Site Plan Development: Tower Crane Placement Based on Data Obtained from IFC File

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Abstract -

One of the fundamental issues of site plan development is the location of a tower crane which needs to be designed to meet specific criteria and specific needs of structures. With today´s traditional techniques it is quite difficult to consider optimal position and to select adequate technical parameters of a tower crane. This task is rather time consuming and complicated. With use of Building Information Modeling (BIM) this process can be simplified and the tower crane can be designed more effectively considering various criteria.

This paper focuses on obtaining the data of all relevant parametric objects from IFC file and using them to compute optimal position of a tower crane. A suggested position is evaluated from the perspective of travel time of a hook, travel distance and length of jib needed to deliver all elements and materials. Data obtained from IFC model are compared with workload curve of a tower crane to ensure constructability and safety.

As a result, map of criteria is done according to the coordinates of a tower crane arranged together with above-mentioned parameters to indicate differences between all possible locations.

Keywords –

BIM; Tower Crane; Building Technology

1 Introduction

During pre-construction stage we need to design the site plan according to a chosen building technology and selected facilities. The issue of a suitable location of tower cranes for the construction is up to date almost within all ranges of buildings. Currently, the cranes are mostly designed according to personal experience of the processor of construction site plan (POV), resp. the planner who has the task to develop a plan of construction site equipment within preparation phase of a contractor. The costs and also the smoothness and speed of construction directly depend on appropriate selection of the type, number and location of cranes. Today's computer technology allows for simplification of work in planning, and therefore it would be benefitial to establish a mathematical model and a computer program that would make this task easier.

2 BIM employment

The goal of BIM is not to create a model itself, but to gain complete, reliable, accessible and easily exchangeable information to anyone who might need it throughout the whole life cycle of the building. One of the essential prerequisites for BIM is to set cooperation between all stakeholders at different stages of a life cycle. Within the workflow, it is necessary to allow users to enter, change, update or correct any information in the model that is relevant to their roles in the project.

Virtual model is composed of 3D parametric objects that allow to bear information by using a specified data format. By assembling them together, we make so-called virtual construction resulting in improved quality of a project. While using traditional CAD (Computer Aided Design) it happens quite often that just a limited part of a building is designed and most of architects select the simplest sections to make their job easier. They do not care what is 200mm behind the cross section is and this may lead to delay in construction and makes the coordination of a project impossible. On the other hand, by using BIM, architect is obliged to design all details in a building so this certainly results in a coordinated project of high quality which is moreover much easier to check.

Key to interoperability, which is another fundamental prerequisite of this approach is an IFC (Industry Foundation Classes) file type – a neutral data format used to describe, exchange and share information between stakeholders and various software.

Not many people are aware that BIM is not just about buildings and civil engineering, but of course highly suitable also for infrastructure - railways, highways, bridges, etc.

3 Proposed methodology

3.1 Actual Developments

In todays practice cranes are often designed without precise conceptuality, which reduces the efficiency of the entire construction site traffic and results in complications in works that cannot be done without a crane. Besides, with increasing pressure to reduce operating costs contractors must emphasize not only savings in management, but also shortening the time of deployment techniques, mechanisms and workers and thus saving resources.

BIM in this issue offers an opportunity to obtain input data directly from a virtual model without extensive manual analysis of the object. By reducing the number of manual tasks, construction planner can devote more time to optimization and alternatives. Depending on the size of the object, this time savings can also be a few days of work.

Although we are able to use sophisticated methods developed by previous authors, there was still an issue with data extraction from traditional plans. Authors (Al-Hussein, Niaz, Yu, & Kim, 2005; Lee, 2009, 2012; Irizarry & Karan, 2012) presented their studies how to take the advantage of parametric modelling in tower crane design but they did not address the question of obtaining information from the object. Although it is clear that all the information we need to design a crane are in a virtual model, currently there is no tool available which can extract this data from virtual parametric model. Model itself contains a lot of information and it is necessary to provide filtering of relevant data for the design of the crane.

3.2 Decision flowchart of methodology

As defined in a scheme shown on Figure 2 decisions are taken according to data obtained from BIM model represented by IFC file.

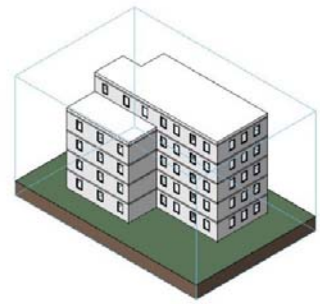

Figure 1 Investigated BIM model, Revit

Primary focus is on the individual data about the position, volume and material type of elements. These data are clear to read and therefore usable for further processing.

