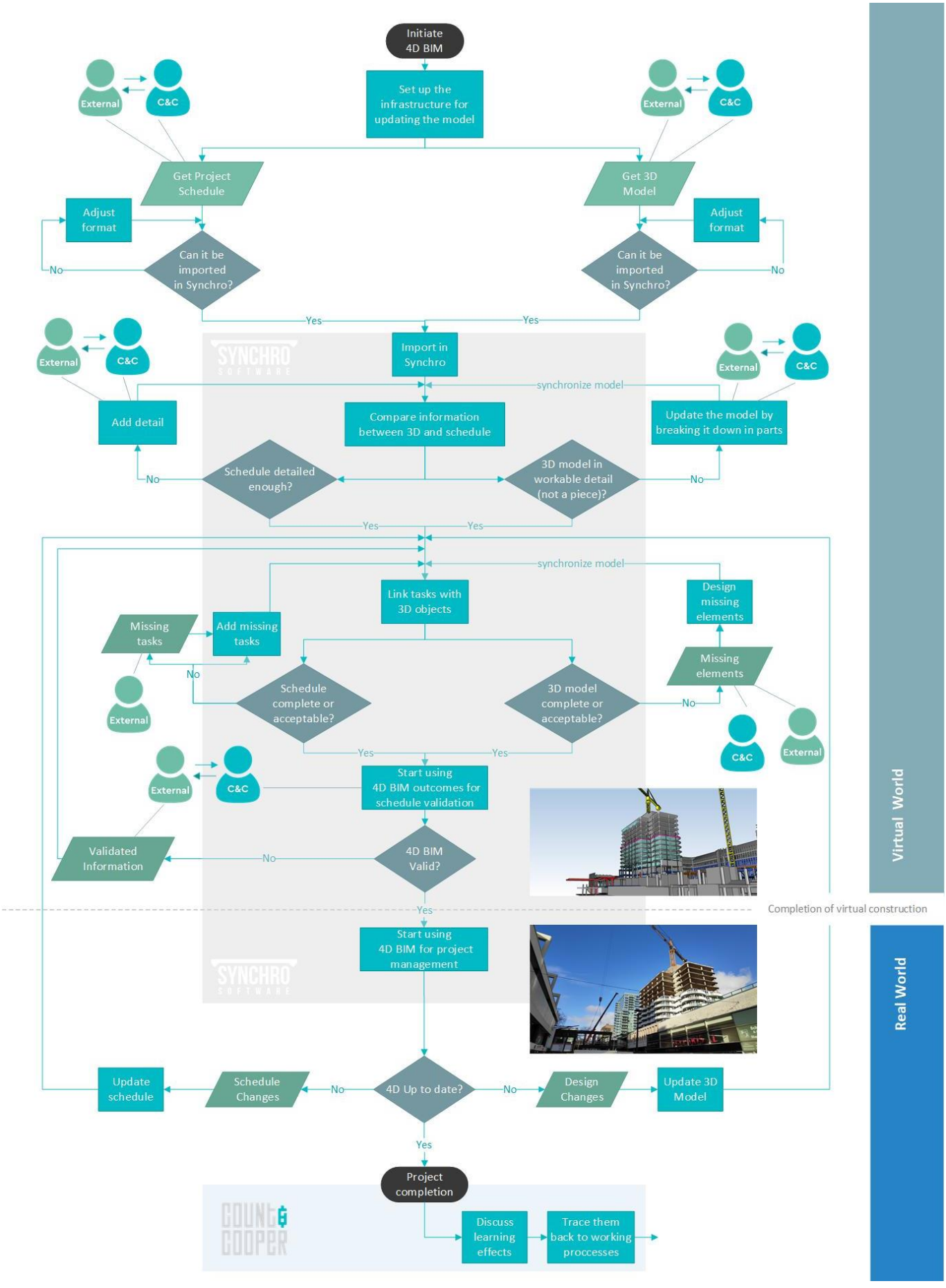
APPENDICES

Appendix I. 4D BIM process flowchart



Appendix II. 4D BIM competencies exploration workshop

Time	Phase	Goal	Technique description (moderation)
14:30 – 14:45	**Introduction**		
2 min	Intro	Feeling comfortable	Welcoming the participants and thanking them for their participation. The schedule of the evening is on the screen.
5 min	Join: Ice breaking	Warming up	The participants split into 3 groups of 4 people according to their roles / disciplines in order to ensure multidisciplinary teams. The teams are known to the participants upon their arrival. In about 10 minutes, the group needs to create a 3D mascot. To do so, each of the team members pick a set of two objects form the warming-up kit envelope. They need to collaborate to create their 3D representation of the mascot. Starting from someone every participant combines their two objects in the team mascot why they try to explain link of their object with the 4D BIM importance for their work (based their own background).
8 min	Inspire: Challenge introduction	Introduction to the session and to the challenge	The importance and the goal of the session is introduced briefly by the facilitator: Objective of the thesis • Why 4D BIM • Goal of the session • Example of the first exploration The challenge of the session is introduced and explained: *To identify 4D BIM competencies (technical and non-technical) that the practitioners need as these can be derived from previous experience regarding their role and examples from previous projects.*
14:45 – 15:15	**First Exploration – 4D BIM Roles**		
5 min	Act: Individual brain writing	Come up individually with 4D BIM planner roles within the 4D BIM process	The teams are provided with a printed copy of the 4D BIM process flowchart. All participants are asked to think of the part of the process they have been involved. Then they take post-its and they are asked to write down as many as possible roles / responsibilities of the 4D planners within the 4D BIM process or tasks that are needed within their everyday tasks (one *role* per post-it).
15 min	Act: Group brainstorming	Discuss the roles in a group set up, cluster them and come up with new ones	One-by-one, participants place their post it on the wall, while they walk their team through the part of the 4D BIM process that they have experienced initiating a small group discussion. They are asked describe the identified roles and the interactions of their role and with the 4D BIM process. At the same time they try to cluster similar roles and group them. If needed, they rephrase the description of the combined roles. At the end the goal is to have identified several clear roles of a 4D planner within the 4D BIM process.
5 min	Act: Dot voting	Evaluate the difficulty	Every participant gives their two dot-voting-stickers to any of the roles that they consider the most challenging ones.

Time	Phase	Goal	Technique description (moderation)
5 min	Act: Group result	Come up to a group result for the most challenging 4D BIM roles	The roles with the most dots are selected and prioritized as 1st, 2nd and 3rd by the whole group. The participants are asked to restate in a clear way their selected 3 roles on the paper so that these can easily be readable and understandable by a third person.
15:15 – 15:20	**Coffee Break**		
5 min	Table touching	Get inspired by the other group ideas	During the break the participants are asked to walk around and read through the other team's work so they can get different insights.
15:20 – 15:55	**Second Exploration**		
5 min	Inspire: Competency sets explanation	Understand which are the categories in which we are looking for competency items	The goal of the second exploration is explained, instructions and a short example are given. Each of the eight identified BIM skill sets from literature are explained to the teams as well.
5 min	Act: Individual brain writing	Come up individually with 4D BIM competencies	Each participant takes 5 minutes to think and write down individually, as much as possible specific competencies that a 4D planner needs in order to overcome challenges or ensure a smoother process (one competency/skill per post-it). For each of the competencies, participants are asked to recall their personal example from previous or current projects.
15 min	Act: Group brainstorming	Discuss the challenges in the group set-up, cluster them and come up with new ones	One-by-one all the participants, place their post-it on the whiteboard wall after they explain to the team the competencies, they identified by using real case examples from their projects and they initiate a short discussion. At the same time, they try to cluster similar competencies and group them. If needed, they rephrase the description of the grouped competencies and they create new ones. At the end the goal is to have several discreet competencies that 4D planners should have or acquire that they overlap to the minimum.
5 min	Act: Classification	Categorize challenges under the skill sets framework	The teams are asked to relate each of their competencies to one of the previously explained competency sets. If it is not possible, they propose new ones that should to be included.
15:55 – 16:00	**Group Results**		
5 min	Reflect / Reframe: Super-fast sprint	Collect the ideas, check if they fit under the framework, reframe if necessary.	On a wall, flipchart papers are posted for each of the skill sets. Each team put the identified competencies under the corresponding skill set after presenting briefly to the overall team. The group as a whole reads through all the challenges and will tries to rephrase the name of the skill set or give a short title if necessary.
Total Duration:	**90 minutes (finish by 16:00)**		

Appendix III. Competencies list

Competency Tier	Competency Set	Competency Topic	No	4D - BIM Competency Item	Codes
Core competencies					
speciality, overall experience, market exposure, and project experience	**Foundational Traits**	Time management	88	Cope with time pressure	4:85;
		Digital affinity	89	Interest and affinity to improve and acquire new digital skills	4:99;
			90	Determination and patience with software related issues	4:97;
		Problem solving aptitude	91	Take responsibility and be resourceful	4:87;
		Effective team player	92	Collaborate and communicate effectively with various types of personalities and backgrounds	4:100;
	Situational Enablers	Creativity	93		
	Qualifications & Licences				
	Historical Indicators				
Domain Competencies					
 Technical	**Technical** individual abilities needed to generate 4D BIM project deliverables across disciplines and specialities	Software data import / export	1	Check if the file format of the 3D model can be used	4:17; 5:32;
			2	Export schedule from different software	4:75; 5:16
			3	Use excel to export, manipulate and re-import data	5:31;
		3D Design Software	4	Draw simple 3D elements and polyline paths in various 3D software	4:74; 5:12; 5:13;
			5	Subdivide 3D elements in external 3D software	4:74; 5:14;
		Basic 4D BIM Software Use	6	Recognise properties and user fields exist in a 3D model	5:15;
			7	Allocate 3D resources on tasks in 4D BIM Software	2:1; 3:37; 5:18;
			8	Navigate through the 4D BIM Software views	2:1; 3:37; 5:19;
			9	Create a schedule from scratch based on the 3D elements (4D BIM Software)	2:1; 3:37; 5:20;
			10	Create and export reports (animations + frames)	2:1; 3:37; 5:22;
			11	Use 3D model user fields for smart filtering	4:62; 5:24;
			12	Create and use cutting planes	5:25;
			13	Create and assign clear appearance profiles	5:26;
			14	Set and modify relationships among the project tasks	6:2;
		Advanced 4D BIM Software Use	15	Create make use of workspaces in 4D BIM Software	4:73; 4:34; 5:23
			16	Compare schedule alternatives or progress in 4D BIM Software (baselines)	4:73;
			17	Create 3D paths in 4D BIM Software	4:73; 5:21;
			18	Ensure "smart" visualisations that follow and explain precisely the construction process	5:29; 5:27;
			19	Ensure "smart" activity coding able to provide information for levels, suppliers, etc.	5:30;
			20	Use scripts within the 4D BIM software to improve working efficiency	6:1;
 Operation	**Operation** daily, hands-on individual efforts required to deliver a project or part/aspect of a project in 4D BIM	Data evaluation and processing (Input)	21	Understand the 3D elements in the model and request clarifications	4:21; 4:22
			22	Evaluate the 3D models in terms of completeness based on the initial agreements	2:03; 4:24
			23	Collect information regarding the initial schedule (Baseline 0)	4:16; 4:29
			24	Identify major phases that may be missing in the initial schedule	2:14;
		Model output use	25	Prepare and generate multiple types of 4D BIM Deliverables	2:22; 4:94
			26	Use 4D BIModel during meetings to provide information and stimulate decision making (based on data)	2:22; 3:38
			27	Use 4D BIModel during meetings to stimulate understanding of the project elements (navigate through the visualisation)	4:35; 3:38
			28	Use multiple 4D BIM outcomes during meetings (to keep notes, make adjustments, etc.)	3:38;
			29	Present information in the 4D BIModel in an understandable way for non-software users (clashes, design mistakes, etc.)	4:57; 4:94; 4:84; 4:67
		Construction engineering basics	30	Identify the structure of complex technical systems (break it down)	2:4; 4:79
			31	Identify the steps and the logical sequence of the construction process	2:5; 3:39; 5:1
			33	Report on hard clashes	2:4; 4:80; 5:3
			34	Identify time depended clashes - constructability reports	2:4; 4:80; 5:4

