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MODELLING AND SIMULATING TIME USE OF SITE WORKERS WITH 4D BIM

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ABSTRACT

This paper presents a research endeavouring to model site work in a 4D BIM model. Next simulations are performed with this model in 5 scenarios including specific interventions in work organisation, notably changing positons of facilities for site workers. A case study has been done in a construction project in the Netherlands. The research has showed the possibility to model time use of site workers in 4D BIM. Next the research has showed potential to perform and calculate specific interventions in the model, and prospect realistic changes in productive time use as a result.

KEYWORDS

BIM, time use, simulation, site work, labour optimisation.

INTRODUCTION

Building Information Modelling (BIM) has proven to have several benefits in visualisation, automatic generation of drawings, code reviews and construction sequencing (Eastman et al 2011; Papadonikolaki et al 2015). In terms of planning, BIM can be used to do four-dimensional modelling. According to Doloi (2013), one of the attributes that influences the cost performance in construction projects at a high level are planning and scheduling deficiencies.

With labour productivity on construction sites between 40 and 50% it is relatively low compared to other industries (Aziz & Hafez, 2013; Forbes & Ahmed, 2011). Whereas, in the Dutch construction industry labour takes up 40 to 60% of the total construction costs and is therefore one of the largest expenses (Nasirzadeh & Nojedehi, 2013).

The improvement of labour productivity can have advantages for the profit of contractors and lead to lower costs for the clients (Eastman et al. 2011). Problems that

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contribute to this low labour productivity are for a large part related to waste and inefficient organisation of labour, materials and equipment.

RESEARCH PROBLEM STATEMENT

The problems causing low labour productivity are mostly related to time and place planning flaws. Different solutions can be found to solve these problems. Currently building information models are mostly used in the design and engineering phase of the project combining the data of different parties into one model. 4D building information models provide the link between space and time (Eastman et al., 2011). If time use by site workers could be modelled in a 4D model, it could help clarifying solving part of the productivity problem. In a 4D building information model the 3D data should then be linked not only to the schedules but also to site work information and show various types of time use, productive and unproductive (Eastman et al., 2011).

RESEARCH OBJECTIVE

The first goal of the research is to provide insight into site labour and movement of workforce with a 4D building information model. This focuses on how to model and visualise the element of site labour and movements of workforce into a 4D building information model. The final product of this part will be a framework that describes which data is needed to properly model the labour and movement of workforce; how to accurately model this into the 4D BIM; and how this can be visualised within this 4D model.

The second goal is to provide insight in the potentials of certain interventions with 4D building information modelling. This is to find indications of the increase of the amount of productive time on construction sites by simulating interventions that reduce walking distances and waiting time particularly. The result of this part provides insight in the effect of interventions that might increase the productive time based on simulating interventions in the model for instance changing the place of an elevator or toilets.

CONCEPTUALISATION OF TIME USE ON SITE

Productive time is well connected to output and productivity. If the productive time is known the output of construction can be calculated. For instance, waiting and walking time is also related to productivity. Productivity may therefore improve when waiting and walking times are reduced, since the available productive time is increased (Thomas et al., 1990). However reducing waiting and walking time does not inherently mean an increase of productivity in itself but increases the available time the workforce has for working.

This contrasts to waste as seen as activities that do not add value to the client’s end product. More specifically it can be defined into value adding and non-value adding activities. Value adding activities are those, which convert materials and/or information in the search to meet client’s requirements. Non-value adding activities, those which are time, resource, or space consuming, but do not add value to the product (Aziz & Hafez, 2013). Vrijhoef (2016) and Eaton (2013) show that the activities can be divided into three categories.

Working time within this research is the time the workforce may use for value adding but also for non-value adding work. This means productive as well as unproductive work time, or activities connected to work and work organisation. Besides time categories waiting and walking are distinguished as non-working times. So in this research the activities are divided between walking, waiting and working. However this does not necessarily relate to productive versus unproductive, or value adding versus non-value adding classifications (Figure 1). The research is indicative though form also these classifications.