Individual steps of methodology are described in the following chapters.

The methodology was further verified on a building with more complicated floor plans. The more complicated building is, the use of automation helps more significantly. Finding the optimal position is not trivial and cannot be determined only intuitively as the mass of the building can be variable from bottom up.

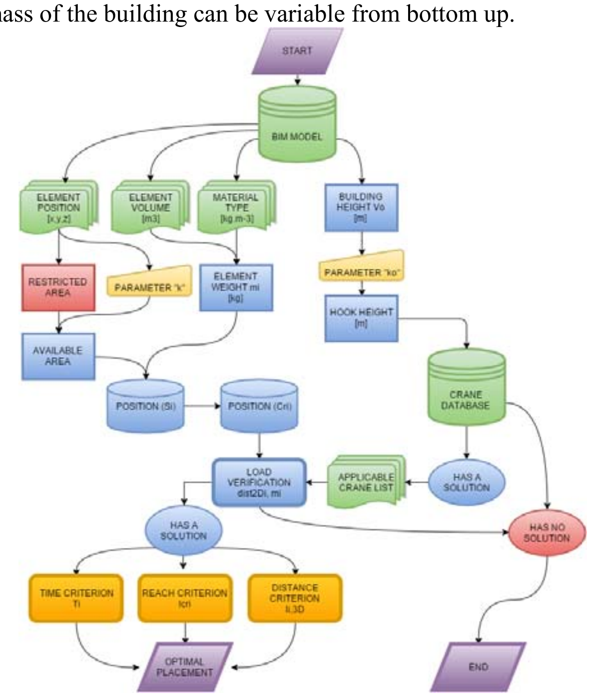

Figure 2 Decision flowchart of methodology

3.3 Model Analysis

To make the whole design process of cranes automatic, it is necessary to ensure that the program is able to obtain information from the virtual model of the building, which was created in an environment using parametric BIM objects.

Table 1 Data export from parametric model

i	x	y	z	Názov prvku	Objem [mm3]	Materiál	Hmotnosť [kg]	Počet dodávok	Hmotnosť dodávky - m [kg]
1	1,92	7,058	-7,803	Wall Foundation:600/1200 na osu:966472	13608000000	Beton prostý	34020	14	2500
2	-7,23	4,758	-7,803	Wall Foundation:600/1200 na osu:966473	2880000000	Beton prostý	7200	3	2500
3	5,695	-1,742	-7,803	Wall Foundation:600/1200 na osu:966474	8172000000	Beton prostý	20430	9	2500
4	11,07	2,658	-7,803	Wall Foundation:600/1200 na osu:966475	5904000000	Beton prostý	14760	6	2500
5	-9,155	3,058	-7,803	Wall Foundation:600/1200 na osu:966476	2340000000	Beton prostý	5850	3	2500
6	-10,48	-2,142	-7,803	Wall Foundation:600/1200 na osu:966477	7056000000	Beton prostý	17640	8	2500
7	-4,78	-6,742	-7,803	Wall Foundation:600/1200 na osu:966478	7776000000	Beton prostý	19440	8	2500
8	0,32	-4,242	-7,803	Wall Foundation:600/1200 na osu:966479	3168000000	Beton prostý	7920	4	2500
9	-3,042	3,158	-7,603	Základová patka s pilotou:1200/1200/800:966779	1152000000	Beton prostý	2880	2	2500
10	1,645	3,158	-7,603	Základová patka s pilotou:1200/1200/800:966780	1152000000	Beton prostý	2880	2	2500
11	3,82	3,158	-7,603	Základová patka s pilotou:1200/1200/800:966781	1152000000	Beton prostý	2880	2	2500
12	6,677	3,158	-7,603	Základová patka s pilotou:1200/1200/800:966782	1152000000	Beton prostý	2880	2	2500
13	8,108	3,158	-7,603	Základová patka s pilotou:1200/1200/800:966783	1152000000	Beton prostý	2880	2	2500
14	9,539	3,158	-7,603	Základová patka s pilotou:1200/1200/800:966784	1152000000	Beton prostý	2880	2	2500
15	-14,266	-10,449	-7,003	Obdĺžnikový Sloup 400x200:961468	224000000	Železobeton - prefa	627,2	1	627,2

The first step is the analysis of the object in 3D environment where we can extract important information about the object itself, its shape, characteristics, and in particular the position and weight of the individual elements. This information is needed for the proposal and it is available and commonly used by structural engineers in the design of the individual sections and elements. The position information must be kept in a coordinate system (x, y, z) linked together with the information about object weight. The transfer of information is maintained through IFC file of a model.