Competency Tier	Competency Set	Competency Topic	No	4D - BIM Competency Item	Codes
	**Operation** daily, hands-on individual efforts required to deliver a project or part/aspect of a project in 4D BIM	Project planning	35	Ensure that all the components are included in the schedule and they are correctly linked with a task	3:50; 4:66
			36	Develop the project planning in more detail. From overall task description to detailed tasks, step-by-step (LoD 2 --> LoD 3)	4:32; 4:81
			37	Organise sessions to acquire more information from multiple specialists	4:26;
			38	Interview specialists about the project planning	4:30;
			39	Identify inaccuracies, missing elements or impossible planning and raise early awareness	4:25; 4:66; 5:2
		Construction monitoring	40	Recognise when the construction starts differentiating from the planning	4:78;
			41	Keep track of the progress and time constraints and changes in the construction site	4:104;
			42	Be alert and identify changes and progress in a construction site	2:7;
			43	Confirm early any inconsistency between the planning and the actual construction with the people in charge	2:15; 4:27
			44	Use the model to prepare client and team updates regarding the progress	4:41;
		Model updating	45	Access and use a changes management platform (Software: Autodesk glue, etc.)	22:5;
			46	Acquire detailed information regarding changes, their urgency and priority	4:70; 5:6; 5:7
			47	Update the model whenever there are schedule/design changes or inconsistencies	4:31;
	**Functional** non-technical, overall abilities needed to initiate, manage and deliver projects with the requirement for 4D BIM	Validation and verification	48	Initiate and run the validation loops (plan, organise and prepare meetings / sessions etc.)	2:12; 4:36
			49	Facilitate and guide the meetings (keep order and time, coordinate, draw conclusions, summarize discussions)	4:89; 4:38
			50	Prepare for the meetings and think of the interaction with the model during them	4:13; 4:11; 5:8
			51	Ask the right questions in order to ensure accuracy and validity of the planning and the information in the model	2:11; 4:96;
		Interdisciplinary collaboration	52	Understand the work of different specializations, address everybody's expertise and contribution in the team goal	4:93; 5:9;
			53	Coordinate work among different disciplines, provide all the necessary information and eliminate irrelevant matter	4:92; 4:68
			54	Set and coordinate a network of different specialists	4:33; 4:15; 4:39
		Effective communication	55	Adjust the way of talking to address all different layers of the project organization	4:91;
			56	Understand the technical terminology and jargon	2:6;
			57	Gain credibility and build trust among the project stakeholders	4:95;
			58	Explain "why" (for each decision, change, action …)	4:90;
		Data visualisation	59	Validate data, filter the key information and distinguish the "signal" from "noise" (checking)	5:10;
			60	Translate data into workable information (presenting)	2:10;
			61	Visualise technical structures	4:76;
			62	Connect information, draw meaningful conclusions and present them in order to rationalise the decision making	4:65; 4:71
		Working flexibility	63	Find out alternative solutions when there is lack of information	4:98;
			64	Think on an analytical way: be able to switch between detailed information and headlines	4:88;
			65	Evaluate time-wise the desired LoD and define accordingly the 4D BIM deliverables	2:9;
			66	Select the proper team management approach, for the team and the task to be performed	6:3;
	Implementation activities required to introduce transformative 4D BIM concepts and tools into an organization	Standardization	67	Standardise the way of working and prepare templates	2:13;
		Knowledge sharing	68	Discuss with managers about the lessons learned after the completion of a project	4:42;
			69	Create manuals, roadmaps and flowcharts regarding the way of working with 4D BIM	2:13; 4:101
		Coaching	70	Explain the way of working and coach new colleagues	4:101; 2:28
		Influence	71	Explain the benefits of 4D BIM in a tangible way to colleagues' and partners	3:51; 3:48; 4:11
			72	Adopt persuasive and convincing techniques to talk about the 4D BIM tools to various management stakeholders	4:72; 4:102; 4:103
			73	Initiate proactively the 4D BIM (Digital Construction) way of working instead of the "traditional planning"	4:72; 4:52; 4:11
	**Administration** day-to-day organizational 4D BIM activities as required to meet and maintain strategic objectives	Initial agreements	74	Analyse the contract and develop a 4D BIM requirements list	4:54; 4:77
			75	Negotiate and agree upon the 4D BIM deliverables with the involved parties	4:54; 4:106
		Process management	76	Outline the 4D BIM process for a project and describe precisely the needs for each of the process steps	4:105; 4:108
			77	Define and agree with all parties the LoD appropriate for each of the different phases of the project	4:58;
			78	Make agreements of the information exchange and format for each of the process phases	4:105; 4:108

Competency Tier	Competency Set	Competency Topic	No	4D - BIM Competency Item	Codes
	Administration day-to-day organizational 4D BIM activities as required to meet and maintain strategic objectives	Information mining	79	Identify the information needs and their sources	2:8; 4:107
			80	Understand the project hierarchy and reach the right people for information	2:14; 4:107
		Balance effort and impact	81	Evaluate the need and the effort for updating the model	4:86;
			82	Understand the project scope and rationalise decisions based on it	2:17; 4:82
			83	Monitor regularly the level of detail and decide on adding more activities or keeping less based on the initially agreed LoD	2:16; 4:64; 4:66
	**Supportive** abilities needed to maintain information and communication technology systems supporting 4D BIM	Competency set from BIM competencies framework that could not be identified for the specific 4D BIM competencies			
	**Research & Development** abilities needed to evaluate existing 4D BIM processes, investigate new solutions and facilitate their adoption - within the organization or by the larger industry	General research and development	84	Find out ways to optimise the process and the way of working with 4D BIM	4:109;
			85	Explore new concepts and innovative ideas regarding 4D BIM implementation	3:12;
		Continuous learning	86	Adopt and learn from scratch new digital tools	4:10; 3:10; 3:9
		Scripting	87	Write simple code lines / Know a programming language	5:11;
	**Managerial** decision-making abilities which drive the selection/adoption of long-term strategies and initiatives regarding 4D BIM	Competency set from BIM competencies framework that could not be identified for the specific 4D BIM competencies			
Execution Competencies					
ability to use specific tools and techniques to conduct an activity or deliver a measureable outcome	**Software Tools** **Field Equipment** **Vehicles** **Techniques**	Competency sets that have already included above as 4D BIM competencies, due to the more technical narrowed down scope of the 4D BIM.			

Appendix IV. Detailed design on the training

Level A

Information management

SYNCHRO SOFTWARE BASICS

4D BIM Software basics

For whom?

Employees who just start being involved in the 4D BIM process.

Goal:

Understand the 4D BIM tools and processes. Manage information that matters for 4D BIM.

- Ice-breaking
- Introduction
- Recall
- Comprehension
- Assessment
- On-the-job Assignment

Information management

Goal:
Reaching, refining and visualizing information that matters for the development of 4D BIM

Ice-breaking – 15 min

Communication game in pairs:
Back-to-Back Drawing

The participants divide into pairs. Each pair sits with their backs to one another. One person from each partnership receives an image (shape or collection of shapes depending on difficulty level wanted) to describe to their partner who is given a pencil and a paper. Each partner must describe their shape(s) to their partners without actually telling them what the shape is. Once pairs think they are done they may compare images.

Introduction – 10 min

Learning Objectives

- Collect information regarding the initial schedule
- Identify major phases that may be missing in the initial schedule
- Understand the project hierarchy and reach the right people for information

Presentation

- Why do we need Information Management?
- What information should we acquire? #task
- What do we do with the information? #process
- How: do we do it? (Addressing the LO on the right)

- Schedule of the day
  → Goal of the day
  → Learning objectives
  → Assignments

- Personal Reflection Quiz

Recall – 120 min

Learning Objectives

- Understand the 3D elements in the model and request clarifications
- Evaluate the 3D models in terms of completeness based on the initial agreements

Mini Workshops
(Parallel mini-workshops of 40' for 3-4 participants
After each workshop participants rotate until the complete all of them)

Mini Workshop I (40 min):
3D BIM Readiness

- Basic concept of BIM
- How can we understand if we can use a 3D model (just 3D or 3D BIM)?
- What kind of information should we look for in a 3D BIM model?
- Mini-assignment:
  Given initial agreements → check the model!

Recall – 120 min

Learning Objectives

- Validate data, filter the key information and distinguish the "signal" from "noise" (checking)
- Translate data into workable information (presenting)

Mini Workshop II (40 min):
Data Visualization

- Evaluate the sources of data
- Understand the data
- Make a story that will resonate with your audience
- Visualize: choose the right way to display your data – make visible to the eye
- Decide the balance between beauty and function of your data
- Mini assignment: make your story with the data

Recall – 120 min

Learning Objectives

- Visualize technical structures
- Identify the structure of complex technical systems (break them down)

Mini Workshop III (40 min):
Technical Drawing

- Similar (/sequential) to Business drawing workshop (based on the book: Visual Thinking)

- Easy ways you can visualize technical structures
  - Breaking down
  - Visualization tricks

- Try out while the facilitator is explaining

Comprehension – 110 min

Learning Objectives

- Identify major phases that may be missing in the initial schedule
- Identify the steps and the logical sequence of the construction process
- Understand the technical terminology and jargon
- Understand the work of different specializations, address everybody's expertise and contribution in the team goal

Group Assignment:
Information Mining Role Play Game
Participants split in teams of three.
Each member of the team gets a role (3D Expert, Information Expert, Visualization Expert) and the group gets the assignment:

"Break down in smaller tasks a high-level schedule for one complicated technical element (e.g. gas station installations). Use simple drawings to understand the steps of the construction. Use the given 3D model and the data you get from the available stakeholders."

Facilitators have the roles of the stakeholders contractor, manufacturer, worker, municipality and they can provide knowledge and datasets from their field. The teams have to plan meetings with all of them in the available time.

Assessment – 30 min

Final Presentations

- Each team presents the final results of the assignment.
- Participants give peer feedback and ask questions
- Experts give feedback and answer remaining questions

- Personal Reflection Quiz

- Training Evaluation Quiz

On-the-job assignment – 1 month

- Open the initial 3D model for an ongoing project. Check yourself if it has the information that you would need to start working on 4D – write down which user fields you would need and for what reason. Discuss with your team leader and check your approach.

- Be present at least in 2 different 4D validation meetings: Try to prepare a simple drawing explaining the structure on discussion. What information do the 4D planner needs from the people present? What data can he provide? Make a list and check it with your team leader.

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Goal:
Reaching, refining and visualizing information that matters for the development of 4D BIM

Evaluation Scheme

	Module 1: Information Management				
	Goal: Reaching, refining and visualizing information that matters for the development of 4D BIM				
	Understand the 3D elements in the model and request clarifications	Verbal Knowledge	Declarative Knowledge	Cognitive Outcomes	Power tests (Accessibility of knowledge)
	Evaluate the 3D models in terms of completeness based on the initial agreements	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Chunking)
	Collect information regarding the initial schedule	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Discrimination)
	Identify major phases that may be missing in the initial schedule	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Generalization)
	Identify the structure of complex technical systems (break them down)	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Chunking)
	Identify the steps and the logical sequence of the construction process	Verbal Knowledge	Declarative Knowledge	Cognitive Outcomes	Speed tests (Speed of knowledge)
	Understand the technical terminology and jargon	Verbal Knowledge	Declarative Knowledge	Cognitive Outcomes	Recognition and recall tests (Amount of knowledge)
	Validate data, filter the key information and distinguish the "signal" from "noise" (checking)	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Error rates)
	Translate data into workable information (presenting)	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Visualise technical structures	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Understand the work of different specializations, address everybody's expertise and contribution in the team goal	Cognitive Strategies	Self-insight	Cognitive Outcomes	Self-report measures (Self-awareness)
	Understand the project hierarchy and reach the right people for information	Knowledge Organization	Mental Models	Cognitive Outcomes	Structural assessment (Similarity to ideal)
	Identify the information needs and their sources	Knowledge Organization	Mental Models	Cognitive Outcomes	Structural assessment (Interrelationships of elements)

SYNCHRO SOFTWARE BASICS

4D BIM Software basics

Goal:
Performing simple 4D BIM software tasks, understanding the software logic and learning fast new software tools, buttons and procedures

Ice-breaking – 5 min

Make your team mascot and explain your 4D BIM learning goal of the day!

In about 10 minutes, the group needs to create a 3D mascot. To do so, each of the team members pick a set of two objects form the warming-up kit envelope. They need to collaborate to create their 3D representation of the mascot. Starting from someone every participant combines their two objects in the team mascot why they try to explain link of their object with their (learning) goal of the day.

Introduction – 15 min

Presentation

- What is 4D BIM? #task
- What does the company do with the new digital tools? (Learning mindset) #process
- Why do we really do it?
- How: do we do it? (Addressing the LO on the right)

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Learning Objectives

- Find out alternative solutions when there is lack of information
- Discuss with managers about the lessons learned after the completion of a project
- Adopt and learn from scratch new digital tools

Recall – 90 min

Presentation (15 min):
Software Introduction

Brief explanation about:
- the synchro Interface
- the synchro main entities (3D - resources - tasks)

Teams receive a step-by-step guide (print screens with indicated clicks) with the steps required for delivering the assignments. Facilitator quickly goes through the steps required for the individual assignment during the presentation.

Learning Objectives

- Navigate through the 4D BIM Software views
- Set and modify relationships among the project tasks
- Create and assign clear appearance profiles
- Create and use cutting planes

Recall – 90 min

Individual Assignment (45 min):
Create a schedule based on the 3D elements

Each participant receives a very simplified 3D BIM model already imported in the 4D BIM software. 3D Resources are grouped therefore tasks can easily be created directly from the 3D model. Participants should link the tasks (FS relationships only), create and allocate properly 3 appearance profiles (steel – concrete – temporary transparency).

Learning Objectives

- Create a schedule from scratch based on the 3D elements (baseline 0)

Recall – 90 min

Presentation (30 min)

- Solution of Individual Assignment
- Introduction to user fields and filtering
- Explanation and instructions of assignment:
  - What do you have to do
  - What do you get
  - Requirements and clarifications
- Facilitator quickly goes through the steps required for the group assignment during the presentation.

Learning Objectives

- Recognize properties and user fields exist in a 3D model

Comprehension – 120 min

Group Assignment:
Prepare a 4D Model

Participants split in groups of 2. Each group receives a real case 3D Model imported in 4D BIM software. The model has all the relevant task lines, appearance profiles and 3D resources. It is the task of the participants to link correctly the 3D resources with the tasks and the appearance profiles as well as to link correctly the tasks in a coherent schedule of activities and export an animation and a construction scenario book (frames). Filters based on 3D user fields should be used and at least 2 cutting planes should be created.

Learning Objectives

- Use 3D model user fields for smart filtering
- Allocate resources in 4D BIM Software
- Create and export reports (animations + frames)
- Ensure that all the components are included in the schedule and they are correctly linked with a task

Assessment – 30 min

Final Presentations

- Each team presents the final results of the assignment.
- Participants give peer feedback and ask questions
- Experts give feedback and answer remaining questions
- Personal Reflection Quiz
- Training Evaluation Quiz

On-the-job assignment – 1 month

- Practice your basic synchro skills (user fields, resource allocation) on one of the existing projects, ask for feedback search new solutions.
- Complete the SYNCRHO PRO FUNDAMENTALS course online and get certified online by Syncrho Academy.

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SYNCHRO SOFTWARE BASICS

4D BIM Software basics

Goal:
Performing simple 4D BIM software tasks, understanding the software logic and learning fast new software tools, buttons and procedures

Evaluation Scheme

Module 2: 4D BIM software basics				
Goal: Performing simple 4D BIM software tasks, understanding the software logic and learning fast new software tools, buttons and procedures				
Recognise properties and user fields exist in a 3D model	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
Allocate 3D resources on tasks in 4D BIM Software	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Error rates)
Navigate through the 4D BIM Software views	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
Create a schedule from scratch based on the 3D elements (baseline 0)	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Speed, Quality of performance)
Create and export reports (animations + frames)	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Quality of performance)
Use 3D model user fields for smart filtering	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
Create and use cutting planes	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Quality of performance)
Create and assign clear appearance profiles	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Error rates)
Set and modify relationships among the project tasks	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Error rates)
Ensure that all the components are included in the schedule and they are correctly linked with a task	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Quality of performance)
Find out alternative solutions when there is lack of information	Attitudinal	Attitude Strength	Affective Outcomes	Self-report measures (Accessibility, Centrality, Conviction)
Discuss with managers about the lessons learned after the completion of a project	Attitudinal	Targeted Object	Affective Outcomes	Self-report measures (Attitude Direction)
Adopt and learn from scratch new digital tools	Motivation	Self-efficacy	Affective Outcomes	Self-report measures (Mastery VS Performance orientations)

Level B

- Advanced 4D BIM
- Scheduling in 4D
- Verification and validation with 4D
- 4D Progress monitoring

For whom?

