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Computer-Assisted Scheduling Tools in the Construction Industry: A Systematic Literature Review

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Abstract: This paper aims to combat the haphazard manual process involved in building-erection planning and the associated lag in productivity growth by pointing industry stakeholders to the tools suited for their needs. It identifies 28 computer-assisted building construction scheduling tools that require no special skills and automate at least one step of the scheduling. Resulting from a systematic literature review of industry-related papers published between January 2008 and 2018, this work will guide construction practitioners through an array of tools classified according to their interface, inputs, and outputs, and will serve as the basis for further development in construction automation.

Keywords: Computer tool, Construction, Planning, Review, Scheduling, Software

1. INTRODUCTION

Barbosa et al. (2017) stated that the labour-productivity growth of the construction sector averaged 1% a year across the world over the last 20 years. This is substantially less than the 2.8% growth of the overall global economy and the 3.6% growth of the manufacturing sector. Although some construction firms have managed to keep pace with their country's overall economy, they represent less than 25% of the sector. This underperformance is partly the result of poor project management and a lack of investment in skills learning, R&D, and innovation (Barbosa et al., 2017). To alleviate this shortcoming, many reports over the last twenty years have suggested the need for an increased use of information technologies (Bayne and Taylor, 2006; Chan and Chan, 2002; Gibb, 2001) in the sector. Seeking to understand why this recommendation has not been implemented yet, authors found that although numerous attempts at modernisation have been made, most of them failed (Kenley, 2017). In light of this observation, Radujković and Sjekavica (2017) recommended that project managers should master a wide range of project management methodologies, methods, tools and techniques. Having multiple tools and strategies at their disposal will enable them to select the ones that best fit their case and help them plan, monitor and control.

Numerous studies were done on the subject of automation in the construction industry, and Faghihi et al. (2015) wrote an exhaustive review on the subject encompassing papers published between 1985 and 2014. This review was not systematic; rather, it examined the algorithms used and their quality, with consideration for three main performance indicators: cost, time, and quality.

This paper is designed to cover more ground. A systematic literature review was conducted to create an exhaustive list of the array of computerized scheduling assistants found in the literature over the last ten years. From the review, 28 tools were selected and classified according to their functionalities and integration method. By focusing on the practical features (interface, input, and output) of the tools, the research paper is meant to guide construction industry practitioners through the current offer of computer-assisted scheduling tools for building construction so as to foster their adoption. The following paper is divided into three parts: a description and report of the research method, the subsequent analyses of the results and a conclusion.

2. RESEARCH METHOD – SYSTEMATIC LITERATURE REVIEW

The method selected to guide the industry through the offer of computer-assisted scheduling tools is the systematic literature review. This approach "uses explicit, systematic methods to minimize bias in the identification, selection, synthesis, and summary of studies. When done well, this provides reliable findings from which conclusions can be drawn and decisions made" (Moher et al., 2015).

Following the guidelines from Moher et al. (2015), three main phases were completed: planning the review, conducting the review and reporting the review (Tranfield et al., 2003).

2.1 Planning the Review

The first phase is the planning of the review. Its first step is to define questions related to the research objectives. The

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answers to those questions are expected to help the construction industry practitioners update their scheduling tools and practices. The main questions investigated by the research team were:

A) What computerized tools and methods for scheduling the erection of a building can be found in recent literature?

B) What are the functionalities of these tools?

C) What performance indicators are considered?

