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COMPARATIVE STUDY OF THREE 4D SIMULATION SOFTWARE

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Abstract
The gradual adoption of Four-dimensional (4D) simulation and its benefits underscore the increased interest in leveraging all its capabilities. Although widely used in AEC projects, 4D simulation tools are still explored for their ease of use, features, and potential. This report presents a comparative study of three 4D simulation software programs: Navisworks Manage, Synchro 4D Pro, and Fuzor. The analysis aims to evaluate their respective effectiveness for 4D simulation based on several criteria grouped into four main categories: collaborative features, 4D features, 3D features, and planning features. Regarding collaborative features, all three tools have comparable strengths, particularly in terms of file import and export. Navisworks Manage stands out for its compatibility with over 60 file formats, while Synchro and Fuzor distinguish themselves with their plug-in system, in addition to compatibility with certain formats, including IFC. In terms of 4D features, Fuzor takes the lead with its extensive capabilities and possibilities. Navisworks ranks second, meeting all criteria in this category, unlike Synchro, which is slightly behind due to its limitations. In terms of 3D features, Fuzor also excels, offering the ability not only to create 3D models but also to fully meet established criteria. Synchro follows, having an advantage over Navisworks with its ability to modify integrated models, even if only through simple subdivisions. Finally, for planning aspects, Fuzor and Synchro stand out for their numerous features, while Navisworks is in last place, offering more limited options for planning development.

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Keywords: building information modeling, construction planning, 4D simulation.

1. Introduction

Four-dimensional (4D) simulation is currently considered and recognized as one of the primary applications of Building Information Modeling (BIM), which involves linking a 3D model with activity planning to visualize the evolution of the construction process over time [1]. Its utility has been evaluated through various studies, highlighting its advantages for a diverse range of needs, such as construction planning and constructability analysis, education, communication and collaboration facilitation, as well as site organization and logistics management [2]. Despite the remarkable advantages of 4D simulation in the construction field, particularly concerning management and planning, it is important to note that the adoption of these tools requires significant adjustment both to schedules and the 3D model to align with work execution expectations. Additionally, it should be noted that 4D simulation tools cannot strictly be considered planning tools, as their usage depends on the prior existence of an established schedule [3]. Furthermore, despite the recognition of high beneficial potential of 4D simulation, adoption rates remain relatively low, primarily due to various factors including limited client demand, specific organizational challenges, as well as varying levels of user experience and competence. It is also essential to note that certain technical obstacles related to currently available software in the market may also hinder the adoption of 4D simulation, potentially compromising its ability to achieve its full potential in terms of efficiency or effectiveness [2]. Following this approach, regarding factors likely to hinder the adoption of 4D simulation in the construction field, the issue of varying levels of user experience and competence raises consideration as to whether this could be linked to difficulties encountered in software usage and if actual implementation of 4D simulation would be challenging. Therefore, the main objective of this study is to compare three 4D tools within a simulation framework. The methodology first involves identifying and understanding current 4D simulation needs by defining comparison criteria. Then, it involves evaluating the effectiveness and capabilities of each software against these criteria. Thus, this report is structured into three chapters: the first chapter focuses on a literature review aiming to identify and examine related concepts, as well as the state of the art in technological advancements and practices to define potential needs; the second chapter outlines the research methodology, and the third chapter presents the comparative evaluation of the tools; finally, a final discussion and conclusion with remarks to support future work are provided.