Employees working within a team developing and using 4D BIM outcomes.

Goal:

Ability to prepare and use different 4D BIM deliverables through the design and construction phase of a project.

- Ice-breaking
- Introduction
- Application
- Analysis
- Assessment
- On-the-job Assignment

Advanced 4D BIM

Goal:
Performing advanced software tasks and standardizing the 4D BIM way of working

Ice-breaking – 5 min

Superlatives Game:

The group is divided in team of 5-6 people. The goal of the game is to re-order themselves as quickly as possible. Some examples are:

- From shortest to tallest – how many letters are in your first name
- From farthest away to closest – birthplace
- From least to most – how many brothers and sisters you have
- Shortest to tallest – height

Introduction – 10 min

Presentation

- Why 4D BIM excellence?
- What is a "smart" 4D BIModel? #task
- What is the coupling between agile concept and 4D BIM (standardization, optimization) #process
- How: do we do it? (Addressing the LO on the right)

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Learning Objectives

- Ensure "smart" visualizations that follow and explain precisely the construction process
- Ensure "smart" activity coding able to provide information for levels, suppliers, etc.
- Find out ways to optimize the process and the way of working with 4D BIM
- Explore new concepts and innovative ideas regarding 4D BIM implementation

Application – 90 min

Presentation (15 min)

Introduction to:
- Synchro Scripting
- Baselines and alternative scenarios

Teams receive a step-by-step guide (print screens with indicated clicks) with the steps required for delivering the assignments. Facilitator quickly goes through the steps required for the individual assignment during the presentation.

Learning Objectives

- Use scripts within the 4D BIM software to improve working efficiency
- Compare schedule alternatives or progress in 4D BIM Software (baselines)

Application – 90 min

Individual Assignment (60 min):
Estimate Durations & Present Alternatives

Participants work on the model they prepared in the previous module (on which tasks are already linked with 3D resources and allocated to appearance profiles). The are requested to estimate all of the task durations based on the material quantities for each task. They receive an excel sheet with the estimations. They have to present and compare two different scenarios of planning in Synchro. applying an optimization by running two activities in parallel.

Learning Objectives

- Use scripts within the 4D BIM software to improve working efficiency
- Compare schedule alternatives or progress in 4D BIM Software (baselines)

Application – 90 min

Presentation (15 min)

Introduction to:
- Workspaces and clash detection
- 3D paths

Facilitator quickly goes through the steps required for the group assignment during the presentation.

Learning Objectives

- Create and use workspaces in 4D BIM Software
- Create 3D paths in 4D BIM Software

Analysis – 140 min

Group Assignment:
Create Workspaces and 3D Paths

Based on the same model (Individual Assignment). In groups of 4, participants have to prepare and present to the client two different solutions for full weekend planning that takes into account restrictions on the amount of people working in one space and workspace clash detection based on the moving path of cranes. The get as an input the amount of people working on site per day from each of the suppliers and the working schedule of the cranes.

Learning Objectives

- Create and use workspaces in 4D BIM Software
- Create 3D paths in 4D BIM Software

Assessment – 30 min

Final Presentations

- Each team presents the final results of the assignment.
- Participants give peer feedback and ask questions
- Experts give feedback and answer remaining questions
- Personal Reflection Quiz
- Training Evaluation Quiz

On-the-job assignment – 1 month

- Be the responsible 4D planner for one of the projects.
- Prepare a 4D BIM project template / manual / script for one of the 4D BIM software processes that are required for your work (estimating quantities, exporting reports, creating 3D paths, etc...) for your future colleagues.

Learning Objectives

- Standardize the way of working and prepare templates
- Create manuals, roadmaps and flowcharts regarding the way of working with 4D BIM

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Advanced
4D BIM

Goal:
Performing advanced software tasks and standardizing the 4D BIM way of working

Evaluation Scheme

	Module 3: Advanced 4D BIM				
	Goal: Performing advanced software tasks and standardise the 4D BIM way of working				
	Create and use workspaces in 4D BIM Software	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Compare schedule alternatives or progress in 4D BIM Software (baselines)	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Create 3D paths in 4D BIM Software	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Ensure "smart" visualisations that follow and explain precisely the construction process	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Error rates, Quality of performance)
	Ensure "smart" activity coding able to provide information for levels, suppliers, etc.	Knowledge Organization	Mental Models	Cognitive Outcomes	Structural assessment (Similarity to ideal)
	Use scripts within the 4D BIM software to improve working efficiency	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Standardise the way of working and prepare templates	Cognitive Strategies	Self-insight	Cognitive Outcomes	Probed protocol analysis (Self-awareness)
	Create manuals, roadmaps and flowcharts regarding the way of working with 4D BIM	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Generalization)
	Explore new concepts and innovative ideas regarding 4D BIM implementation	Motivation	Self-efficacy	Affective Outcomes	Self-report measures (Perceived Performance Capability)
	Find out ways to optimise the process and the way of working with 4D BIM	Motivation	Self-efficacy	Affective Outcomes	Self-report measures (Perceived Performance Capability)

Scheduling in 4D

Goal:
Developing a highly detailed construction schedule in 4D BIM

Ice-breaking – 10 min

Spaghetti and marshmallow challenge

Teams of 4:
20 sticks of dry spaghetti
one meter of string
one meter of tape
one marshmallow

Goal: To build the tallest tower possible in 18 minutes that will support the marshmallow.

Success: kinder garden students (prototyping), engineers + architects (specialized knowledge), CEO with executive admin (facilitation skills)

Introduction – 10 min

Presentation

- Why direct scheduling in 4D BIM software
- What is the challenge of coordinating work of different disciplines #task
- What is the role of the company as a scheduling partner #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Application – 80 min

Workshop (40 min):
MECE Approach

- What is MECE approach
- How it works?
- How do you use it when scheduling in 4D?

- Mini-assignment: Change a non-MECE breakdown structure in order to follow the MECE principle.

Learning Objectives

Think on an analytical way: be able to switch between detailed information and headlines

Application – 80 min

Workshop (40 min)
Sprint Approach

- What is the sprints approach
- How it works?
- How do you use it when scheduling in 4D?

- Mini-assignment: Prepare a sprint schedule for detailing a 4D model from level 2 to level 3.

Learning Objectives

Develop the project planning in more detail. From overall task description to detailed tasks, step-by-step (LoD 2 --> LoD 3)

Organize sessions to acquire more information from multiple specialists

Application – 80 min

Presentation (20 min)
Topic: Clashes

- Hard clashes and soft clashes
- Constructability reports
- Useful tips - lessons learned

Learning Objectives

Report on hard clashes

Identify time depended clashes - constructability reports

Analysis – 140 min

Group Assignment:
Impossible Planning

Participants are given a 4D model with an impossible planning. Every team has to identify what is impossible (hard clashes, time depended clashes, stakeholder and regulation requirements.

Facilitators have different roles (client, power supplier, contractor) and teams have to set and run a meeting with each of them (30min) during which they gather input to resolve the planning.

They have to come up with a solution and prepare the meeting outline for presenting it to the stakeholders.

Learning Objectives

Interview specialists about the project planning

Identify inaccuracies, missing elements or impossible planning and raise early awareness

Coordinate work among different disciplines, provide all the necessary information and eliminate irrelevant matter

Assessment – 30 min

Final Presentations

- Each team presents the final results of the assignment.
- Participants give peer feedback and ask questions
- Experts give feedback and answer remaining questions

- Personal Reflection Quiz

- Training Evaluation Quiz

On-the-job assignment – 1 month

- Work in one of the on-going projects that is current in the planning phase. Apply what you have learned.

  Discuss about your questions and lessons learned with your team leader.

Operation

Functional

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Scheduling in 4D

Goal:
Developing a highly detailed construction schedule in 4D BIM

Evaluation Scheme

	Module 4: Scheduling in 4D				
	Goal: Developing a highly detailed construction schedule in 4D BIM				
	Report on hard clashes	Verbal Knowledge	Declarative Knowledge	Cognitive outcomes	Recognition and recall tests (Amount of knowledge)
	Identify time depended clashes - constructability reports	Verbal Knowledge	Declarative Knowledge	Cognitive outcomes	Recognition and recall tests (Amount of knowledge)
	Develop the project planning in more detail. From overall task description to detailed tasks, step-by-step (LoD 2 --> LoD 3)	Verbal Knowledge	Declarative Knowledge	Cognitive outcomes	Recognition and recall tests (Amount of knowledge)
	Organise sessions to acquire more information from multiple specialists	Cognitive Strategies	Self-insight	Cognitive outcomes	Probed protocol analysis (Self-regulation)
	Interview specialists about the project planning	Verbal Knowledge	Declarative Knowledge	Cognitive outcomes	Recognition and recall tests (Amount of knowledge)
	Identify inaccuracies, missing elements or impossible planning and raise early awareness	Verbal Knowledge	Declarative Knowledge	Cognitive outcomes	Speed tests (Speed of knowledge)
	Coordinate work among different disciplines, provide all the necessary information and eliminate irrelevant matter	Verbal Knowledge	Declarative Knowledge	Cognitive outcomes	Recognition and recall tests (Amount of knowledge)
	Think on an analytical way: be able to switch between detailed information and headlines	Cognitive Strategies	Metacognitive skills	Cognitive outcomes	Probed protocol analysis (Self-regulation)

Verification and validation with 4D

Goal:

Using properly the 4D BIM outcomes for validation and verification of the construction planning

Ice-breaking – 5 min

Yes, but... / Yes and... Game

Participants in groups of two have a short-talk about a vacation plan (dream trip):

- Participant A shares with B where they should go
- Participant B respond with "Yes, BUT..." and a critic to the destination
- Participant A defend his/her choice with "Yes, BUT..."

After two minutes Participant B shares his/ her vacation destination. Now, the response should be, "Yes, AND..."

Discuss shortly: How did it feel in each case? What emotions came up? What is usually your approach?

Introduction – 15 min

Presentation

- Why V&V with 4DBIM?
- What is the goal of V&V meetings #task
- What 4D BIM can offer for V&V #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Application – 40 min

Workshop (25min)
Way of working – Meetings Coordination

- Asking the right questions
- Coordinating a meeting discussion
- Preparing a meeting agenda, keeping track of time
- Addressing participants expertise, eliminate irrelevant matter
- Mini-assignment: Participants are given a 2 hours meeting agenda and a list of the meeting participants with their disciplines and their characteristics. They have to come up with questions addressing to each of them in order to achieve the meeting goals within time.

Learning Objectives

- Connect information, draw meaningful conclusions and present them in order to rationalize the decision making
- Initiate and run the validation loops (plan, organise and prepare meetings / sessions etc.)
- Facilitate and guide the meetings (keep order and time, coordinate, draw conclusions, summarize discussions)
- Adjust the way of talking to address all different layers of the project organization
- Ask the right questions in order to ensure accuracy and validity of the planning and the information in the model

Application – 40 min

Presentation (15 min):
Way of working 4D BIM during meetings

- Types of interaction with the 4D BIM models
- Steps for the correct preparation and use of the model during a meeting

Learning Objectives

- Use 4D BIModel during meetings to provide information and stimulate decision making (based on data)
- Use 4D BIModel during meetings to stimulate understanding of the project elements (navigate through the visualization)
- Use multiple 4D BIM outcomes during meetings (to keep notes, make adjustments, etc.)

Analysis – 100 min

Group Assignment:
Prepare a V&V meeting with 4D

- Participants receive a complete 4D BIM Model of an on going company project,
- The have to prepare a V&V meeting outline and generate relevant 4D BIM output for use during the meeting.
- Each group has different stakeholders as targeted participants for the meeting (installations company, contractor, crane operator). And they have to verify the sequence and duration of activities.

Learning Objectives

- Prepare and generate multiple types of 4D BIM Deliverables
- Present information with the help of the 4D BIModel in an understandable way for non-software users (clashes, design mistakes, etc.)
- Prepare for the meetings and think of the interaction with the model during them

Assessment – 30 min

Final Presentations

- Each team presents the final results.
- Discussion of the meeting outlines with the group:
  - What are the main differences between the targeted stakeholders?
- Participants give peer feedback and ask questions
- Experts give feedback and answer remaining questions
- Personal Reflection Quiz
- Training Evaluation Quiz

On-the-job assignment – 1 month

- Improve and run the meeting you prepared with the project stakeholders.
- Discuss with the team leader the experience and the learning effects.

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Verification and validation with 4D

Goal:
Using properly the 4D BIM outcomes for validation and verification of the construction planning

Evaluation Scheme

	Module 5: Verification and Validation with 4D				
	Goal: Using properly the 4D BIM outcomes for validation and verification of the construction planning				
	Prepare and generate multiple types of 4D BIM Deliverables	Automaticity	Tuning	Skill-based Outcomes	Hands-on testing (Embedded measurement)
	Use 4D BIModel during meetings to provide information and stimulate decision making (based on data)	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Use 4D BIModel during meetings to stimulate understanding of the project elements (navigate through the visualisation)	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Use multiple 4D BIM outcomes during meetings (to keep notes, make adjustments, etc.)	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Present information with the help of the 4D BIModel in an understandable way for non-software users (clashes, design mistakes,	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Connect information, draw meaningful conclusions and present them in order to rationalise the decision making	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Generalisation, Discrimination)
	Initiate and run the validation loops (plan, organise and prepare meetings / sessions etc.)	Cognitive Strategies	Self-insight	Cognitive outcomes	Probed protocol analysis (Self-regulation)
	Facilitate and guide the meetings (keep order and time, coordinate, draw conclusions, summarize discussions)	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Prepare for the meetings and think of the interaction with the model during them	Cognitive Strategies	Metacognitive skills	Cognitive outcomes	Probed protocol analysis (Self-regulation)
	Ask the right questions in order to ensure accuracy and validity of the planning and the information in the model	Knowledge Organization	Mental Models	Cognitive Outcomes	Free sorts (Similarity to ideal)
	Adjust the way of talking to address all different layers of the project organization	Attitudinal	Targeted Object	Affective Outcomes	Self-report measures (Attitude strength)

4D Progress monitoring

Goal:
Using the 4D BIModel for monitoring the construction process.