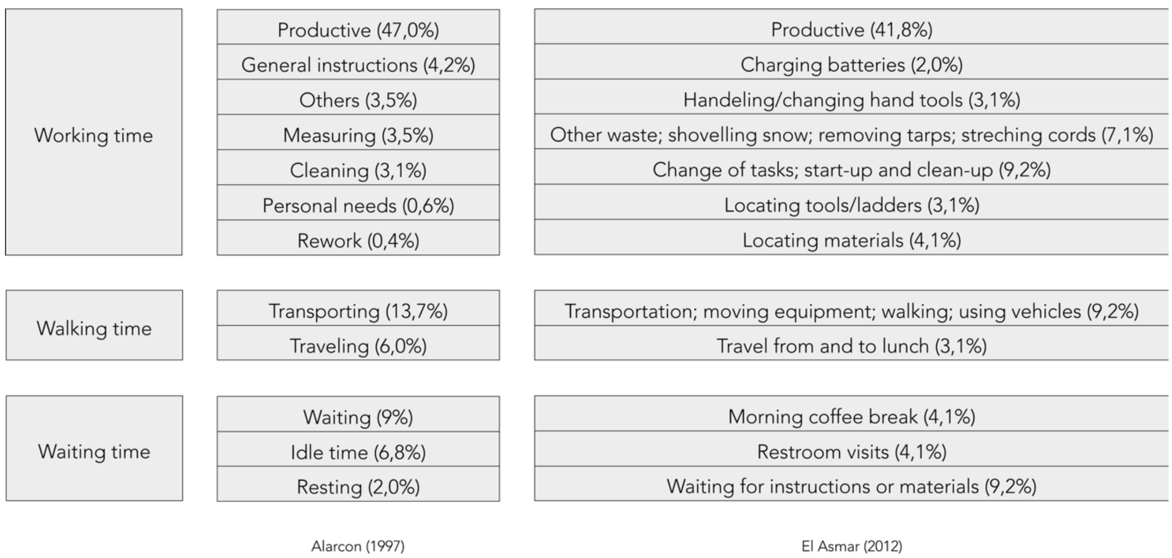

Figure 1: Division of working, walking and working time, compared to prior classifications of time use on site (Alarcon 1997, El Asmar 2012)

RESEARCH METHOD

RESEARCH DESIGN

The exploratory design is chosen to conduct this research. According to Fellows and Liu (2015) the exploratory design is to test, or explore aspects of a theory. As this research look into the extent in which a 4D building information model can provide insight in labour and movements of workforce and can help to indicate potentials for the increase of productive time, further research has to find out what the actual change in productive time when this framework is applied. Because the theoretical framework that largely derived from an in-depth literature study, provides the theory behind the research. This theoretical framework acts as a guide for which variables to collect, adopt and analyse. Since this research is mainly focussed onto a single construction project and does not provide concrete number, qualitative research is chosen as the overall strategy.

CASE STUDY

The case used for the data collection within this research is the construction project of 'het Noordgebouw' near the central station of the city Utrecht in the Netherlands. This is a building of 23,000 m2 that will accommodate offices, dwellings, retail, restaurants/cafes and a hotel. Within this construction project the main contractor is using a BIM model which is enriched with the models of subcontractors. Besides materials to the project are delivered JIT based on daily work packages shipped from a central hub facility.

Because the construction project itself is relatively large this research will narrow down for the time use modelling on one subcontractor i.e. interior walls. This work is consisting of multiple components of metal stud walls covered with plasterboard and all the wiring and electricity in and on the wall.

4D BIM MODELLING

The particular aim of this research aimed at modelling and simulating time use on site has required a 4D BIM modelling. In addition in the case study a 4D model had been made for various operational aspects of the project.

With the 4D model both the temporal and spatial aspects of a schedule had been presented, and this way of communication appeared more effective than a traditional Gantt chart. Second, the 4D model provided a basis for multiple stakeholder communication. Third, it helped planners with site logistics, coordinate access to and from the site, and locations of large equipment like cranes. Fourth, it helped to coordinate the trades on the project. It assisted planners with the coordination of expected time and space flow of trades on site as well as the coordination of work in small spaces. Fifth, project managers could compare different schedules easily, and quickly identify whether or not the project was on schedule.

Added to the 4D model Dynamo is the software used within this research to model and calculate the additional data to identify the time use. Dynamo is provided by Autodesk and is based on visual programming. It creates its own geometry and reads and writes to external databases. Revit has been used as the database of the parametric geometry to and from which Dynamo was able to write and read the data needed (Sgambelluri 2014).

MODELLING WALKING PATHS

The simulation and analysis of a dynamic subject, like pedestrian circulations, relies on a representation consisting of a number of interrelated components (Table 1).