2. Literature Review

2.1. Use of 4D simulation in construction

4D simulation involves associating a schedule (time) with a three-dimensional (3D) model of a structure, enabling a simulation of the construction process over time. This approach is widely recognized for its ability to significantly enhance the planning and management of construction projects. Its increasing adoption in this field offers undeniable potential advantages. This approach proves extremely useful in detecting, preventing, and rectifying errors that may occur throughout the construction process, thanks to its ability to detect spatial-temporal conflicts. Additionally, it enhances site safety and optimizes organization by providing a better understanding of execution stages. With its capability to generate animations and simulations by integrating the schedule into the 3D model, 4D simulation facilitates the presentation of construction progress during meetings and presentations. Another essential advantage of this approach lies in its ability to improve communication and mutual understanding among different stakeholders. By providing a spatio-temporal visualization of the structure, 4D simulation offers real-time information on project progress. Through this, stakeholders can make crucial decisions, thus avoiding unnecessary time and cost losses and constraints [4]. 4D simulation is also a powerful integration tool, enhancing collaboration among various stakeholders in a construction project. Communication is a key element of project success, but traditional methods and previous information exchanges have often hindered smooth collaboration between designers and builders. However, the 4D model facilitates information exchange and encourages more effective collaboration by allowing stakeholders to use a common model and benefit from each other's perspectives. Additionally, this approach also serves as an analytical tool by enabling the evaluation of the implementation of the construction project schedule, further reinforcing its relevance and utility in the construction sector [5]. Moreover, 4D Computer-Aided Design (CAD 4D) is commonly used as a communication and explanation tool [6].

2.2. Recent Developments

Over the years, it is heartening to note that the scope of 4D simulation usage has significantly expanded, revealing additional applications and varied benefits that 4D simulation can offer. Among these benefits, specific mention can be made of excavation and earthwork simulation, a possibility that provides invaluable support to planners in carrying out their leveling operations. Equally crucially, its incorporation into the educational sector represents a major asset. Indeed, 4D simulation greatly facilitates students' practical understanding, especially through its ability to optimize efficient information sharing. This seamless integration into the educational field thus contributes to making concepts more accessible, fostering an immersive and enriching pedagogical approach [7]. In this context, the daily use of 4D models becomes more valuable as they integrate with other visualization technologies. Its linkage with virtual reality (VR), once possibly considered imaginary, is now a feasible possibility. VR, as a computer technology aimed at creating simulated spaces, proves to be an exceptional visual tool in the construction domain, stimulating innovation in traditional practices. This harmonious interaction between 4D simulation and virtual reality promises realistic visualization of construction projects, facilitating detailed inspection of digital models, optimizing collaboration among stakeholders, and further simplifying the decision-making process. The integration of 4D simulation with virtual reality is envisaged through two distinct approaches: on the one hand, via direct connection with the APIs of BIM and VR tools, and on the other hand, by integrating BIM data into the Unity3D game engine. Although the second possibility has been tested through the development of a prototype aimed at facilitating this linkage, this practice has allowed for the evaluation of certain functionalities. Nevertheless, constraints have been identified and will be examined in depth, with potential solution paths considered in future work [8]. The benefits and innovations of 4D modeling continue to expand in the construction domain. Linear projects, which typically span vast territories or regions, are frequently sources of significant environmental impacts. These projects require an environmental assessment strategy integrating variant analysis. This variant analysis constitutes a preliminary step before planning Environmental Impact Assessments (EIA). Its objective is to evaluate the best methods for project implementation, involving comparisons between the advantages and disadvantages of each possibility. This aims to identify the optimal method by considering multiple criteria related to economic, technical, and environmental aspects. 4D modeling, with its advanced features, plays a crucial role in construction and site planning. On-site elements such as logistics, traffic flows, safety, delivery, etc., are considered in 4D simulation. By linking 3D model objects to the project schedule to simulate construction over time, this approach facilitates effective spatial visualization. In this context, it enables an effective visual representation of the spatial-temporal attributes of various environmental impacts [9].

2.3. Similar comparison works

The comparison of 4D simulation tools is not a new approach. Since their introduction to the market, research has been undertaken to evaluate the productivity of 4D tools; however, no comparison of 4D software productivity was conducted before the year 2011 [10]. Users show constant interest in exploring these tools. In search of the tool best suited to their project needs, prioritizing ease of use, or desiring to explore new offerings present in the market, among other criteria. In this context, over the years, many authors have compared various 4D simulation software.