Ice-breaking – 5 min

Introduction game:
Repeat the move

Participants stand in a circle in order to be able see each other. First the facilitator, says his/her name followed by a confident single move of his/her body. One-by-one all members have to do the same after they repeat first all the previous names-moves in the right order.

Introduction – 10 min

Presentation

- Why progress monitoring with 4D BIM?
- What? Current practice regarding progress monitoring #task
- What? Future of the progress monitoring #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Application – 40 min

Presentation (10 min)

Way of working with 4D BIM
- Change management and 4D BIM
- Good practices - common mistakes in progress monitoring
- Preparing an update for a client / site team / management with 4D BIM
- Critical points for future developments (why people will be replaced by robots?)

Learning Objectives

Recognize when the construction starts differentiate from the planning

Confirm early any inconsistency between the planning and the actual construction with the people in charge

Application – 40 min

Group Assignment (20 min)

Participants split into groups. Each group gets the 4D model of a real project with the schedule baseline and the status information updated 2 weeks ago.

They have to prepare a 3 min presentation in order to update a client / site team / management team (each team different audience).

Feedback – Discussion Round (10 min)

- Each team presents the final results of the assignment (2 min presentation + 3 min questions)
- Experts and other participants give feedback

Learning Objectives

Use the model to prepare client and team updates regarding the progress

Analysis – 110 min

Workshop (80 min):
On-site progress surveying

The participants visit the project given in the assignment previously

With the help of the facilitators they observe changes and they document the current progress of the work

Individual Assignment (30 min)
Up – to – date 4D Model

Each participant has to update individually the given 4D BIM model based on the current status of the construction works, then, they need to export a report.

Learning Objectives

Be alert and identify changes and progress in a construction site

Keep track of the progress and time constraints and changes in the construction site

Assessment – 30 min

Feedback - Discussion

- Personal feedback is given to each of the participants and they have the opportunity to resubmit their assignment to be evaluated later
- Participants ask questions
- Experts give feedback and answer remaining questions

- Personal Reflection Quiz

- Training Evaluation Quiz

On-the-job assignment – 1 month

Search an present a technological tool / future development for process monitoring and make a presentation for a company update:

- What are the benefits?
- What should being further developed?
- Costs involved?
- What should change in the current practice to facilitate the future development?

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4D Progress monitoring

Goal:
Using the 4D BIModel for monitoring the construction process.

Evaluation Scheme

Module 6: 4D Progress Monitoring Goal: Using the 4D BIModel for the monitoring the construction process				
Recognise when the construction starts differentiating from the planning	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Speed of performance)
Keep track of the progress and time constraints and changes in the construction site	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
Be alert and identify changes and progress in a construction site	Automacity	Automatic processing	Skill-based Outcomes	Hands-on testing (Secondary Task Performance)
Confirm early any inconsistency between the planning and the actual construction with the people in charge	Cognitive Strategies	Self-insight	Cognitive Outcomes	Probed protocol analysis (Self-awareness)
Use the model to prepare client and team updates regarding the progress	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
Update the model whenever there are schedule/design changes or inconsistencies	Cognitive Strategies	Self-insight	Cognitive Outcomes	Probed protocol analysis (Self-awareness)

Level C

4D BIM Hacks

4D BIM Process Management

4D BIM Coaching

For whom?

Experienced 4D BIM employees responsible to lead, consult and coach project teams.

Goal:

Ability to outline the 4D BIM process and needs, solve any related problems and coach employees on their 4D BIM related developments.

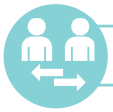
Preparation (On-the-job)

Ice-breaking

Introduction

Synthesis

Evaluation



Assessment

On-the-job Assignment

4D BIM Hacks

Goal:
Using multiple software tools in order to solve issues between 3D models, schedules and 4D BIM. Coding simple lines for data manipulation and future development purposes

Preparation (On-the-job) – 3 months

Prepare a mini-workshop (40 min)

In one of the following topics:

- File types, software workflow & basic scripts for linking 4D BIM, excel and databases
- 4D BIM data graphs
- 3D Software basics

Introduction – 10 min

Presentation

- Why getting familiar with different software?
- What are the software tools in the company toolbox? #task
- What is the role of each software tool in a 4D BIM project? #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Introduction – 10 min

Presentation

- Why getting familiar with different software?
- What are the software tools in the company toolbox? #task
- What is the role of each software tool in a 4D BIM project? #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Synthesis – 120 min

Learning Objectives

- Check if the file format of the 3D model can be used
- Write simple code lines / Know a programming language

Workshop (40 min):
File types, software workflow & basic scripts for linking 4D BIM, excel and databases

- Facilitated by one of the participants
- What are the different type files used in the 4D BIM process.
- How do you set up initially a 4D BIM model (import schedule + 3D, create resources)
- Basic scripts for linking 4D BIM, excel and databases
- Mini – assignment: prepare the initial set-up and files workflow of a 4D BIM model.

Synthesis – 120 min

Learning Objectives

- Use excel to export, manipulate and re-import data

Workshop (40 min):
4D BIM data graphs

- Facilitated by one of the participants
- How to prepare data graphs in 4D BIM software.
- Which information can be relevant and how the results can be used?
- How can we import and export data to/from excel sheets?
- Mini – assignment: Prepare graphs in 4D BIM software and present their results.

Synthesis – 120 min

Learning Objectives

- Draw simple 3D elements and polyline paths in various 3D software
- Subdivide 3D elements in external 3D software

Workshop (40 min):
3D Software basics

- Facilitated by one of the participants
- Which are the most important commands in 3D software?
- How you can easily open a file break an element into smaller, save, export and re import in 4D BIM?
- Differences between 3D software.
- Mini-assessment: Practical example for practicing the above skills.

Evaluation – 30 min

Individual Assignment:
From Task lines and 3D to 4D BIM

Participants are provided with a 3D Revit model and excel schedules from different suppliers / contractors (in different software: excel, P6, etc) and they have to combine and import them in 4D BIM software and prepare the environment, in order for one of their colleagues to start working on the 4D BIModel.

Assessment – 30 min

Feedback - Discussion

- Personal feedback is given to each of the participants and they have the opportunity to resubmit their assignment to be evaluated later
- Participants ask questions
- Experts give feedback and answer remaining questions
- Personal Reflection Quiz
- Training Evaluation Quiz

On-the-job assignment – 1 month

- Practice and re-submit your assignment in order to get a better grade.
- Practice creating graphs in 4D BIM software for one of the on-going company projects.

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4D BIM Hacks

Goal:
Using multiple software tools in order to solve issues between 3D models, schedules and 4D BIM. Coding simple lines for data manipulation and future development purposes

Evaluation Scheme

	Module 7: 4D BIM Hacks				
	Goal: Using multiple software tools in order to solve issues between 3D models, schedules and 4D BIM. Coding simple lines for data manipulation and future development purposes				
	Check if the file format of the 3D model can be used	Automacity	Automatic processing	Skill-based Outcomes	Hands-on testing (Secondary Task Performance)
	Export schedule from different software	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Use excel to export, manipulate and re-import data	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Draw simple 3D elements and polyline paths in various 3D software	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Subdivide 3D elements in external 3D software	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Write simple code lines / Know a programming language	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)

4D BIM Process Management

Goal:
Outlining the complete 4D BIM process, making agreements and influencing all parties involved regarding the adoption of 4D BIM

Ice-breaking – 5 min

A shrinking vessel :

Using a rope, the facilitator makes a shape on the floor that every participant can fit into. Slowly shrinks the space over a time period of 2 minutes. Participants should together to figure out how to keep everyone within the shrinking boundaries.

"Technological innovation and disruption are happening faster than ever before. People, teams, and organizations in construction have to learn how to adapt and transform so they can stay on top."

Introduction – 15 min

Presentation

- Why digital transformation with 4D BIM?
- What are roles of a 4D Planner #task
- What is the role of others in the development of 4D BIM (why you cannot do it alone? #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Synthesis – 70 min

Workshop 1 (30 min)
Way of working: The 4D BIM Process

How does the 4D BIM process couple with the current tendering and construction phases followed by the company? 4D BIM process flowchart is presented and discussed.

Practice: Draw the information exchange needs on the 4D BIM process flowchart. Participants receive a 4D BIM process flowchart and they have to draw the necessary input and output for each phase.

Learning Objectives

- Outline the 4D BIM process for a project and describe precisely the needs for each of the process steps
- Define and agree with all parties the LoD appropriate for each of the different phases of the project
- Make agreements on the information exchange and format for each of the process phases

Synthesis – 70 min

Workshop 2 (40 min):
Motivational Speaking / Storytelling

- Storytelling / Motivational speaking secrets and techniques
- Structure
- Body language

Learning Objectives

- Storytelling regarding 4D BIM use and benefits in a tangible way to colleagues' and partners
- Adopt persuasive and convincing techniques to talk about the 4D BIM tools to various management stakeholders
- Initiate proactively the 4D BIM (Digital Construction) way of working instead of the "traditional planning"

Evaluation – 120 min

Group Assignment:
4D BIM Process plan for new contract

Participants split into teams and they have to perform the following assignment: Read the contract for a new project of the company and derive the 4D BIM requirements, set a 4D BIM process plan (with tasks, roles and deadlines) and set a first steps plan (meetings, participants and goals for each meeting) in order initiate the 4D BIM process.

Learning Objectives

- Set and coordinate a network of different specialists
- Understand the project scope and rationalise decisions based on it
- Analyse the contract and develop a 4D BIM requirements list
- Negotiate and agree upon the 4D BIM deliverables with the involved parties

Assessment – 30 min

Final Presentations

- Each team presents the final results of the assignment.
- Participants give peer feedback and ask questions
- Experts give feedback and answer remaining questions

- Personal Reflection Quiz

- Training Evaluation Quiz

On-the-job assignment – 3 months

On the 4D BIM flowchart imagine and draw a future C&C activity (based on 4D) and prepare a presentation about it for your team (way of working, skills required, desired results).

Or

Prepare and give a speech about the 4D BIM way of working in C&C for university students.

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4D BIM Process Management

Goal:
Outlining the complete 4D BIM process, making agreements and influencing all parties involved regarding the adoption of 4D BIM

Evaluation Scheme

	Module 8: 4D BIM Process Management				
	Goal: Outlining the complete 4D BIM process, making agreements and influencing all parties involved regarding the adoption of 4D BIM				
	Set and coordinate a network of different specialists	Cognitive Strategies	Metacognitive skills	Cognitive Outcomes	Probed protocol analysis (Self-awareness)
	Storytelling regarding 4D BIM use and benefits in a tangible way to colleagues' and partners	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Adopt persuasive and convincing techniques to talk about the 4D BIM tools to various management stakeholders	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Initiate proactively the 4D BIM (Digital Construction) way of working instead of the "traditional planning"	Motivation	Goal setting	Affective Outcomes	Self-report measures (Level of goals, Complexity of goal structures)
	Analyse the contract and develop a 4D BIM requirements list	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Chunking)
	Negotiate and agree upon the 4D BIM deliverables with the involved parties	Motivation	Motivational disposition	Affective Outcomes	Self-report measures (Appropriateness of orientation)
	Outline the 4D BIM process for a project and describe precisely the needs for each of the process steps	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Generalisation, Discrimination)
	Make agreements on the information exchange tasks and format in each of the process phases	Knowledge Organization	Mental Models	Cognitive Outcomes	Structural assessment (Similarity to ideal)
	Understand the project scope and rationalise decisions based on it	Compilation	Composition	Cognitive Outcomes	Hands-on testing (Generalisation, Discrimination)
	Define and agree with all parties the LoD appropriate for each of the different phases of the project	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)

4D BIM Coaching

Goal:
Overviewing the 4D BIM process, coaching on the way of working and balancing between effort and impact for updating 4D BIM

Ice-breaking – 10 min

Argumentation battle game.
The group is divided in 2 teams. There is a controversial topic to discuss (e.g. the statement: "Nuclear Power Plants will secure a sustainable future for Europe"). Participants flip a coin in order to decide which team will argue pro and which team will argue against the statement. Teams have 5 min to prepare their arguments 3 min per team to present them and 1 min per team to respond to the opposite team's argumentation. Facilitator decides the winning team by judging ONLY the strength of their arguments and the persuasiveness of the speech, not his/her opinion.

Introduction – 5 min

Presentation

- Why 4D BIM leadership?
- What is the role of a 4D BIM coach? #task
- What does it mean for a 4D BIM project team to be resilient to change? #process
- How: do we do it?

Schedule of the day
→ Goal of the day
→ Learning objectives
→ Assignments

Personal Reflection Quiz

Synthesis – 80 min

Workshop (20 min):
Influencing

- Influencing techniques - gaining credibility
- Innovation adoption factors
- Mini-assignment: Convince about the adoption of 4D BIM in a project

Learning Objectives

- Gain credibility and build trust among the project stakeholders
- Explain "why" (for each decision, change, action ...)

Synthesis – 80 min

Workshop (40 min):
Change Management and Respond to Changes

- Monitoring changes on a project
- Implementing changes in a project
- Mini Assignment: Write down the steps for updating 4D BIM in case of a design change in an under development project.

Learning Objectives

- Acquire detailed information regarding changes, their urgency and priority
- Access and use a changes management platform (Software: Autodesk glue, etc.)
- Evaluate time-wise the desired LoD and define accordingly the 4D BIM deliverables
- Evaluate the need and the effort for updating the model
- Monitor regularly the level of detail and decide on adding more activities or keeping less based on the initially agreed LoD

Synthesis – 90 min

Workshop (20 min):
Coaching Techniques and Team Dynamics

- Provocative Coaching
- Giving Instructions or not

Learning Objectives

- Explain the way of working and coach new colleagues

Evaluation – 60 min

InterVision Session (3x20 min):
4D BIM Changes and Team Challenges

- Split in groups of 3
- Each participant brings a personal issue / challenge / problem relevant to the 4D BIM process (owner)
- Group ask questions to clarify and understand
- Participants brainstorm alternatives for action (owner listens only)
- Group synthesize quickly to draw one or two recommendations
- Owner debriefs:
  What did I hear? / What can I do? /
  What do I take home?