The second step is to define clear eligibility criteria, followed by a justification for each. For this study, it was decided that the tools selected would be related strictly to work planning and scheduling. This excluded delivery methods, procurement strategy, materials, design, etc.: In an effort to reach as many users as possible, the tools should also be viable in any environment. At least one task in the creation of an operational plan had to be automated: Add-ons offer support for various tasks or performance analyses (safety, CO_2, waste, etc.). However, if they are too descriptive or predictive, it cannot be said that they help in scheduling (Delen et al., 2014). On the other hand, add-ons that provide prescriptive analytics will give users straightforward answers according to the stated objective and conditions, and reduce their workload. The automated management of information is also eligible. The tools and methods had to be computerized and in a functional state. They had to require no programming or operational research knowledge or skills: The reason for this was to reinforce the practical intent of the study and ensure its favourable reception by the industry (Rolfsen and Merschbrock, 2016). This could hardly be achieved by recommending products that are not functional, ideas that have not been implemented yet, or manual solutions. The period considered was from January 2008 to January 2018: The study's objective being centred on the current offer in the literature, a scope of ten years seemed appropriate to qualify a tool or a method as potentially new and adapted to current realities. The papers had to concern building erection rather than single-family homes, as building multi-storey or non-residential buildings typically involves more stakeholders and activities and necessitates greater planning and coordination.

With these criteria established, the scope of the study is well determined, and the results can be interpreted appropriately.

The next step is to structure the methodology used while conducting the review. It involves:

1) Identify the keywords used in the review;
2) Select databases compatible with the field and the methodology;
3) Adapt the search equations to the databases;
4) Extract and compile all the articles obtained;
5) Check for duplicates and apply the eligibility criteria;
6) Screen the remaining abstracts according to the study's criteria;
7) Read the remaining articles to ensure their relevance;
8) Classify the tools presented in the remaining articles.

This structure will be detailed in the next subsection.

2.2 Conducting the Review

The second phase is conducting the review. It entails the eight steps mentioned above, from defining the keywords to analysing and classifying the results.

The selected keywords are a decomposition of the main research questions, with the addition of synonyms taken from *Termium Plus*. The following equation was used during research: (((Plan* OR Optimisation OR Optimization OR Schedul*) NEAR/5 ("BIM" OR "Computer program*" OR "Computer application*" OR software* OR model*)) AND ((Construction*) NEAR/5 (site* OR plan* OR layout* OR logistic* OR industr*)) AND (Building* OR Multi*stor*)). In *Engineering Village,* the "NEAR" operators had to be replaced by "AND" because of the limitations of the search engine.

The resources selected for the search were *Web of Science, Engineering Village (Compendex* and *Inspec), Proquest, Google Scholar, Microsoft Academic, JSTOR,* and *IEEE Explore*. Only the first three databases were used in the study; the following two were discarded because of their incompatibility with a systematic literature review, and the last two did not provide any new results. The search was performed in November 2017 and updated in February 2018.

In the fourth step of conducting the review, 5,016 articles were extracted and compiled using reference management software. The fifth step was the removal of the duplicates, which left 3,459 papers. This was followed by the application of the eligibility criteria through the titles and the keywords, leaving 556 studies. The sixth step brought the number down to 446, by screening the remaining abstracts according to the eligibility criteria. These 446 articles were then read thoroughly, and 35 papers were selected for the final classification and analysis. From those papers, 28 tools were considered for the final analysis. Fig. 1 shows the approach used during the selection of the studies.

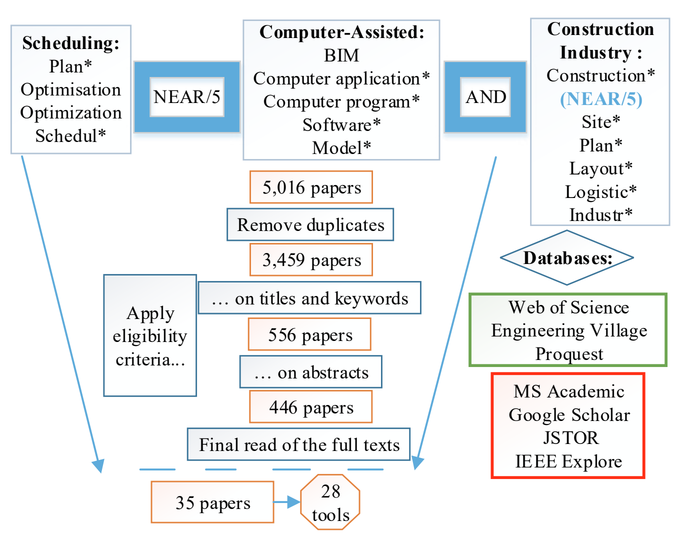

Fig. 1. Search equation, databases used and removed, and filtering sequence of the study.