In 2017, Ronja Korhonen undertook an analysis of production phase schedule planning, with the aim of highlighting the selection of the most performant and suitable 4D software based on the advantages offered by 4D simulation. During her thesis, she compared different software such as Tekla Structure 21.0, Navisworks Simulate 2016, and Synchro Pro 2016.2. The study was conducted with the same 3D model for all, aiming to ensure a fair evaluation, and its conclusions established that Synchro Pro 2016.2 stands out as the most versatile 4D tool among the examined software, however, it also requires a more in-depth familiarity. Korhonen [10] also conducted a comparative evaluation of the productivity of three 4D simulation tools, namely Vico Office, Autodesk Navisworks Simulate, and Synchro Professional. The objective of this analysis was to quantify the time required for each of the four steps of the process necessary for 4D model creation. These steps included accessing the product model (3D), planning access, linking the 3D model to the schedule, and visualizing the 4D model. It is worth noting that the study was conducted with the same 3D models for all evaluated tools. The conclusions drawn from this research demonstrated that, in the case of Vico Office, the total duration of the steps was shorter compared to the other software. In 2020, Nechyporchuk and Bašková [4] conducted a comparative analysis to evaluate two 4D simulation tools, namely Autodesk Navisworks and Synchro Pro, regarding their compliance with the requirements for using and creating 4D models for buildings. The conclusions of this study suggest that preferential decision-making between these two software should be based on an evaluation of source data, desired outcomes, etc. Indeed, each tool presents strengths and weaknesses that require assessment in the selection process [4].

3. Methodology

3.1. Methodological Approach

To successfully compare the 4D simulation tools, the process revolved around three steps: firstly, the identification and definition of comparison criteria, which would form the basis of the evaluation. Secondly, the actual evaluation of the selected software, performed based on the pre-established criteria. Thirdly, the comparative analysis of the performance of each software studied. The choice of software for the comparative study was oriented towards Navisworks Manage, Synchro 4D Pro, and Fuzor. The choice was justified by the fact that they are the most mentioned in the literature and Fuzor symbolizes the new generation. Both Navisworks and Synchro are widely recognized project review tools. Moreover, these two software tools are frequently mentioned in various previous comparative studies. Navisworks is considered a traditionally used software in the field of 4D simulation, while Synchro is a widely adopted tool in the industry. In contrast, Fuzor represents the new generation of 4D simulation software in the construction sector. Therefore, given these distinctions, it was particularly relevant to compare them in terms of their capabilities to perform simulations. This choice aimed to determine why using Synchro could be more advantageous than using Navisworks, while evaluating the potential added value of Fuzor as a new generation software, as well as its ease of use.

3.2. Criteria identification

Many researchers have highlighted the importance as well as the numerous advantages of 4D simulation in the construction sector, while shedding light on the criteria that a 4D simulation tool should meet to effectively address users' needs. In this perspective, an in-depth search was conducted through scientific articles and specialized works on 4D simulation to determine relevant criteria for this comparison. Some of these criteria were inspired by previous works that had already compared 4D simulation tools, while others emerged from specific features, efficiency, and capabilities sought in a tool qualified as "4D," in line with the expectations expressed to enhance the construction domain through 4D simulation, following the consulted articles. Once these criteria were established, further research was conducted through search engines such as Google and supplier websites to identify certain available 4D simulation tools.

3.3. Software comparison

The evaluation of the software took place taking into account several factors. First, it should be mentioned that the versions of the software used for the comparison were different. Navisworks Manage was in version 2024, this choice proved convenient as Autodesk provides students access to downloads of various versions. As for Synchro 4D Pro, the version used was 2021, following some difficulties encountered with a newer version, notably the inability to integrate the Microsoft Project schedule. Fortunately, Bentley technicians were able to provide this version to ensure smooth work. Regarding Fuzor, the version used was 2022, a student version for which I had a valid license. The evaluation of the 4D simulation software was conducted fairly, using a single 3D model as well as a schedule for all three tools. This 3D model representing an institutional building was imported from Revit, accompanied by an activity schedule established from Microsoft Project software. Subsequently, the 4D simulation was carried out. Additionally, equipment such as a crane and a concrete mixer were added to evaluate the software's ability to create animations of these specific construction site equipment.