Learning Objectives

- Select the proper team management approach, for the team and the task to be performed

Assessment – 30 min

Brainstorming:
Future 4D BIM Training

- A short brainstorming sprint whole of the completed training and bringing up topics for the future improvements / changes in the training of 4D BIM engineers

On-the-job assignment – 3 months

- Take the role of a 4D BIM leader in one of the new or on-going company projects
- Run another InterVision session every month (for the period of the 3 months) to discuss and solve problems and challenges.

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4D BIM Coaching

Goal:
Overviewing the 4D BIM process, coaching on the way of working and balancing between effort and impact for updating 4D BIM

Evaluation Scheme

	Module 9: 4D BIM Coaching				
	Goal: Overviewing the 4D BIM process, coaching on the way of working and balancing between effort and impact for updating 4D BIM				
	Access and use a changes management platform (Software: Autodesk glue, etc.)	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Acquire detailed information regarding changes, their urgency and priority	Knowledge Organization	Mental Models	Cognitive Outcomes	Structural assessment (Similarity to ideal)
	Gain credibility and build trust among the project stakeholders	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Explain "why" (for each decision, change, action …)	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Fluidity of performance)
	Evaluate time-wise the desired LoD and define accordingly the 4D BIM deliverables	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Generalisation)
	Select the proper team management approach, for the team and the task to be performed	Cognitive Strategies	Metacognitive skills	Cognitive Outcomes	Probed protocol analysis (Self-regulation)
	Explain the way of working and coach new colleagues	Compilation	Composition	Skill-based Outcomes	Hands-on testing (Chunking)
	Evaluate the need and the effort for updating the model	Cognitive Strategies	Metacognitive skills	Cognitive Outcomes	Readiness for testing (Self-awareness)
	Monitor regularly the level of detail and decide on adding more activities or keeping less based on the initially agreed LoD	Compilation	Proceduralization	Skill-based Outcomes	Hands-on testing (Generalisation)

Appendix V. Evaluation interview protocol

"Welcome and thank you for finding time for our discussion. I know that you are very busy, and I greatly appreciate your contribution to this project. You have been selected to participate because your point of view is important for this research.

May I have your permission to record our discussion and keep some notes? Both the recording and the notes will be destroyed after the analysis of the results."

Introduction (5 min)

Research Objective:

The research objective of this project is the development of

"A training curriculum for acquiring the technical and non-technical competencies for successful 4D BIM implementation in the construction sector".

The research method was consisted of three discreet steps. An initial exploration of the 4D BIM needs and competencies of the practitioners, a design phase during which these competencies were organized into learning objectives and modules and the current final validation phase.

Definitions:

- The term competency has been used to describe knowledge, skills and experience.
- 4D BIM for the purposes of this assignment has been defined the coupling of a 3D BIM model with the construction schedule.
- 4D BIM training is not approached as a software tool training (Synchro, Navisworks, etc) but a process training and this is due to the preliminary results of this study.

Purpose:

The main purpose of interview is to ascertain if the proposed design for a 4D BIM training is relevant, feasible and valid for BIM practitioners. Therefore, the three main questions that you will be asked to answer in the following hour are:

- To what extent is the proposed learning objectives and modules reflect the overall needs of professionals working with 4D BIM?
- To what extent could the proposed features (modules, learning and evaluation method) assist the practitioners acquire and apply the above competencies in a company project after the completion of each module?
- To what extent is the proposed training (9 training sessions followed up by on-the-job training assignments) a feasible investment for a construction company?

Part 1 (About 30 min)

During the first exploration there has been an extensive listing of 4D BIM competencies that have been identified by the practitioners on Count & Cooper that includes 87 different competencies. These have been categorized under the generic BIM competency sets identified by Succar, Sher and Williams, (2013):

Each competency is one learning objective of the course. When reading through the competencies keep in mind that they are written as if there was the sentence "Being able to…" before each of them.

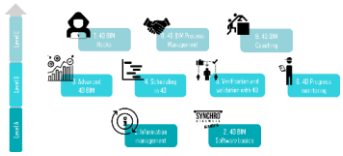
Please read through and examine carefully the list (list of competencies is provided printed). While doing that try to answer the following question:

Question1:
To what extent do the proposed learning objectives and modules reflect the 4D BIM practitioner needs? Are they comprehensive? Do you miss anything?
(Please use the numbers in the list to refer to specific learning objectives)

Part 2 (About 30 min)

All the nine modules have been organized under three 4D BIM development levels.

The modules are sequential, so you can only complete a module after you have successfully completed the previous ones. After each module there is an assessment based on the results during the assignment and the results of a self-evaluation quiz.



The learning method for each of the modules includes a training session of 3-5 hours and an on-the-job training assignment to be completed after the training session. In total in order to complete Level A, a new employee will approximately need about 2 months:

In the presentation attached you can find the overall design of the modules in levels as well as an example of the detailed design for three modules (one from each level).

Please read the detailed design of the three modules (detailed design is provided in print). After try to answer the following questions:

Question 2:
To what extent would the proposed features for the three modules (learning and evaluation method), appropriate for assisting practitioners acquire the above 4D BIM competencies?

Question 3:
To what extent could the proposed training, ensure that the participants will be able to apply the above competencies in a company project after the completion of each module?

Question 4:
Do you have any additional remarks?

This is the end!
I would like to thank you one again for your valuable contribution.
Your input was very important for my research outcomes. In case you would like to receive updates on my research outcomes, I would be glad to stay in contact with you.

Appendix VI. Evaluation outcome

Result Summary	Results	Interview Notes	Reference
Criterion: Relevance of the identified 4D BIM competencies			
Target group: Overall reflects on 4D BIM planner needs. The proposed competencies and therefore the training could also be relevant for more people involved in the 4D BIM process (not only the 4D BIM planners)	The list of competencies it is agreed to be very extensive, and that it holistically maps competencies relevant for 4D BIM planners and crucial for a 4D BIM training.	"If you are a planner, then the answer is YES all of the listed items are very necessary competencies"	3:19
		"I see a lot of competencies that are very relevant for our clients and that we have also been asked to address in our BIM implementation approach"	5:5
	However, not only planners are involved in the 4D BIM process. Therefore, it was argued that in order to achieve successful implementation of 4D BIM in the construction sector more people involved in the 4D BIM process should also be trained. The identified competencies could cover the needs for other roles as well. Selecting some the modules to be followed by different people within a project could have successful results.	"There are some modules that are not related only to 4D BIM but it could be for the whole company. For example, information management should be addressed in a broader company level"	2:1
		"Not only the scheduler needs this kind of training, there are several roles within a project that need at least part of this training to be able work within the 4D BIM process"	2:3
		"About 10-12 people in different functions could use the outcomes of 4D BIM. To implement successfully 4D BIM in the sector the rest of the people involved in the process should be trained as well"	2:25
		"I can see the benefit of using 4D as a team. And if the interface is a bit trickier people will depend to one or two people managing the interface without investing further on technical skills"	3:23
		"You could take this training and bring it to a bit tender team to teach them about 4D BIM and bring everyone on the same level of 4D BIM understanding'	4:28
		"It's very good to involve the other people of a project coalition who don't work directly with software but they are involved in the process […] stimulates the implementation process"	10:14
	Participants indicated the need for contractor firms to train work-preparators (or estimators) instead of planners for delivering 4D BIM outcomes due to their advanced software skills and their job scope. Although some of the needs of work-preparators are covered in list of competencies, more planning competencies should be included. Also, taking into account the time for training and performing 4D BIM tasks is significantly important.	"Some of these modules are not only for the 4D BIM planners, but can also be used for the work preparators or for estimators training"	2:2
		"You can train practitioners with skills in 3D software to be the coordinators of the 4D BIM and not the planners themselves; this is a practice that works"	2:8
		"Our scope is to train more people involved in the process as well like work preparators, schedulers, BIM managers"	2:17
		"If you ask a work preparator, a project engineer I would pick different modules from the ones you propose for each of them"	3:20
		"90% of the cases is the work preparator who is responsible for many other things in the projects […] if it's not in their core tasks but requires extra effort, it is often not successful"	10:4
	The progress monitoring competencies should not be only for the 4D Planners but should ideally be trained to everybody who can update on the progress of the tasks.	"Progress monitoring, it is interesting, but the information comes from the outside. So you should give this module to construction site managers or work preparators"	2:5
		"Progress tracking, should be – ideally - decentralized. Everybody involved in the process should be able to update on the progress of relevant tasks and report on them"	4:26

Missing competencies: Emphasising planning skills could make it relevant for work-preparators as well. Planning temporary equipment should probably be included as a competency. Module 7 could be enriched with more futuristic competencies	Participants were all finding a common point on the fact that when the work-preparators become responsible for 4D BIM then there is a need for extra competencies to be training related to construction planning. In the proposed training, it has been considered a pre-requirement to have knowledge and experience with planning techniques (CPM, Network planning etc.) before proceeding with the development of a 4D BIM training, but this should not be the case in order for the training to be applicable in a broader audience. For achieving broader applicability, module 4 should be enriched with general planning and scheduling competencies not directly linked with 4D BIM.	"Use of the model information to generate the scheduling information, should be included as a competency"	1:8
		"There are questions like “how do I build the schedule in general?”. What is a CPM, network method but also more process related: how does Synchro fit in the bigger picture of the project etc."	3:2
		"Of course, it can be used for monitoring quantities over time, but we are not that far yet because these people are not very skilled, so they don’t know how to use it"	3:3
		"Unfortunately, 4D must be developed by the people who are the least skilled in planning"	3:4
		"People who are doing 4D are not the best planners because they are work preparators and these are the ones who benefit more from the 4D BIM. So, we have to focus on training regarding planning"	3:6; 3:7
		"You should probably enhance your 4D planning module with more scheduling techniques and more planning knowledge in general"	3:9
		"But we don’t think that you need any extra skills if you know how to make a planning"	4:3
		"The main skill you need is experience in construction, about how things on the planning work"	4:4
	Participants with experience in 4D BIM training suggested to move comp 47 from module 6 to module 7 and rephase: "synchronise and update the model and schedule". Also participants indicated other competencies that should be included in the future in module 7 such as: "company wise 4D BIM management of projects - business development approach", "logistics with 4D BIM", "use of a server based application for collaboration within the 4D BIM process".	"Synchronizing and updating the models and schedules. It has also has to do a but with the 3D models and information management (Comp.47 probably move on module 7)"	10:13
		"Consider he development of 4D BIM planning in a company level (overviewing all the company projects and managing human and equipment resources in a company wise)"	4:12; 4:13
		"Business intelligence should be included as a skillset from a management perspective. The tool doesn't exist yet but it can be developed in house or it will be in the market soon"	4:13
		"Doing logistics with 4D BIM should also be included as a future skill. 4D BIM has great potential for planning the workspace, or excavation volumes or on time delivery of materials"	4:14
		"I think module 7 is more related to a business developer or someone who is using the 4D BIM data to visualize them through PowerBI or similar"	10:10
		"Maybe add a topic related to the SWP the server application for using Synchro pro in a collaborative way"	10:15

Scope: There are significant differences in the 4D BIM process between consultancy and contractor firms and between building and infrastructural projects. This training is based on the 4D BIM process of a consultancy working with infrastructural projects.	Participants recognised that the overall approach is focused on the 4D BIM process within a consultancy firm that can differentiate from the 4D BIM process of a contractor firm as requires more effort managing interfaces within a project coalition.	"Is a different way of looking at 4D BIM […] from a consultancy perspective, what the software can do but the difference for a contractor company is that we look from a roles perspective"	2:31
		"The scheduling of the different construction works (sub-contractors) is the responsibility of our own people. We do not ask for a schedule […] For exchanging information we run lean sessions together"	3:8
		"Your approach is focused on a consultancy firm. Consultancy works among and in between different companies and a contractors. In our field (contractors) we work above other companies"	4:27
	In the same scope there is also significant difference between infrastructural and building construction projects. The complexity of the 4D BIM process is linked with the complexity of decision making for infrastructural projects when in building construction one and only experienced planner may be able to set the definite plan of the construction alone.	"There is need, to firstly develop a very good framework on how we want to approach the planning and then fit 4D BIM in" - infrastructural projects	3:5
		"We feel that you don't need to do anything extra when doing 4D BIM. If you are doing a Gantt chart for the project anyway just do it in 4D software" - building construction	4:2
		"There is a very big difference here, because we are a company that mainly does building construction projects. Making decisions is way simpler –the planners make the decisions and the rest parties follow"	4:9; 4:10
		"We are usually the main contractor and we don't have other contractors and we don't need the persuasive power that you need in order to influence the rest of the parties" - building construction	4:11
Roles: Selecting specific modules (competencies) for different roles within the 4D BIM process	Most of the interview participants indicated the need to select specific competencies from the ones addressed in the training modules in different roles. It seems that the allocation of competencies to different modules work sufficiently but the modules should be addressed to different people working within a project. According to the recommendations the most optimal approach for selecting which modules are relevant for which roles within a project coalition could be: (4D) BIM Project manager - modules 8, 9 | (4D) BIM Coordinator - modules 1,5,7,8 | 4D BIM Planner / Work preparator - modules 1,2,3,4,5,6 | Other roles (field manager / site manager) - modules 1,6. However, there should still be flexibility to address and evaluate specific training needs for each trainee.	"Ideally, it's the role of a BIM coordinator to validate the data and not the role of the 4D BIM planner. However, being able to validate the data yourself can be very valuable"	1:4
		"Some of these competencies are not necessarily needed for the 4D planners. The allocation of responsibilities may depend on the project hierarchy and on the project size"	1:5
		"I fall a bit over the levels' logic, it would be better to define which of the modules (or even competencies) are necessary for every employee […] having more flexibility on the levels"	1:20; 1:21
		"Modules 8 and 9 can be linked with the philosophy in the company so this is more for company managers, it is in a management level so not for the 4D planners specifically"	2:9
		"Divide the training in different functions or roles within a project. For example: 2,3,7 for 4D BIM specialists | 4,5 work preparators | 8,9 BIM specialists | 1,6 everybody (also site manager etc.)"	2:12
		"It needs a bit of twisting to align roles with modules and needs. Probably some roles do not need extensive software skills but only a viewer version or specific skills (e.g. stakeholder manager)"	2:27
		"Can those levels be directed to one of the roles within the BIM process? (BIM director, BIM coordinator, BIM manager, BIM modeler)?"	4:19
		"People on a higher level do not need the exact knowledge of the software but it may be enough for them to know about the process"	4:22
		"The modules should be linked with the BIM roles and a way could be: BIM director: modules 8 – 9 | BIM coordinator: modules 5 - 7 | 4D BIM modeler: modules 1 – 4	4:23
		"Knowing why you do something it is more important than be able push the buttons for some of the roles"	4:24
		"These modules can be the right ones but a selection of them for each role - doesn't hurt someone to know more, but it should be necessary for their work to put time and effort for learning it'	4:25
		"It would be interesting to do level A for everyone and from level B or C select modules depended on their function. It's good to check which roles can be linked to which module"	10:7; 10:8