Two types of modelling walking paths have been considered: Euclidian distance and City-block distance. The Euclidean distance, also called straight-line distance is a metric is inspired by the 'distance on the ground' (Pan et al., 2013). The Euclidean distance is based on the Pythagorean theorem. The city-block uses the sum of the x and y coordinates. This is often called the Manhattan metric as it is relating to the walking distance 'around the block' (Sarstedt & Mooi, 2014). In the research of Manning, Kahana, and Sekuler (2006) they found that when a direct path is possible theoretically, still the most realistic path distance is equal to the city-block distance. Therefore, the city-block distance is a better representation of a real world situation and use in this research.

Table 1: Route analysis data (Koutamanis et al., 2001)

Data	Operationalisation
Starting point	The location from where one or multiple actors depart. In buildings, the centroid of a space can be seen as starting point or a doorway. Multiple starting point indicate an aggregation of routes.
Destination	The endpoint of an actor, the place it wants to end at. Multiple destinations are not necessarily product of aggregation, a route can also have intermediate destinations such as stairs and elevators.
Path	The path has a starting point and destinations which can be complemented by intermediate destinations. The path can be the actual path or an approximation of it.
Means of transportation	How movement is achieved along the path, this includes the speed the actor travels at and the capacity of these means.
Activities	These are the activities that take place along the path. Two options appear: activities related to the transportation; or the intervening opportunities, such as relations to other routes, activities and actors.

IMPLEMENTING THE MODEL

As basis for the final model a backbone had been deduced from the Revit model of the case project. Next the construction site lay-out and waiting and working times in spaces had been added (Figure 2). The next step was to map the rooms and the room locations with their coordinates. With the coordinates of the rooms the lines of the walking paths and distances were calculated. The vertical distance together with the means of transport, and the average speed related to that mean of transport gives the time needed for the vertical travel.

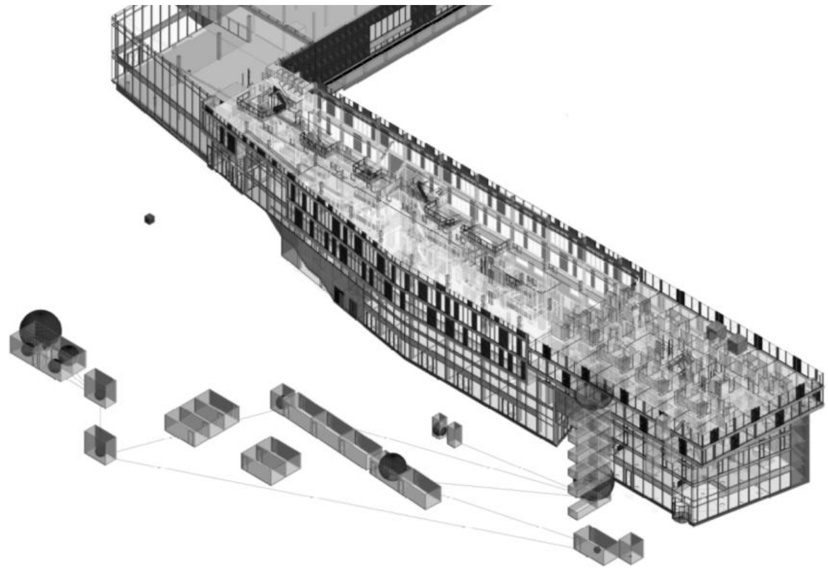

Figure 2: Visualisation of the benchmark simulation in the case BIM model

SIMULATION OF BENCHMARK AND INTERVENTIONS

A total of five simulations were performed within this research. The benchmark simulation was the real situation in the case project. In addition four virtual interventions were simulated: extra elevator; toilets on levels; elevator to corner; elevator near work.

Table 2: Overview of performed simulations

Type	Description
Benchmark	Simulation with the characteristics which are similar to the current construction site lay-out and typical workday
Intervention 1: Extra elevator	The capacity of the elevator is doubled, from one to two elevators. Assumed is that this intervention decreased the waiting time for the elevator by half.
Intervention 2: Toilets on levels	This intervention eliminated two up and down movements per typical workday. Achieved by placing toilet on every level of the building.
Intervention 3: Elevator to corner	The elevator and staircase relocated from the centre of the building to the corner of the building. This should decrease the walking distance on ground level.
Intervention 4: Elevator near work	The elevator is relocated from the front side of the building to the rear side, next to the workspace. This reduces the walking distance on the building levels but increases the walking distance on ground level.