4. Main results

The comparison of 4D simulation software is based on the application of specific standard criteria aimed at measuring their compliance as 4D tools against defined requirements. These criteria were carefully selected as essential, divided into four main categories, as indicated in Table 1.

4.1. 4D Features

4.1.1. Animation, Linked and Unlinked Equipment Animation to Schedule

In terms of animation, all three software tools have the ability to create animations. Navisworks software offers the ability to create animations to stage building objects. To do this, the Animator tool allows creating scenes by recording key positions of each movement or each desired position for the animated object. This step differs from the process of linking tasks to objects for construction simulation, as simply linking an object to its task instantly displays it in the simulation. However, it is conceivable to integrate these scenes as animation sets into the schedule for animated construction elements. However, this will require separate animation for each element, which can be considered unproductive due to the time and difficulty in correctly placing the element back to its original position after performing the scenes. With this software, it is also possible to animate equipment, whether included or not in the project schedule, by repeating the same process with Animator, used for the 3D model elements. In this context, the principle in Navisworks to view animations in construction simulation involves adding the scene sets created in Animator to each corresponding task. In Synchro software, when linking tasks to objects or afterward, it is possible to use the Usage Profiles tool to define the construction growth simulation of elements. This feature includes the ability to integrate animations, which somewhat reminds me of the Navisworks process because creating a user profile for elements for simulation is also necessary. However, unlike Navisworks, once the type of usage profiles is created, it can be assigned to all desired 3D model elements adopting the same animation style. This avoids wasting time and repetition of animation, as well as not requiring the movement of elements.

Regarding equipment animation, it is important to note that, in Synchro software, the task must be present in the schedule before having the opportunity to animate the desired equipment. The equipment animation process differs from that of the model elements. To animate any equipment, whether fixed like a crane or moving like a concrete mixer, it is possible to use the 3D path tool by adding steps to the path created with the desired angles or positions. Fuzor, like Synchro, offers the ability to animate elements at the time of linking tasks to the 3D model object or afterward. In this software, animation of construction elements is already integrated by default with a logic of construction growth based on reality, but it is still possible to modify the software's predefined orientations. This process is carried out in the 4D simulation tool, where the option to edit animations is found. Just like Navisworks, Fuzor allows animating equipment, whether included in the schedule or not. The equipment animation process is somewhat similar, as it relies on adding key positions, much like keyframe captures. For fixed equipment like cranes, this method is exactly used, while for moving equipment like concrete mixers, they can also be animated using a 3D path. In Fuzor, just like in other software, it is necessary to link animations to a task for them to appear in the simulation. However, in Fuzor, animations made with 3D paths automatically loop, whether linked to a task or not, and are represented as animation sequences.

In terms of comparison, it seems that Fuzor stands out by offering more extensive capabilities, notably through its variety of options available in the content library. This diversity eliminates the need to download families for animations, which helps avoid potential file compatibility issues. Additionally, Fuzor allows the creation of more sophisticated animations, such as manipulation and storage of construction objects. As a result, this provides a more realistic simulation experience of a construction site.

4.1.2. Linking 3D Models to Schedule, Manual and/or Automatic Linking Capability

All three software tools have the ability to link 3D model elements to their corresponding tasks in the schedule. However, some offer more possibilities than others.

The linking process between the 3D dimension and the schedule in Navisworks can be done either manually or automatically. The manual method involves individually associating each object with its respective task in the schedule sequentially. In contrast, automatic linking relies on the application of specific rules, such as selection sets or other predefined criteria. The use of selection set rules is particularly interesting because in case of no initial configuration of shared parameters of the 3D model before its integration into the 4D software, this method simplifies automatic linking by simply adding a corresponding column in the schedule associated with the same names as the selection sets, thus creating groupings of elements. These linking processes are performed using the Timeliner tool. With the Synchro tool, linking between the 3D dimension and the schedule must be done manually, which may not pose a problem for small-scale projects. However, for considerably large projects, it would be advantageous to have the ability to perform this linking automatically. This approach not only would streamline the work but also ensure that all elements are correctly linked to the corresponding project tasks. In Synchro, once in the 3D object tool, simply select the chosen task and construction element, then from the right-click dropdown list, find the option to assign to the selected task.