Result Summary	Results	Interview Notes	Reference
Criterion: Validity of the training features			
Structure: Overall the structure proposed for the specific modules is good.The modules in each of the levels address appropriately the content of a 4D BIM training curriculum. An adjusted version of Level A is necessary that should also include module 4 as a second module.	Almost all participants pointed out that the structure of the overall training curriculum and the structure within each module is helpful. However, they proposed that module 4 (Scheduling in 4D) should be part of level A. Also, module 1 (Information management) there are two contradicting statements regarding the importance of the module in level A. Following the feedback of the 4D BIM training experts, information management should remain as the first module and should followed by everybody within a project coalition.	"The structuring of the knowledge and the modules schedule you prepared looks good"	2:13
		"I think that the way you categorize it in levels would definitely help"	3:10
		"Whichever structured way of learning could help"	4:17
		"You have a good structure with three levels A-B-C.	5:34
		"I think the levels have a very good combination with a good follow up after each level"	10:24
		"Although you can easily get a “push the buttons” training this is clueless if you don’t have knowledge about how planning management works"	3:1
		You are assuming that everyone knows how scheduling works […] moving the scheduling workshop in the first level would be appropriate so the people have a clear understanding (pre-requirement)	3:14; 3:17
		Level A: the most delay in the training is because of the lack of general knowledge regarding the 3D […] the object-oriented approach instead of the drawing is very important	10:2; 10:3
		It would be an idea to set module 1 as an optional module or even allocated in a different level. If you start with the information management, it may get a little bit to complex.	1:6; 1:27
		Everybody should follow modules 1 – 2 – 3	4:20
	Participants gave positive feedback on the specific content of the modules in each of the three levels. They indicated that the Level A as a basic level is approached correctly in terms of basic software competencies. Regarding information management, the combination with a more broad BIM explanation could be considered. Modules of Level B have been recognised as the most important in terms of upgrading the 4D BIM process within a firm. At the same time, modules in level 3 have been identified as an innovative approach regarding 4D BIM training that could establish knowledge within an organisation more stable grounds.	"It is a basic level, so what you give as a knowledge would work positively"	2:14
		"In Level A, understanding the user fields and software buttons is not different than you describe"	3:16
		"Would be nice if you could combine this very first step (Module 1. Information Management) with other BIM courses. Because these should be the basics regarding BIM in general"	3:18
		"Overall it seems a very good program for someone starts getting involved in the 4D BIM process. Especially the structure of Level A – Module 2 and all the elements of Level B"	1:26
		"Previous grad. students identified two missing points in our 4D BIM process that you confirm: Expectations management regarding the process (mod 8) and verification and validation of 4D (mod 5)"	2:33
		"Level B is the most interesting because there the magic happens, or doesn’t happen. I consider this as the most beneficial part of the training"	3:12
		"The modules are very good and especially the last ones (Level C) are very interesting and above the software and its about process management which is necessary and do not happen at the moment"	5:20

Training features: Most of participants and both training experts indicated that the learning features can be sufficient to help participants acquire and apply the competencies. Specifically, they recognised a good mix of training methods that may require slightly more time than planned for each session. They found the evaluation and the on-the-job assignment after the training very important to secure that participants can apply their competencies in real conditions.	The training experts agreed that the selection of the learning methods it is good and fit with the character of the training. There is a good mix of different activities that makes it interactive, it has clear structure and goals and for the basic software competencies has the same training material as professional software trainings (a step by step guide on which participants can refer).	"The mix of activities looks very good (ice-breaking, presentations, individual and group assignments)"	5:10
		"It is a well made training script with a lot of interaction which makes it is very good"	5:35
		"You have very clear deliverables, and this is helping very much on the learning process"	5:16
		"Clarifying the goals in this way help participants to decide if the course is relevant for them or not"	5:17
		"We usually have a course book and everything we explain in the training is on the course book so people can look it up whenever they want"	5:11
		"We provide a basics training that is based on the software manual"	10:11
	Two participants indicated as a limiting factor of the design, the time allocated for each of the modules. The is extra time that should be considered due to questions, difficulty of participants to understand the concepts or other unpredictable reasons. Also the time that trainers need to evaluate the assignments should be considered.	"If you say that this is a four-hour workshop (Mod. 3), this is a lot to do within the four hours. Scripting is very challenging, and it can be quite tricky to grab the concept of baselines"	3:15
		"The modules are very condensed. Consider that the modules may take way longer than you expect"	5:14
		"Think about the time allocation for evaluation. Would you evaluate within the time available for the training? The evaluation may take as much time as the course itself"	5:12
		"Check also about the time allocation for discussion within the modules. Is there enough space for discussion and asking questions?"	5:13
	Training experts found the evaluation part of the training significantly important. They raised a point for future improvement to justify the process in case participants do not succeed in one of the modules as well ensure an external observer to evaluate their performance.	"The modules in your training are sequential so a question would be how to cope with the fact that someone may fail one level. Is there any process?"	5:08
		"After each training the participants evaluate the training and they are evaluated, and this is something very important that we also do in the company"	5:18
		"It is very important that you have an external observer to evaluate the participants and it is very good that this is covered in your training"	5:19
	Most of participants agreed that the on-the-job assignment is a necessary component of the training curriculum and that it ensures that participants can apply their skills in real life projects. However, it should be ensured that the trainees will actually have the opportunity to apply their recently acquired competencies in one of the company projects and this may not be easy if the company is just starting with 4D.	"With the training session maybe they get a very good idea but […] I don't believe that in this way you can get fully the skills to apply them in a project directly"	1:12; 1:13
		"If you are not able to apply something on the project, then you miss the on-the-job assignment and the skills are gone"	2:16
		"If anyone needs more advanced training then we listen to the contractor and what do they really need and we make a training on the job"	10:12
		"It's very interesting to have feedback in your on-the-job assignment. […] It's very good that there is an on-the-job assignment in all modules"	10:16; 10:18
		In the on-the-job assignment you experience realistic conditions that influence the 4D BIM process. And that's the most interesting part of the training if you ask me. I think it's a good idea.	10:19
		"The real world is different than our training room […] during the training people can acquire the competencies they need to start but they are often disappointed from the real-life situation"	10:20; 10:22
		"We don't use the 4D BIM model for progress monitoring yet as we just started with 4D, one year ago"	1:9
		"Do they get 40 hours per week to work with it or it's a side job? The biggest risk for implementing your training may be that they don't have enough time and it becomes something extra and less important"	10:23

Overall: Very complete and detailed approach that addresses similar efforts of companies in the construction sector. It is very well visualised and this helps for a better understanding. The quality of the training outcomes highly depends on the competency level of the participants.	All participants found the quality of the training approach very detailed and complete up to the extend that they could even see it recommended for 4D BIM practitioners.	"In general, it looks very complete, you touched upon everything I have been thinking regarding the implementation of the 4D BIM within our company over the last year"	1:24
		"We would most probably need a training like this"	2:10
		"You have made a very good pragmatical and detailed report that a company can actually use directly. Your approach is good"	2:29; 2:30
		"I think you have a very thorough set up here […] especially for the people that are specialized in scheduling this should be recommended"	3:24; 3:25
		"I think overall it looks a very good training as it integrates so many different activities and stimulates interaction not only listening"	5:6; 5:9
		"I'm impressed how detailed is your approach and how precisely you developed your work in something that could be used by different companies"	5:30
		"We would be interested to work further on your idea as a new product so let's keep in touch to discover potential opportunities after your graduation"	5:33
	Most of the participants indicated that they already make efforts to develop similar training activities on the job.	"We do several of these modules with on-the-job trainings (learning by doing) for example 2 – 3 – 7"	2:6
		"What we currently do in the company is the modules 1 – 2 – 3 – 4 in an on-the-job training way for work preparators. It is very new for us, so we have to see how that works"	3:13
		"With the BIM project team we try to work as an example for the other teams to teach the process. However, it is very difficult to say to others how they should work, they will not listen to you"	4:8
		"We apply training on the software site mainly […] the people change process is very interesting and not something that we address"	5:1; 5:3
		"We are also considering asking trainees bring their own 3D model […] I'm very interested because you help me to look at our own training method as well"	10:21; 10:26
		"We have a 5 days course to learn the basics and then after some months of practicing on the job you can take the second training for experts"	5:26
	Some participants indicated that the quality of the training results depends very much on the previous experience of the trainees and therefore this should be a factor to take into account when giving a training.	"3D modelers are very good at understanding the logic of the software and not scared by all the buttons. Employees without software experience may have a hard time"	2:7
		"Depends very much on the project and the peer pressure. There are people that are very good in 4D BIM and they inspire the rest of the team to learn as well"	2:18
		"In the beginning there were many people that were eager to learn the software but later a lot of them were pushed to learn the software, so they were not eager anymore and it was harder"	5:2
	Participants complimented the visualisation of the training steps and they believe that a good visualisation is helpful for training activities. They indicated an extra arrow in order to clarify the content of the on-the-job assignment.	"You made a very nice presentation; it is very professional. My compliments on that"	2:24
		"You also have very good visualization of you approach"	5:31
		"Maybe for the visual part you could draw an arrow from the on-the-job assignment to the recall and comprehension because they will repeat these steps during their assignment"	10:25

Result Summary	Results	Interview Notes	Reference
Criterion: Feasibility of the proposed training curriculum			
Duration: Overall the complete training involves a very long experience of about one and a half year. In order to become more feasible this should be broken down in different courses optional for different functions. It is significantly important to address the specific needs of the each participant therefore an initial assessment could help design the learning path for each participant.	Several participants - among which both the training experts - find the training very long and extensive. It should be considered not only the time investment but also the perception of people that start working with 4D BIM (it looks difficult). They proposed different modules to be combined under one and the overall training to be split into three courses each of which should address one of the levels. In this way, it would be more clear to the trainees that after the first course (level) they can already start working with 4D BIM and they can get the second course (level) to expertise their knowledge and the third course (level) if they want to manage the 4D BIM activities within a company of within a project.	"My initial feeling is that is much about 4,5 days of trainings which is not that bad but depends highly on the target group that you would like to train"	2:19; 2:20
		"It's only the time factor that you need to work a bit further"	5:15
		"It's a really long process with an on-the-job experience with Synchro"	10:17
		"Maybe you can do two modules at once"	2:21
		You could probably combine a session with time for supervised on-the-job training. Walk around solving questions etc.	5:29
		"It takes a very long time to become intermediate or expert. So, it looks very difficult now to plan in 4D"	5:7
		"I really find it very long; it takes about 17 months to become an expert"	5:23
		"Level 2 has the focus for optimizing the process and giving them expertise, and this should be pinpointed (otherwise people are overwhelmed in the beginning with a two-years programme)"	5:24
		"An idea could be to split it in three courses so if someone wants to know when they would be able to work with 4D this is already after the first course (and not after 2 years)"	5:25
	Participants, also indicated their wish to be able to customise the learning experience of each trainee in order to make the training more feasible and attractive. They proposed that there should be an initial assessment of the participants to decide upon the learning path and the specific modules to be followed, based on previous experience and on the scope of their work. A basic training regarding 4D BIM should be followed by all the company employees working within the 4D BIM process.	"It would be more feasible to pick the specific parts of this detailed training that fit precisely the needs of the company and implement them in a similar way"	1:14
		"They need to gain skills in a very limited time as they are very busy in their schedules […] teaching them only what they specifically need for their current work would be more valuable"	1:16; 1:17
		"It would be very interesting to customize the learning experience for each of the employees"	1:22
		"We would check for each of our (people) what kind of skills do they need and which of these modules they should follow […] two - three modules from the ones you designed should be feasible"	2:11; 2:22
		"Probably a level 0 would be interesting to be added as an evaluation of the starting level and do some expectations management"	2:32
		"Everybody should follow levels 1 – 2 – 3 , for the rest there should be an assessment according to the level and position you are if you would need and want to follow specific extra modules"	4:21