RESULTS IN THE SIMULATION

Of all categories, the working time stays constant among all categories. The other categories do change due to the simulations. The sum of those categories is called ‘travelling time’ i.e. the sum of horizontal city-block time; vertical time by elevator; vertical time by stairs and waiting time are presented in Figure 3. This figure shows the results of all changeable categories during simulations per level. The time calculations due to interventions have been based on changing distances multiplied with known speeds of people and elevators, and reduced waiting in case of additional elevators.

From Figure 3, the following trends can be observed. First, for all simulations a large difference appears between level 4 and level 5. Which in fact is the result of the contractor's elevator policy saying the elevator can only be used from level 5 and up. Till level 4 using the stairs is mandatory for all staff. Second, the increase of time per simulation is progressive as the level rise. This is the result of previously mentioned reasoning, that with a higher level the vertical travel time increases. Due to the fact that the travel time is a product of vertical height. Third, comparing the different interventions with the benchmark results in the following ranking.

Intervention 4 is the only intervention that results in longer travelling time than the benchmark; 1:02 minutes longer in average per level. Second is Intervention 3. Which is only slightly better than the benchmark, with an average improvement of 1 second per level. Third, is Intervention 1, which has quite a difference compared with the previous two interventions, of 21:38 minutes in average per level. Fourth, the intervention with the largest improvement and difference from the benchmark is Intervention 2. This intervention reduces the average travelling time per level by 33:28 minutes.

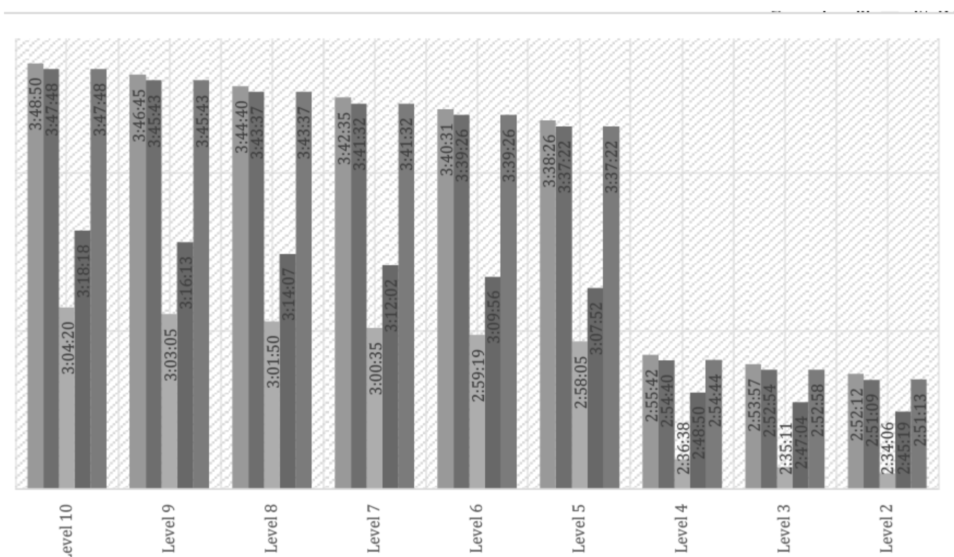

Figure 3: Total traveling time (sum of city-block time; vertical time by elevator; vertical time by stairs and waiting time) for all five simulations per level of the building

ANALYSIS OF THE RESULTS

Further analysis of the ratio between walking, working and waiting showed that the share of working time varied between 62,3% and 70,4%. Though, when comparing this to the real activities performed by the dry-wall contractor and its crews it appeared not to be comparable with the realistic productivity figures found. Remarkable differences appeared between the three crews of the dry-wall contractor.

Comparing this to the construction schedule the reason was found that the three crews performed different construction activities in addition. Crew 2 and 3 in particular performed many more construction activities than included in the working time calculations. This had to do with the fact that the dry-wall contractor was not only building the walls but appeared to be installing the ceilings as well. Therefore, the second and third crew are also working on the ceiling and other activities as well. This would have resulted in a larger share of working time for crew 2 and 3 in particular. Crew 1 was mainly building the metal-stud walls and therefore came closest to the calculated total working time (Figure 4).