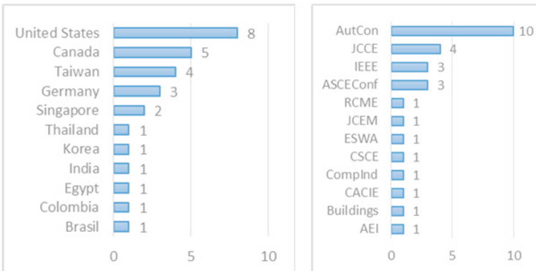

Fig. 2. Number of tools developed according to the countries in which the research were conducted, and the publishing journal.

2.3 Reporting the Review

The last phase of the review is to report the results in connection with the research questions. The first and main question of the study aimed to find out what computerized tools and methods for scheduling the erection of a building are mentioned in recent literature. In the 35 papers eligible for the study, 28 different tools were presented. As shown in Fig. 2, 13 tools come from North America, and 9 from Asia. Most of the papers were published in the journal Automation in Construction. The full list of tools and their latest appearance in the literature are listed in Table 1. This is interesting for the study, since the context in which the papers were written is similar to the context in which the conclusions of the project could be implemented.

The study's second question involved finding the functionalities of these tools. To do this, each time a paper showcased one of its tool's functionalities, a keyword was added to a list. Fig. 3 shows the frequency of each functionality in the 28 tools presented. All these keywords or functionalities were then grouped together according to three main groups: technologies and virtual infrastructure, analytical features and project peculiarities. Technologies and virtual infrastructure encompasses every advanced device (drones, laser scanners, etc.), specialized technology (image processing, model querying, etc.) or virtual infrastructure (Cloud-based setups, geo-information systems, etc.) that may interest industry stakeholders or indicate a need to invest in hardware.

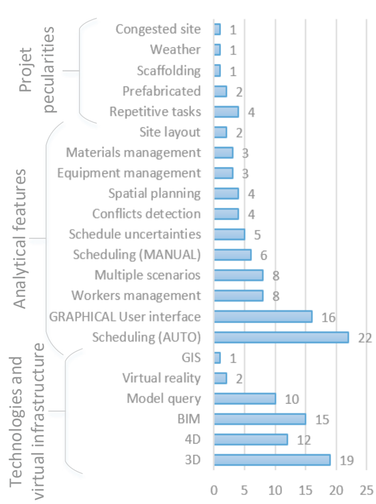

Fig. 3. Frequency of the functionalities in the tools presented.

Table 1. List of the computer-assisted tools classified in this study, with their latest appearance in the literature.