As for Fuzor, it offers the flexibility to allow the user to choose between manual and automatic linking between the 3D dimension and the schedule. Similar to Navisworks, the manual method involves individually associating each object with its respective task in the schedule. Automatic linking in Fuzor relies on predefined rules, such as level filters, category filters, parameters, etc. This approach gives users the option to choose the method that best suits their needs and the complexity of their project.

4.2. Collaboration Features

The data export feature of a 4D simulation software is of considerable interest as it allows visualizing the generated content in the form of videos outside the 4D simulation software environment, for presentations and other applications. Navisworks Manage, for example, offers the ability to export both animations and simulations created by linking 3D elements to the schedule. Navisworks' Timeliner tool allows these exports in formats such as JPEG, PNG, Windows AVI, and Windows Bitmap, with the choice of Windows AVI format resulting in a video of the created animations or simulations. Regarding Synchro 4D Pro, it is possible to export only the animations created. If one wishes to view the construction sequence as a video, it is necessary to create it as an animation. In Synchro's animation tool, simply select the animation to export via the AVI export option. The software supports multiple export formats such as MP4 Video, AVI Video, JPG Frames, PNG Frames, and BMP Frames. As for Fuzor, its export features are similar to those of Navisworks Manage, in that it allows the export of animations and simulations created by linking activities to 3D model elements. However, Fuzor offers a greater variety of possibilities. The "Flythroug" application allows creating and exporting 4D sequence videos, and also provides access to many other related applications, giving full control over the animations. Export can be in MP4 or FMP format. It is possible to automatically generate a 4D cinematic of the simulation or edit it before export. Additionally, during export, it is possible to choose to view only moving equipment, with a wide range of presentation options. Overall, Fuzor software offers superior advantages in this area.

When integrating 3D models into 4D simulation tools, it is observed that all these tools rendered the model fairly accurately to that of Revit. In the case of Navisworks, the Revit model was downloaded in its format directly, while for Synchro Pro and Fuzor, the download was done via their plugins integrated into Revit. At the end of the download, Fuzor did not properly define the curtain walls, presenting them all with a blue color instead of the intended glass (Figure 1).