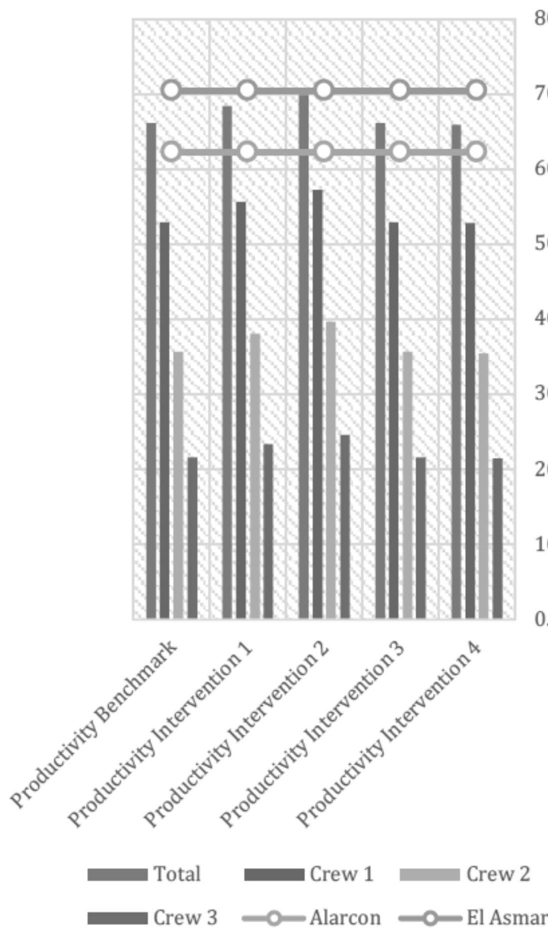

Figure 4: Average share of productive working time per simulation

The differences between the different simulations, show that the Intervention 4 seems the least effective in improving in productive working time shares among all crews. It even seems to reduce the productive time slightly. Second is the Intervention 3 which improves the productivity just a small bit, but it is almost equal to the benchmark. Third, is the Intervention 1 which shows the second best improvement of the share of productive time. For the total productive working time the improvement is approximately 3.5%. Fourth, the best improvement would be achieved applying Intervention 2 i.e. an improvement of approximately 5.5% of the share of productive time.

DISCUSSION

When looking at the approach to productivity in which the working time is divided by the total time. The working time has remained constant during all simulations. Improvement have been found in the increase of the share of productive time, when the share of walking and waiting time were reduced with the interventions presented.

The order in which these rooms are modelled is subject to debate, because of two contradictory reasons. First, the model presented within this research is meant to be used in the early stages of a project. Within the early stages, it is generally hard to tell which subcontractor is going to execute the job and what the operational process is going to be. Second, during the early stages of the construction process, uncertainty is high (Winch, 2010). Thus, the typical workday can help generate certainty. As the typical workday is used as part of the model to help make decisions in i.e. the construction site lay-out, it helps to provide information within the process.

Within the model of this research, the horizontal walking distances are drawn on the ground level or on the different levels of the building. Excluded from the current model are the walking lines on the building levels, e.g. to the place where the materials are stored, or where waste is collected. This would increase the walking distances of the construction worker and makes this category of the model more prominent.

Within this research the working time, which is set as a constant, is used to gain productivity numbers that can show this productivity increase. Without the working time the different simulations can be compared with each other to show which construction site lay-out is the most productive, since the model focusses on the decrease of time used for waiting and walking. Nevertheless, the importance of the working time can be explained when different projects want to be compared. Without the working time, no productivity figures can be presented, and it becomes hard to compare different projects.

The ratio between walking, waiting and working time ratio is used to compare the results of the simulations with the data found in literature. Items categorised are for example ‘locating tools and ladders’ or ‘locating materials’ which are categorised under working time. It can be questioned if this does not belong to walking time, which would increase walking time by 7,2%.

CONCLUSION

Currently, no modelling exists to provide insight in walking, waiting or working times of construction workers, or to visualise their movements, waiting and working times. This model is a first step in providing this insight, as it shows how simulation can be done which generates figure on walking, waiting and working times of construction workers. Furthermore, it generates visual images which provide even more insight the movements and waiting times of construction workers.

Providing this insight shows indications and locations of non-value adding activities. This helps to indicate potential interventions to decrease the amount of non-value adding activities. This would increase productivity in terms of the ratio between value adding and non-value adding activities, when addressing the potential to increase and use the additional available working time in a productive manner on construction sites.

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