Future perspective: An optimal way of doing 4D BIM is being addressed. 4D BIM is a very new field of work and it is very much depended on the technological developments. There are a couple of future dimensions that could also taken into account in future training developments.	Participants agreed that several of the identified competencies are linked to an optimal way of working with 4D BIM. The fact that this is not the current way of working but there is the aim to reach that higher level of 4D BIM competency was agreed by all participants. One of the participants (experienced leader on 4D BIM) expressed the thought that the list of competencies could even be helpful for challenging his own knowledge.	"Being aware that you need to discuss and reflect on the learning after each project it is quite important and for now is only happening in an informal way (coffee talks)"	1:1
		"Being able to adopt new digital tools is a very nice idea. It should absolutely be embraced as it could very much help our business"	1:2
		"4D BIM planners should have the competencies to be able to start working and develop the schedule directly in the 4D BIM software'	1:7
		"It's good that the training focuses on the ideal process even if this is not necessarily the current way of working"	1:25
		"Thank you, I have a whole list of things I need to learn myself!"	3:28
		"What is very important is to start working the schedule directly in 4D BIM"	4:5
		"Making estimations within the 4D BIM it's not there yet. It's the point where we would like to go"	4:7
	Most participants said that the effort allocated for 4D BIM training depends on future technological developments. It seems that the technology will establish 4D BIM as a core activity of the companies in the construction sector but this is not the case yet.	"4D is not considered yet core activity to invest that much time […] when 4D BIM becomes the core task of our employees, then probably the complete program you presented is very useful"	1:18; 1:19
		"The interfaces of the technology are defining how we are using or how we will be using 4D BIM in the future. When we use HoloLens everyday on site then we should invest time for 4D BIM training"	3:21
		"The main reason why we don't do much training yet in the field of 4D is because the demand by the construction sector is not that high so far, but it seems that it is growing fast"	5:32
	Participants also indicated some future dimensions that could be addressed in further research: investigating the 4D BIM process under a life-cycle lens, facilitating discussions among experts and investigating the potential of 4D for other sectors (e.g. manufacturing).	"Did you look at the construction process from design to construction and demolishing again (life cycle)"	2:26
		"We should do more often discussions in the construction sector about 4D BIM. […] Just bringing different people together to discuss what they are doing and gain knowledge out of it"	4:30
		"More disciplines are interested in 4D. We have seen manufacturers and several disciplines for which detailed 3D design is necessary, asking for 4D. Similar training could be applied in other sectors"	10:1
Product: The training is designed as an in-house activity but it could even have potential to become a separate training product. In case of the last, more factors should be optimised.	Most of the participants agreed that with some improvements the training, this could be used as a separate training product for construction companies. It should be defined how the training can be customised to the company needs, standardise the duration of the training sessions and define who could be the trainers for each of the modules.	"It could be a business idea. […] You should be able to define a selling point (tender at a better price, or faster etc.). It should also be adjustable to the new needs"	4:29
		"You need to be able to sell your training. Have you thought about how much this would cost? It's nine training sessions and some on-the-job consulting hours"	5:21
		"Think about standardizing the time for your courses (e.g. 09:00 – 16:00). Having short sessions (3,5 h) is not sustainable (time for commuting and time for learning) either for the trainer or for the trainee"	5:27; 5:28
		"We would be interested to work further on your idea as a new product so let's keep in touch to discover potential opportunities after your graduation"	5:33
		"Think how you could give it to different companies and up to which expend you be relevant for different companies in the construction sector"	1:23
		"Who should be the trainers? From the company or external?"	2:28
		"Do they have on-the-job consultancy from a trainer?"	5:22

Appendix VII. Implementing module 2 for deciding on the instructional method

During the detailed design, an additional side-question came up, regarding the most efficient instructional method for providing procedural information. Two different scenarios for providing procedural information have been developed and they have been tested in a trial training session in a group A/B setup. The two groups have been selected to have similar characteristics. The first group (Group A) followed a self-learning-oriented approach (printed step-by-step guide with the basic steps for completing their assignment). The second group (Group B) received a step-by-step demonstration by the instructor regarding all the steps and buttons they had to use during their assignment. During the testing, the hypothesis was tested:

- Providing detailed instructions and step-by-step demonstration by an expert (Group B) can be more efficient (higher participants grades) as a method for providing procedural information during a 4D BIM training session than providing a step-by-step guide and having participants explore the software buttons and tools themselves (Group A).

Methodology for the design choice

For the testing of the instructional method, Module 2 was selected that focuses on 4D BIM software basics. Within this module, 13 learning objectives are included:

- Allocating resources in 4D BIM Software
- Navigating through the 4D BIM Software views
- Creating a schedule from scratch based on the 3D elements
- Creating and export reports (animations + frames)
- Using 3D model user fields for smart filtering
- Creating and using cutting planes
- Creating and assigning clear appearance profiles
- Setting and modifying relationships among the project tasks
- Ensuring that all the components are included in the schedule and they are correctly linked with a task
- Finding out alternative solutions when there is lack of information
- Discussing with managers about the lessons learned after the completion of a project
- Adopting and learn from scratch new digital tools

In the detailed design of this module, during the ice-breaking and the introductory part the last three learning objectives have been addressed as they are mainly related to supportive information. The rest ten of the learning objectives have been addressed in the components of Recall and Comprehension and they are mainly linked to procedural information. As a Recall learning component an individual assignment with a very simple training model has been designed and as a Comprehension learning component a team assignment (in teams of 2 or 3) with a simplified real case scenario has been used. Both groups started together in a common set up and only during these two steps they were split in different rooms. They also had the same amount of time (3,5 hours) to complete these two learning tasks. By the completion of the team assignment the groups gathered together again and continued with the step of evaluation.

The procedural information that both groups received was the same sequence of steps for completing their assignments. The only difference was in the instructional method between Group A and Group B as explained previously: Group A had a step-by-step demonstration with the training when Group B had a printed step-by-step booklet for completing each of the assignments under the expert's supervision. The

experts giving the training were experienced professionals in 4D BIM and the training was hosted and organised by the researcher. The detailed description and the instructions for each of the groups can be found in Table 19.

Table 19. Detailed script of Group A / B testing

Time	Method	Technique description	Learning Objectives
12:30	**Welcoming & Lunch**		
30 min	Arriving Having Lunch Welcoming	Demonstration video of a 4D animation plays on background Who are we? Introduction of the company and the people.	
13:00	**Introduction**		
5 min	Ice – breaking game	Who are you? Split into teams. Make your team mascot and explain your 4D BIM learning goal of the day! *In about 10 minutes, the group needs to create a 3D mascot. To do so, each of the team members pick a set of two objects form the warming-up kit envelope. They need to collaborate to create their 3D representation of the mascot. Starting from someone every participant combines their two objects in the team mascot why they try to explain link of their object with their 4D BIM (learning) goal of the day.*	
5 min	Initial Assessment		
10 min	Introduction to the topic of the module	Introductory presentation by the facilitator: *- What is 4D BIM? #task* *- What do we do with 4D BIM #process* *- Why do we do it?* *- How: do we do it* *A. Learning mindset* *B. Goal of the day (learning objectives, schedule, deliverables)*	Find out alternative solutions when there is lack of information Discuss with managers about the lessons learned after the completion of a project Adopt and learn from scratch new digital tools
Group A			
13:30	**Training Part I: Try out, to find out**		
10 min	Brief explanation of the interface and the steps to be done	Teams get a brief explanation about: *- the synchro Interface* *- the step-by-step guide that they receive with the steps to solve the assignment*	
40 min	Assignment I (Individual)	Explanation and instructions of assignment: *- What do you have to do* *- What do you get* *"Create a schedule based on the 3D elements"*(very simple and clear structure and resources)	Navigate through the 4D BIM Software views Set and modify relationships among the project tasks Create and use cutting planes Create a schedule from scratch based on the 3D elements (baseline 0)
10 min	**Break**		
14:30	**Training Part II: Try out, to find out**		
5 min	Brief explanation of the assignment and the steps to be done	Teams get a brief explanation about: *- the step-by-step guide that they receive with the steps to solve the assignment*	
135 min	Assignment II (Group)	Explanation and instructions of assignment: *- What do you have to do* *- What do you get* Prepare a 4D simulation	Recognize properties and user fields that exist in a 3D model Use 3D model user fields for smart filtering Allocate 3D resources on tasks in 4D BIM Software

		(use filters to link tasks with objects, create and allocate appearance profiles, set task relations and export frames book)	Create and assign clear appearance profiles Create and export reports (animations + frames)
10 min	**Break**		
Group B			
13:30	**Recall – Part I**		
30 min	Step-by-step demonstration Part I	Step-by-step demonstration training - Part I: - *Synchro interface (navigation, windows, toolbars)* - *Navigation and appearance profiles* - *Task logic and functions*	Navigate through the 4D BIM Software views Set and modify relationships among the project tasks Create and use cutting planes
30 min	Assignment I (Individual)	Explanation and instructions of assignment: - *What do you have to do* - *What do you get* "Create a schedule based on the 3D elements" (very simple and clear structure and resources)	Create a schedule from scratch based on the 3D elements (baseline 0)
10 min	**Break**		
14:40	**Recall – Part II**		
30 min	Step-by-step demonstration Part II	Step-by-step demonstration training – Part II: - User fields and smart filtering - Assign resources to tasks - Cutting planes - Reports	Recognize properties and user fields that exist in a 3D model Use 3D model user fields for smart filtering Allocate 3D resources on tasks in 4D BIM Software Create and assign clear appearance profiles Create and export reports (animations + frames)
15:00	**Comprehension**		
100 min	Assignment II (Group)	Explanation and instructions of assignment: - What do you have to do - What do you get - Requirements and clarifications Prepare a 4D simulation (use filters to link tasks with objects, create and allocate appearance profiles, set task relations and export frames book)	Ensure that all the components are included in the schedule and they are correctly linked with a task
10 min	**Break**		
17:00	**Assessment**		
30 min	Feedback - Discussion	Presentation of the results Discussion of the experience - *Do you recall your personal goal?* - *Did you meet it?*	
5 min	Final Assessment	Self-reflection quiz	
5 min	Training Evaluation	Short evaluation form	
17:30	**Closing**		

The sample of participants was consisting of ten university students in their masters' studies mainly on the field of construction management and engineering in University of Twente (Table 20). All the participants were familiar with the concept of BIM and they had completed successfully a course related to construction planning as a requirement to participate to the training session. Half of them were Dutch and half were international students. The two groups formulated in a way to ensure as much diversity as possible among the participants (sex, year of studies, international or not).

Table 20. Sample of participants in the Group A/B testing

	N	Frequency	%
Gender	10		
Male		6	60%
Female		4	40%
Master program	10		
Construction Management & Engineering		9	90%
Spatial Engineering		1	10%
Year of studies	10		
1st		5	50%
2nd		5	50%

After the completion of the group assignment both groups gathered together and followed the final, feedback and evaluation steps. Both the evaluation techniques described in the detailed design have been used to determine whether the learning objectives of the training session have been met or not for each of the groups. Firstly, the self-evaluation questionnaire before and after the training was used in order to evaluate the confidence of the participants to use in practice the addressed competencies. The short self-evaluation questionnaire for the participants can be found in Figure 12.

How comfortable would you feel to perform the following tasks in your daily work? *

	I have already forgotten everything	I am familiar with the idea	I have the feeling of it but I would need more training	I got it but I need more time to practice	I feel comfortable using it in a professional project
Navigate through the 4D BIM Software views	○	○	○	○	○
Set and modify relationships among the project tasks	○	○	○	○	○
Allocate 3D resources on tasks in 4D BIM Software	○	○	○	○	○
Create and assign clear appearance profiles	○	○	○	○	○
Create a schedule from scratch based on the 3D elements	○	○	○	○	○
Recognise properties and user fields exist in a 3D model	○	○	○	○	○
Use 3D model user fields for smart filtering	○	○	○	○	○
Create and use cutting planes	○	○	○	○	○
Create and export reports (animations + frames)	○	○	○	○	○

Figure 12. Self-confidence evaluation questionnaire

Secondly, an evaluation matrix, has been used to determine up to which extend participants met the skill-based outcomes. The evaluation matrix was filled-in by the trainers during the training, for the two learning objectives in which the fluidity of performance has been checked. For the rest of the learning objectives (measured by the error rates and quality of performance) the evaluation matrix was filled-in based on the deliverables of the two assignments after the training. The evaluation scale for the skill-based outcomes for the individual and for the team assignment can be found in Table 21.

Table 21. Evaluation scale for the individual assignment of trainees

Individual Assignment		Evaluation Scale: 1- 5
Navigation	Fluidity of Performance	**1 →** Not able to change from the current view. **5 →** Able to drag and move, zoom in and out, rotate in all 3D, locate the task properties and the appearance profile properties.
Task relationships	Error Rates	**1 → 9 or more** mistakes in predecessors / successors. **5 → 1 or none** mistake in predecessors / successors**.**
Resource allocation	Error Rates	**1 → 9 or more** tasks with wrong resource allocation. **5 → 1 or none** tasks with wrong resource allocation.
Appearance profiles	Error Rates	**1 point for each** of the following: - Creating a separate steel profile - Creating a separate concrete profile - Using correctly the appearance profiles for resources - Creating an extra appearance maintain profile - All the above
Schedule from scratch	Speed & Quality of Performance	**1 point for each,** planned in a correct and logical sequence: - Foundations - Pipe racks - Steel structures - Air coolers - All the above
Subtotal		**25**

Table 22. Evaluation scale for the group assignment

Team Assignment		Evaluation Scale: 1- 5
Accessing / checking user fields	Fluidity of Performance	**1 point for understanding each** of the following by clicking on a 3D object: **-** Location / phase - Material - Quantity (volume) - Difference among elements with same values - All the above
User fields filters	Fluidity of Performance	**1 point for performing each** of the following: - Creating, copying 3D filters - Activating / deactivating 3D filters - Filtering with one user field - Filtering with more than one user fields simultaneously - All the above
Cutting planes	Quality of Performance	**1 point for performing each** of the following: - Cutting planes X + Y - Cutting planes in a separate 3D view - Hide manipulators - Hide planes - All the above
Report	Quality of Performance	**1 point for each** of the following being present in report: - Focus time - Second 3D view (with cutting planes) - Hide manipulator - Legend - Clear view of all elements
Completeness of deliverable	Quality of Performance	**1 point for each** of the following: - Constructability - Milestones in correct dates - No objects on the scene before tasks start - Both deliverables (ppt, avi) - All the above
Subtotal		**25**

Results

The summarized results of the trial training session can be found in the Table 23. Detailed descriptive evaluation regarding the performance of each participant / team in each of the learning objectives and therefore the corresponding grade can be found in *Tables 23-26.*

Table 23. Deliverables scoring for individual and team assignment. The evaluation scale per learning objective is 1-5 and for the average has been converted to a scale of 1-100.

		Individual Assignment					Team Assignment							
		Navigation	Task relationships	Resource allocation	Appearance profiles	Schedule from scratch	Accessing / checking user fields	User fields filters	Cutting planes	Report	Completeness of deliverable	Individual Assignment Avg	Team Assignment Avg	Final Grade
Group A	Participant 1	4	5	4	4	3	3	5	3	0	0	80%	44%	62%
	Participant 2	3	5	5	2	3	3	5	3	0	0	72%	44%	58%
	Participant 3	3	5	4	2	3	3	5	3	3	1	68%	60%	64%
	Participant 4	4	5	4	5	3	3	5	3	3	1	84%	60%	72%
	Participant 5	3	5	1	2	1	3	5	3	3	1	48%	60%	54%
Group B	Participant 6	4	2	4	2	0	4	4	2	3	2	48%	60%	54%
	Participant 7	5	4	4	1	2	4	4	2	3	2	64%	60%	62%
	Participant 8	3	4	1	2	1	3	3	1	4	0	44%	44%	44%
	Participant 9	4	4	3	1	4	3	3	1	4	0	64%	44%	54%
	Participant 10	4	0	5	2	0	3	3	1	4	0	44%	44%	44%
	pass	100%	80%	80%	20%	50%	100%	100%	50%	80%	0%	60%	50%	40%
	fail	0%	20%	20%	**80%**	**50%**	0%	0%	**50%**	20%	**100%**	40%	50%	60%

General observations on the assignment grades

If 60/100 is considered the passing grade for each of the learning objectives, 60% of the participants have been completed successfully the first assignment and only 50% of them have completed the second assignment successfully.