a b c

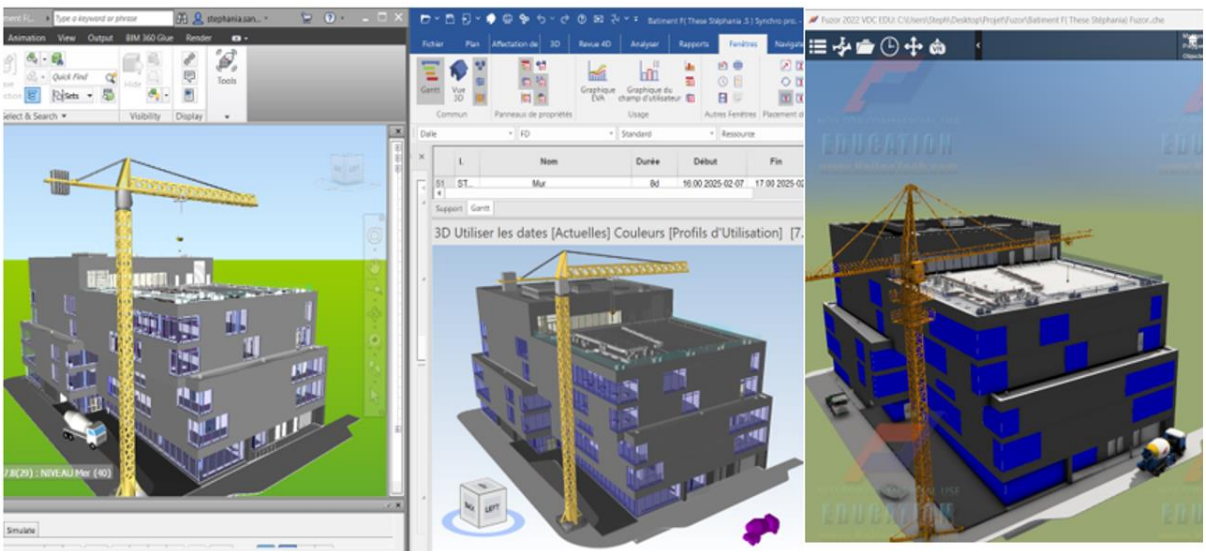

Figure 1. Presentation of the three Revit 3D models integrated into the 4D simulation tools. (a) Naviswork Manage; (b) Synchro 4D Pro; (c) Fuzor.

Fuzor stands out from the other software in this comparison by its ability to modify the material types of elements. To do this, simply select the desired object, then from the appearing properties menu bar, choose the desired material type. With this functionality, I was able to modify the model's appearance in Fuzor. When integrating the model into Synchro Pro, I noticed that it was impossible to select an individual element directly from the 3D model. At each attempt, the entire model was selected, which I found neither advantageous nor efficient. Indeed, this required selecting the desired object in the tree structure, which was not always straightforward and time-consuming.

4.3. 3D Features

4.3.1. Creation, Import, and Manipulation of 3D Models

Navisworks software is primarily used as a coordination and review tool, meaning it does not have the intrinsic ability to create or modify 3D models. However, it offers an extremely robust import functionality, capable of supporting nearly all available 3D file formats on the market. Similarly, in Synchro Pro, creating 3D models is not possible. Although the software allows manipulation of integrated models, it generally limits to subdividing elements without the possibility of deep modification. It is also capable of importing 3D models in various formats, including via plugins, although Revit families are not supported. In contrast, Fuzor offers the ability to create 3D models right from the software's startup, allowing to initiate a new project. The manipulation of 3D models is much more extensive, offering the ability to subdivide elements, modify materials, textures, etc. Additionally, it allows adding or removing details such as families. Fuzor supports several common 3D file formats such as FBX, OBJ, DWJ, DXF, CHE, CHL, 3DS, EXE, and SKP, as well as the ability to integrate plugins for certain software.

In Navisworks, the quality of graphical rendering is very crisp, although lacking in realism. Regarding the persistent link with the model, the software is capable of updating the model in the Navisworks tool from the source 3D model. Similarly, in Synchro Pro, the graphical detail visualization is clear but also lacking in realism, as in Navisworks. It also has the ability to update the model in Synchro from the source 3D model. Additionally, it integrates a bidirectional linking option in the program, although this functionality is not operational. Fuzor, on the other hand, offers advanced features for model graphical rendering, tending towards increased realism with high resolution and real-time shadows. It also provides an extensive range of graphical parameters and visual effects, facilitating the creation of detailed and realistic visualizations. Furthermore, the software is capable not only of maintaining a persistent link with the model in the software from the 3D model source but also ensuring bidirectional update. In the Revit model, the synchronization request option in the plugin allows updating the Revit model from Fuzor. What is interesting to note is that the user has the option to manually choose the modifications to be made to the source model, as all changes made are listed.