CasCADe	(Ivson et al., 2018)
Automated scheduling using context aware construction requirements	(Yeoh Justin K. W. et al., 2017)
Cost schedule integration system	(Fan et al., 2015)
Spatial information reasoner	(Kim and Cho, 2015)
BIM-based construction scheduling	(Liu et al., 2015)
Fuzzy project scheduling with minimal precedence relations	(Ponz-Tienda et al., 2015)
Multi-objective genetic optimization for scheduling	(Agrama, 2014)
Scheduling with genetic algorithm	(Faghihi et al., 2014)
Automated multi-objective construction logistics optimization system (AMCLOS)	(Said and El-Rayes, 2014)
Automated scheduling using context-aware construction requirements	(Shan and Goodrum, 2014)
Simulation-based scheduling for modular building	(Taghaddos et al., 2014)
BIM and simulation integrator for schedule support	(Wang et al., 2014)
Resource-constrained scheduling	(Benjaoran and Intarasap, 2013)
N-Dimensional project Scheduling and Management system	(Chen et al., 2013)
FReMAS	(Chua et al., 2013)
Space planning with simulation and Pareto	(Dang and Bargstadt, 2013)
Automated data extraction and scheduling using BIM	(Kim et al., 2013)
Safety compliance checker	(Melzner et al., 2013)
Scheduling with discrete event simulation	(Konig et al., 2012)
Post sim visualization to schedule modular building construction	(Moghadam et al., 2012)
BIM-based structural framework optimization and simulation	(Song et al., 2012)
Space planning with GIS and topology	(Bansal, 2011)
Temporary facility planning of a construction project using BIM	(Kim and Ahn, 2011)
Multi-dimensional project scheduling system	(Feng and Chen, 2010)
Visual scheduling application	(Karshenas and Sharma, 2010)
High-rise building strategies using linear scheduling and 4D CAD	(Russell et al., 2009)
Construction Project Management Information System (MD-CPMIS)	(Feng and Chen, 2008)
Weather-aware BIM and simulation scheduler	(Hegazy and Kamarah, 2008)

Analytical features are often the main points of interest of a tool and indicate what can be done with it. Project peculiarities are any additional perks of the tool that may be of interest for a planner in a particular situation. For example, the project manager of four buildings involving two towers and 25 stories each may want to look into "repetitive tasks."

The last question was what performance indicators are considered in the tools. Since this study focuses on scheduling, time and cost appear as the most frequent objectives of the tools, with the addition of a few unconventional (though interesting) indicators. Fig. 4 shows the frequency of the various performance indicators considered by the tools.

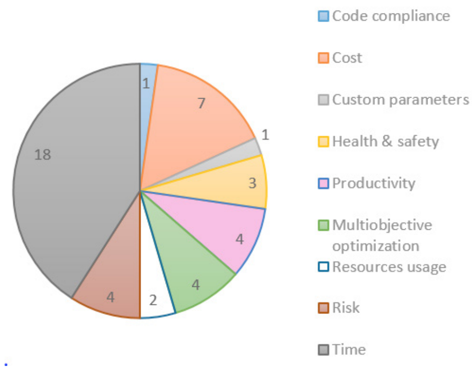

Fig. 4. Frequency of performance indicators in the tools.

3. SUSBSEQUENT ANALYSIS AND SYNTHESIS

Because this work was carried out to help the construction industry adopt technological tools in its planning, a subsequent analysis was required to try and understand the way construction companies could select one planning tool over another. It also meant that the selection guide would have to take into account the wildly variable size, capabilities and interests of these companies. This is also where this study pushes farther than past reviews.

To help structure the data, the tools were separated into four categories: integrator, add-on, software solution, and Excel spreadsheet. Integrators link together specific software or types of files and help manage information or automate certain tasks. Add-ons are bound to a software solution and are the perfect choice for a company that already has a suite of programs but is looking for additional features. For those only starting in computer-assisted scheduling, a software solution or Excel spreadsheet is a better fit. A software solution can collect, collate and display information all in the same place but requires some time to master. Excel spreadsheets simply apply an algorithm programmed by the creator. The user needs to input the necessary data, and the sheet outputs a schedule. Fig. 5 displays the number of tools from each category.

This separation of the tools into four categories helped address the fact that potential users will have various starting points when seeking to upgrade their scheduling methods.

All that was left was to ensure that, through the use of the selection guide, industry stakeholders would be able to transform their needs and interests into a scheduling tool proposition. Fig. 6 shows a preliminary framework to achieve this goal. While the "needs" help indicate that a particular feature must be an output of the tools, the filters are a softer constraint and simply specify whether certain functionalities are considered by the tool (input or output).