Checking also the self-confidence evaluation results (Table 28) in comparison with the score of the participants in the deliverables there is also an interesting observation.

Table 24. Descriptive results of testing Individual Task - Group A

	Team 1				Team 2					
Group A	Name 1: **Participant 1**		Name 2: **Participant 2**		Name 3: **Participant 3**		Name 4: **Participant 4**		Name 5: **Participant 5**	
Individual Task										**Average**
Navigation	**4**	Messy windows allocation and minor problems locating commands. Good ability to navigate around the software (+).	**3**	Difficulties to locate the commands in the software interface	**3**	Messy windows allocation and some difficulties to locate the commands in the software interface	**4**	Messy windows allocation and minor problems locating commands Good ability to navigate around the software (+).	**3**	Difficulties to locate the commands in the software interface.	3,4
Task relationships	**5**	Only two mistakes in relationships but in the extra structure that was beyond the scope of the assignment.	**5**	No errors for the elements within the scope of the assignment.	**5**	No errors in the task relationships! (+)	**5**	No errors in the task relationships! (+)	**5**	Only air coolers are missing predecessors / successors.	5
Resource allocation	**4**	There are three elements that are not allocated in tasks (Steel suspended structure, Foundations and two of the air-coolers).	**5**	Foundations are not allocated in tasks.	**4**	There are three elements that are not allocated in tasks (Steel suspended structure, Foundations and one of the Air-coolers).	**4**	There are three elements that are not allocated in tasks (Air Coolers, Steel Structure, Steel Suspended Structure).	**1**	Foundations, Steel Structure, Air Coolers are not allocated in tasks.	3,6
Appearance profiles	**4**	There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	**2**	Wrongly allocated appearance profiles for several structures (steel structures are having a concrete profile and reverse). There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	**2**	Wrongly allocated appearance profiles for some structures (steel structures are having a concrete profile and reverse). There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	**5**	There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	**2**	All appearance profiles are wrongly allocated, although they exist. There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	3
Schedule from scratch	**3**	Foundations and the suspended steel structure are not included at all in the schedule	**3**	Foundations are not included at all in the schedule.	**3**	Foundations and the suspended steel structure are not included at all in the schedule.	**3**	Air coolers and suspended steel structures are not included at all in the schedule.	**1**	Foundations, Steel Structure, Air Coolers are not included in the schedule at all.	2,6
Subtotal	20		18		17		21		12		

Table 25. Descriptive results of testing Individual Task - Group B

		Team 3				Team 4						
Group B		Name 1: **Participant 6**		Name 2: **Participant 7**		Name 3: **Participant 8**		Name 4: **Participant 9**		Name 5: **Participant 10**		
Individual Task												**Average**
Navigation	**4**	Minor problems locating commands. Good ability to navigate around the software (+).	**5**	Good ability to navigate around the software (+).	**3**	Some difficulties to locate the commands in the software interface	**4**	Minor problems locating commands. Good ability to navigate around the software (+).	**4**	Minor problems locating commands. Good ability to navigate around the software (+).	4
Task relationships	**2**	There are only the sir-coolers linked correctly to each other, all the rest do not make sense.	**4**	Some task relationships are wrong. Air coolers start being constructed in the air and suspended steel structure is not included in the schedule at all.	**4**	Some task relationships are wrong. Air coolers and steel structures have not been included.	**4**	Task relationships are correct however, air coolers have not been included.	**0**	No task relationships!!	2,8
Resource allocation	**4**	Although there are tasks for all elements, they are not created in any kind of order.	**4**	Foundations and Suspended Steel Structure are missing.	**1**	Foundations, Suspended Steel Structure, Air Coolers are not allocated in tasks.	**3**	Air Coolers are not allocated in tasks.	**5**	All elements correctly allocated in tasks (+).	3,4
Appearance profiles	**2**	All appearance profiles are wrongly allocated, although they exist. There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	**1**	There is only one appearance profile created. Wrongly named and no elements correctly allocated to it. There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	**2**	Appearance profile for concrete is missing. There is no temporary appearance profile created in order to be able to watch the construction of the foundations. Correctly allocated steel appearance profile (+).	**1**	Appearance profile for concrete is missing. There is no temporary appearance profile created in order to be able to watch the construction of the foundations. Mistakes in the allocation of steel appearance profile.	**2**	No steel or concrete appearance profiles. However, other appearance profiles created for which there is correct appearance profiles allocation (+).There is no temporary appearance profile created in order to be able to watch the construction of the foundations.	1,6
Schedule from scratch	**0**	There is no Schedule Health Report. The schedule of activities makes no sense at all.	**2**	Foundations and suspended steel structure are missing. There is no Schedule Health Report. The schedule of activities makes no sense at all.	**1**	Foundations, suspended steel structure and air coolers are missing. There is no Schedule Health Report.	**4**	Air coolers are missing. There is no Schedule Health Report.	**0**	There is no schedule of the activities at all! There is no Schedule Health Report.	1,4
Subtotal		12		16		11		16		11		

Table 26. Descriptive results of testing Team Task - Group A

	Team 1			Team 2					
Group A	Name 1: **Participant 1**		Name 2: **Participant 2**	Name 3: **Participant 3**		Name 4: **Participant 4**	Name 5: **Participant 5**		
Group Task									**Average**
Accessing / checking user fields	**3**	There was difficulty to understand were and how to access the user fields and understand the information provided in them	**3**	There was difficulty to understand were and how to access the user fields and understand the information provided in them	**3**	There was some difficulty to understand were and how to access the user fields and understand the information provided in them.	**3**	There was some difficulty to understand were and how to access the user fields and understand the information provided in them.	**3**	There was some difficulty to understand were and how to access the user fields and understand the information provided in them.	3
User fields filters	**5**	All of the members understood the role and the steps to create user fields and they were able to use them properly while working on the assignment (+).	**5**	All of the members understood the role and the steps to create user fields and they were able to use them properly while working on the assignment (+).	**5**	All of the members understood the role and the steps to create user fields and they were able to use them properly while working on the assignment (+).	**5**	All of the members understood the role and the steps to create user fields and they were able to use them properly while working on the assignment (+).	**5**	All of the members understood the role and the steps to create user fields and they were able to use them properly while working on the assignment (+).	5
Cutting planes	**3**	Cutting planes not placed according to the instructions.No separate 3D window for the cutting planes. Both cutting planes present and correctly named (+).	**3**	Cutting planes not placed according to the instructions.No separate 3D window for the cutting planes. Both cutting planes present and correctly named (+).	**3**	No second cutting plane. Cutting planes not placed according to the instructions.	**3**	No second cutting plane. Cutting planes not placed according to the instructions.	**3**	No second cutting plane. Cutting planes not placed according to the instructions.	3
Report	**0**	No report exported at all.	**0**	No report exported at all.	**3**	No focus time present. Not the complete project is present in the final report.	**3**	No focus time present. Not the complete project is present in the final report.	**3**	No focus time present. Not the complete project is present in the final report.	1,5
Completeness of deliverable	**0**	Not all of the tasks are linked (not a complete schedule). No feasible schedule (constractability). There is no animation or scenario book exported.	**0**	Not all of the tasks are linked (not a complete schedule). No feasible schedule (constractability). There is no animation or scenario book exported.	**1**	Not all of the tasks are linked (not a complete schedule). Limited scope of the assignment (only the 10kV building). There is no scenario book exported.	**1**	Not all of the tasks are linked (not a complete schedule). Limited scope of the assignment (only the 10kV building). There is no scenario book exported.	**1**	Not all of the tasks are linked (not a complete schedule). Limited scope of the assignment (only the 10kV building). There is no scenario book exported.	0,5
Subtotal	11		11	15		15	15		

Table 27. Descriptive results of testing Team Task - Group B

		Team 3				Team 4						
Group B		Name 1: **Participant 6**		Name 2: **Participant 7**		Name 3: **Participant 8**		Name 4: **Participant 9**		Name 5: **Participant 10**		
Group Task												**Average**
Accessing / checking user fields	**4**	Not both participants showed the same level of fluidity, when accessing the information stored in the 3D properties user fields. However, in general both showed that they can understand their meaning and	**4**	Not both participants showed the same level of fluidity, when accessing the information stored in the 3D properties user fields. However, in general both showed that they can	**3**	Not all participants showed the same level of fluidity, when accessing the information stored in the 3D properties user fields. However, in general all showed that they can understand their	**3**	Not all participants showed the same level of fluidity, when accessing the information stored in the 3D properties user fields. However, in general all showed that they can understand their function (+).	**3**	Not all participants showed the same level of fluidity, when accessing the information stored in the 3D properties user fields. However, in general all showed that they can understand their function (+).	3,5
User fields filters	**4**	There were some minor difficulties for the participants to understand how they can filter based on user fields and how to activate / deactivate them. However, at the end both show that they understood well as they could perform it (+).	**4**	There were some minor difficulties for the participants to understand how they can filter based on user fields and how to activate / deactivate them. However, at the end both show that they understood well as they could perform it (+).	**3**	There were some minor difficulties for the participants to understand how they can filter based on user fields. As a result there are several mistakes in object allocation to tasks.	**3**	There were some minor difficulties for the participants to understand how they can filter based on user fields. As a result there are several mistakes in object allocation to tasks.	**3**	There were some minor difficulties for the participants to understand how they can filter based on user fields. As a result there are several mistakes in object allocation to tasks.	3,5
Cutting planes	**2**	The planes and the manipulators are present in the cutting planes view. Cutting planes not placed according to the instructions.	**2**	The planes and the manipulators are present in the cutting planes view. Cutting planes not placed according to the instructions.	**1**	There is only one cutting plane. Cutting planes not placed according to the instructions. The planes and the manipulators are present in the cutting planes view	**1**	There is only one cutting plane. Cutting planes not placed according to the instructions. The planes and the manipulators are present in the cutting planes view.	**1**	There is only one cutting plane. Cutting planes not placed according to the instructions. The planes and the manipulators are present in the cutting planes view.	1,5
Report	**3**	Although the complete project is visible in the report, the legend is not readable.	**3**	Although the complete project is visible in the report, the legend is not readable.	**4**	Although the complete project is visible in the report, the legend is not readable. No second window for cutting planes. Extra camera path for increasing the visibility of the process (+).	**4**	Although the complete project is visible in the report, the legend is not readable. No second window for cutting planes. Extra camera path for increasing the visibility of the process (+).	**4**	Although the complete project is visible in the report, the legend is not readable. No second window for cutting planes. Extra camera path for increasing the visibility of the process (+).	3,5
Completeness of deliverable	**2**	Not all of the tasks are linked (not a complete schedule). Although there is the attempt to complete both buildings in the scope of the assignment the missing links are a significant problem. There is no scenario book exported.	**2**	Not all of the tasks are linked (not a complete schedule). Although there is the attempt to complete both buildings in the scope of the assignment the missing links are a significant problem. There is no scenario book exported.	**0**	Not all of the tasks are linked (not a complete schedule). No feasible schedule (constractability). Although there is the attempt to complete both buildings there are floors present in the start of the animation (not assigned resources). There is no scenario book exported.	**0**	Not all of the tasks are linked (not a complete schedule). No feasible schedule (constractability). Although there is the attempt to complete both buildings there are floors present in the start of the animation (not assigned resources). There is no scenario book exported.	**0**	Not all of the tasks are linked (not a complete schedule). No feasible schedule (constractability). Although there is the attempt to complete both buildings there are floors present in the start of the animation (not assigned resources). There is no scenario book exported.	1
Subtotal		15		15		11		11		11		

Table 28. Self-confidence evaluation results. (Percentage of participants based on their answer in groups A and B)

	I got it but I need more time to practice		**I feel comfortable using it in a professional project**	
	Group A	Group B	Group A	Group B
Navigation	100%	100%	0%	0%
Task relationships	80%	80%	0%	20%
Resource allocation	100%	40%	0%	**60%**
Appearance profiles	40%	40%	20%	**60%**
Schedule from scratch	100%	40%	0%	20%
Accessing / checking user fields	80%	60%	20%	40%
User fields filters	40%	60%	**60%**	20%
Cutting planes	40%	20%	40%	**60%**
Reports	100%	40%	0%	20%

About 60% of the participants in group B feel confident to use their skills in a professional project regarding the creation of cutting planes and the allocation of appearance profiles when none of them has a passing grade in these competencies. At the same time, in group A most participants didn't have a passing grade regarding the allocation of appearance profiles and indeed only one of them declared confidence to use this competency in a professional project. Also 60% of participants in group A feel confident to apply their skills professionally regarding the use of 3D filters, and indeed all the participants of group A scored the highest grade in that competency (5/5).

Discussion of trial training results

Checking again the original hypothesis: "Providing detailed instructions and step-by-step demonstration by an expert (Group B) can be more efficient as a method for providing procedural information during a 4D BIM training session than providing a step-by-step guide and having participants explore the software buttons and tools themselves (Group A). Based on the results the hypothesis doesn't seem to be confirmed.

Closing, this design choice workshop resulted in a mix of the two instructional methods for the proposed detailed design. Participants in the beginning receive detailed instructions for setting up the software interface, understanding the requirements of the assignment and the sequence of steps required for it. Then they receive a detailed step-by-step guide for the assignment steps and the instructor who is present during their learning task, provides corrective feedback and further instructions only this is requested. Also, the time allocation for providing procedural information has been increased and the scope of the assignments has been reduced in order to ensure that there will be enough time to achieve more complete deliverables. At last, the trial workshop confirmed further the criticality of the part-task practice after the completion of the training session. Almost, all participants indicated that for most of the competencies, although they have gotten a very good picture regarding how the 4D BIM process and tools work, they would need more time to practice in order to feel confident apply their competencies in their professional environment.