4.4. Planning Features

All three software tools have the ability to create and import schedules. In Navisworks' Timeliner tool, there is the ability to create and modify project calendar activities with an added 3D model. Through the "Add Task" option, it is possible to create a complete schedule or add activities to an already integrated calendar. Regarding the "Data Source," the software allows importing Ms Project, Primavera, and CSV files. However, Navisworks does not have network process analysis tools (Gantt chart) or features to modify predecessors. Although it is possible to move tasks in the diagram, it is difficult to realistically assess the impact of a change on other activities because the entire logic of the schedule is not visible. To visualize the construction progress in our schedule, it is necessary to switch to simulation, and even when returning to the schedule, attention is required to make necessary corrections before restarting the simulation, which can be impractical. In Navisworks, it is therefore preferable to have a complete and ready-to-use schedule before integrating it for 4D simulation. In Synchro software, once the 3D model is integrated, one can begin to create a calendar. And if a schedule has already been created in another scheduling software such as Primavera or Ms Project XML, it can be imported. Creating a project calendar in Synchro is similar to other scheduling software such as MS Project; options like "finish-start" and others can be used. When linking tasks with 3D objects, in the "3D Resource" column, one can observe the number of elements attached to each task. A very interesting feature of Synchro is the ability to instantly validate all changes made to the schedule as it is being created or adjusted. Simply drag the red timeline in the desired direction, allowing to quickly visualize the impact of decisions on the project's progress. Fuzor software, like other compared 4D simulation software, allows once a 3D model is added, to create a schedule. If a schedule has already been developed in another scheduling software, it can be imported into Fuzor, but it only accepts XML and CSV files, from scheduling software such as Asta Power Project XML, Microsoft Project XML, Primavera P6 XML, and Microsoft Excel CSV. Creating a project calendar in Fuzor is similar to other scheduling software such as MS Project; one can determine days off, working hours, and other parameters. When linking tasks with 3D objects, in the "Obj #" column, one can observe the number of elements attached to each task. Unlike Synchro, where the timeline can be moved from right to left, Fuzor has a fixed timeline. However, while manipulating the simulation, it is still possible to visualize our position in the schedule. Furthermore, when creating tasks, one can determine their type, for example, whether it is a construction task, equipment, sequence, etc. This is displayed below the bar to play the simulation. This feature is interesting as it offers more options to create a schedule that closely resembles the reality of a construction site.

The persistent and bidirectional linking of the schedule is ensured by the synchronization process. Once a calendar is added in the 4D simulation software, any modification made aiming to update the source schedule is called "sync to." Similarly, if changes are made in the source schedule and one wishes to update the data in the simulation software, this is known as "sync from." This method avoids re-downloading, as re-downloading a schedule results in the loss of already established links with the 3D model. Synchronization allows maintaining these links and simply modifying or adding changes made in the schedule. However, some tools are only capable of providing persistent linking, which is an update from. Navisworks software only offers the persistent linking functionality between the current schedule and the source calendar. It offers two distinct options in this process: the first is "rebuild," which allows reimporting all activities and rebuilding the task hierarchy. The second option is "synchronize," which updates the modified information from the source schedule. Synchro Pro offers bidirectional linking allowing to update the schedule. In the synchronization process, different options are available depending on the information one wishes to update or not. It is thus possible to choose to "skip a step," meaning that this data will not be updated at all. One can also opt for "synchronize," where the schedule in Synchro Pro will be entirely replaced by the new updated schedule. "Consolidate": where the schedule in Synchro Pro will be merged with the new updated schedule, without deleting data. Finally, there is "integrate," where the schedule in Synchro Pro will also be merged with the new updated schedule during synchronization. Elements deleted in the new schedule will also be deleted in Synchro Pro when updating information. It should be noted that refreshing from Synchro to the external source is not possible if the source file is a Ms Project file. Although this option is well integrated into the software, it works with Primavera or similar software. However, it is possible to export the schedule in several formats such as Ms Project XML, Primavera P6 and P3, IFC, and Microsoft Excel. Fuzor software, similar to Navisworks, offers an exclusive persistent linking feature. It allows the integration of schedule updates directly from the source calendar into Fuzor, with various additional options. Among these, there is the "add" option, which allows the addition of a new schedule even if a schedule is already created in the software. The information from this new schedule will simply be added to the existing schedule. There is also the "merge by ID" option, which updates tasks with a common identifier with the imported activities. "Replace" is another option that completely overrides existing data with imported data. Finally, the "reload" option allows synchronizing changes made in the source calendar with the current Fuzor calendar.