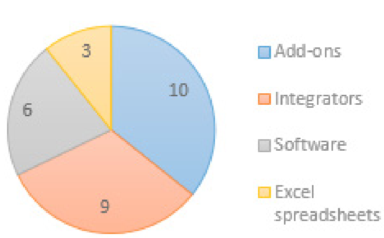

Fig. 5. Number of tools in each category.

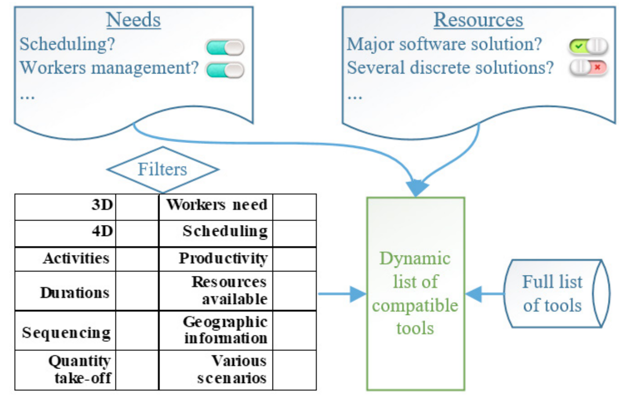

Fig. 6. Framework of the decision support system.

Using the selection guide, users should be presented with a list of tools that fit their needs, preferences and present situation.

Before creating this decision support system, a classification of the tools was achieved following the canvas shown in Fig. 7. The functionalities included in the latter figure are referred to as "filters" in Fig. 6. These elements are essential as they cover the key milestones in the planning of a building's construction: 3D modelling of the building, the division of the work into tasks, the prioritization of these tasks, and the amount of material and man-hours needed to devise a schedule. The 3D model is almost always an input when considered by the tool, and is sometimes used to extract information and automatically deduce from the geometries the tasks to conduct and their hierarchy. The tools considered for the present paper come in various forms and most of them automate at least the scheduling. Those that do not, will aggregate and show the information in a way that facilitates planning. As an example, the tool from Melzner *et al.* (2013) checked whether the security measures of the project followed German and/or OSHA standards, and automatically included in the tasks the addition of security barriers (if required).

Another important aspect of the tools is their compatibility with commercial design and project management software. In almost half of the cases, the *Industry Foundation Class* (IFC) standard is requested for 3D models. This means that any design software should be compatible with the tools. The second most popular standard is *Revit Architecture*, followed by *Autocad Architecture*. *Tekla Structures* and *ArcGIS* are only used once. On the project management side, *Microsoft Project* has almost full exclusivity amongst integrators.

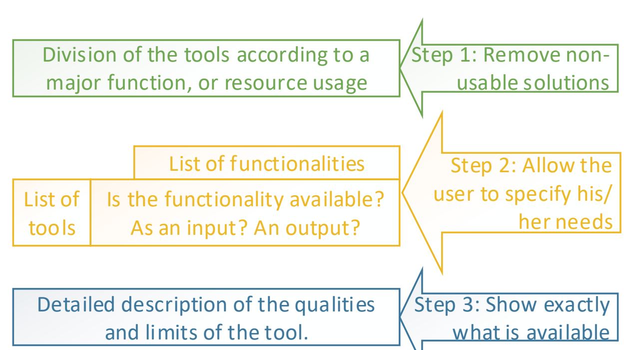

Fig. 7. Information compiled in the classification of the tools.

4. CONCLUSION

With the construction industry lagging behind other sectors in terms of productivity, better planning and a heightened presence of technology is advisable. To assist in this endeavour, this systematic literature review presents 28 computer-assisted scheduling tools, their functionalities and their performance indicators.

Such a review should help paint a clearer picture of all the tools and strategies available, and industry stakeholders and researchers will have a common starting point from which to build on in the development of relevant scheduling assistants.

The next step in the project is to validate the relevance of the work done to date. In particular, companies in the construction industry will evaluate the presentation of the tools to ensure that they have access to the information they need in a way that suits them.

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