4.5. Comparation summary table

The evaluation of each criterion for each software is performed to obtain the comparison table. For the evaluation, a scale of 0 to 3 is used: 0 = the criterion does not exist, 1 = the criterion exists and is not very effective, 2 = the criterion exists and is effective, and 3 = the criterion exists and is very effective.

Table 1. Evaluation of BIM 4D simulation software based on identified criteria.

Categories	Criteria	Definition	Navisworks	Synchro Pro	Fuzor
4D Features	Simulation creation	The software's ability to create simulations	3	3	3
	Animation	The software's ability to create animations such as construction equipment or building elements.	2	2	3
	Equipment animation	The software's ability to create animations of construction equipment.	2	2	3
	Non-planning-related equipment animation	The software's ability to animate equipment that is not linked to the schedule.	3	0	3
	Linking 3D model elements to the schedule	The software's ability to link 3D model elements to the schedule.	3	3	3
	Manual linking capability (3D+planning)	The software's ability to manually link 3D model objects to their schedule tasks.	3	3	3
	Automatic linking capability (3D+planning)	The software's ability to automatically link 3D model objects to their schedule tasks.	3	0	3
	Conflict detection	The software's ability to detect interference between elements of multiple models.	3	3	3
Collaboration Features	Export/Import of data	The software's ability to export or import project data	2	2	3
	Interoperability and file formats	The software's ability to communicate and exchange data with other software and/or systems, as well as its ability to support various types and formats of files.	3	3	3
3D Features	3D model creation	The software's ability to create 3D models	0	0	-
	3D model import	The software's ability to import 3D models	3	3	3
	Manipulation/Modification of 3D Models	The software's ability to manipulate and modify 3D models.	1	1	3
	Graphical and Temporal Detail Visualization	The software's capability in graphical representation of models and maintaining quality after importation.	2	2	3
	Persistent Link with the 3D Model	The software's ability to update the integrated model based on modifications made to the source 3D model.	2	3	3
Planning Features	Planning Creation	The software's ability to create a schedule.	1	3	3
	Planning Import	The software's ability to import a schedule.	3	3	3
	Persistent Link with the Source Schedule	The software's ability to update the integrated schedule based on modifications made at the source.	2	3	3
	Bidirectional Link between Two Schedules:	The software's ability to update the integrated schedule based on modifications made at the source and vice versa.	0	2	3
Total			41	41	54

Conclusion

Building Information Modeling (BIM), as evidenced by the literature review, stands out as one of the most significant digital innovations in the construction industry. 4D simulation, among the various dimensions of BIM, represents an innovative approach to efficient construction project planning and management. It involves integrating a temporal schedule into a three-dimensional (3D) model of a structure, thus simulating the construction process over time; resulting in a 4D model that offers various possibilities, such as creating animation sequences, conflict detection, simulation, and visualization of construction stages of the structure before the commencement of work. The work reported in this paper aimed at proposing a comparative study of three 4D simulation software tools to assess their effectiveness and capacity to perform 4D simulations as well as their ease of use. The adopted methodology consists firstly in identifying and understanding the current needs in 4D simulation by defining comparison criteria, and then evaluating the effectiveness and capabilities of each software through the execution of three simulations based on a single institutional building and schedule. The results obtained are synthesized in a comparative table using a scoring system to differentiate the performance of each software tool. It should be noted that this report is limited to the evaluation of 4D simulation tools based on the defined criteria at the beginning and does not take into account other software functionalities outside of this aspect. Furthermore, the criteria were treated with equal importance, without assigning specific weighting to each; they were all deemed to have the same level of necessity and usefulness. However, this work provides a new understanding of the possibilities and limitations of certain current 4D simulation tools in terms of functionalities. Compared to previous works that often focus on comparisons between Synchro, Navisworks, or Fuzor with other tools, this current comparison emphasizes the three software tools often selected for such studies. In future research, it would be relevant to broaden the analysis to all 4D simulation software tools on the market to comprehensively evaluate their performance across all their functionalities dedicated to construction project planning and management, this time including specific weighting for each criterion.

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