As a result of the analysis, following information is extracted from a model:

- Weight of individual elements (calculated from volume and material type),
- Location of elements,
- Transport paths of elements.

Essential part of the collection of data from the project is programing of suitable algorithms and the use of C # programming language, to allow the automation of the process.

3.4 Analysis of Extracted Parameters of an Object

After analyzing the virtual data model, from which we obtain the necessary information - critical parameters of elements, it is necessary to evaluate them properly. Based on these parameters, it is possible to calculate the necessary radius to cover all construction processes – length of a jib, the required bearing capacity of the crane and the optimal position in relation to the distribution of load and location of individual elements in 3D space.

3.5 Defining the Length of the Jib

For each position, it is necessary to obtain the information about the distance from the centre of mass to the individual elements, and use this data for the design of the crane in working load diagrams of different types of cranes.

Value l_{cri} is the desired length of the jib, which is calculated based on the distance of the crane (C_{ri}) and the location of individual elements (D_i), respectively the location of supply point (S_i).

$$|l_{cri}| = \sqrt{(x_{cri} - x_{Di})^2 + (y_{cri} - y_{Di})^2}$$

Equation 1 Calculation of length between the crane and demand point

$$|l_{cri}| = \sqrt{(x_{cri} - x_{Si})^2 + (y_{cri} - y_{Si})^2}$$

Equation 2 Calculation of length between the crane and supply point

The maximum value of the $l_{cr,max}$ is the maximum distance of the element from the crane position. This value is considered as the minimal length of jib needed to cover all locations of demand and supply from selected crane location.

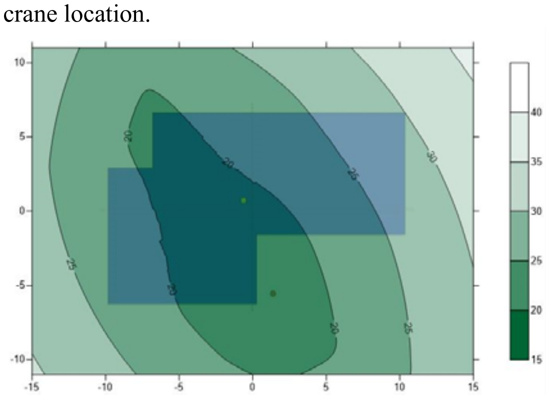

Figure 3 Map of the length of a jib according to its position

3.6 Defining the Bearing Capacity

In many cases, verification of a bearing capacity of a crane is done solely based on the information of the heaviest and furthest element. It is caused mainly by difficulty to obtain information about all elements manually, mainly in larger scale projects. In certain cases it might be misleading resulting in improper selection of a crane. Using traditional methods it is almost impossible to ensure the weight of all elements transported to its demand point will be within load curve of a selected crane. Therefore it is necessary to compare the set of all ordered pairs [di, mi], where d_i is the distance from the position of the crane i-th element and m_i is the weight, with working load diagram. This criterion ensures that all elements will be transported to the point of demand by specified type of crane.

3.7 Optimal Location of a Tower Crane

The proposed methodology approach consists of the steps that lead to the effective design of tower crane, including its location and the point of supply. As a result, a list of suitable cranes associated with critical parameters ordered from the most optimal location to the least optimal is composed. Following parameters are taken into consideration:

- Time of transfer of materials from (S_i) to (D_i),
- Required length of boom (L_{CR}),
- Sum of the distances between all (S_i) and (D_i).

An important criterion for placing the crane is to have a suitable assessment of traffic time of elements. Used formula was developed by the authors (Zhang, P., Harris, Olomolaiye, & Holt, 1999). Calculation of a time of transport consists of vertical, horizontal and radial movements from (S_i) to (D_i). Two parameters are taken into account - α and β. Alfa reflects the level of coordination within radial and tangential movement in horizontal direction and Beta parameter sets time overlap between horizontal and vertical movement. Both parameters are taken from the research of (Kogan, 1976). By observing transport paths estabilished $\alpha = 0,25$ and $\beta = 1$.

Figure 2 shows the range of transport times which differs by location of a crane. Contour map is created in order to help the planner to select optimal location according to site conditions. This map makes the decision faster and easier mainly in cases that some of the areas are not suitable for crane location.

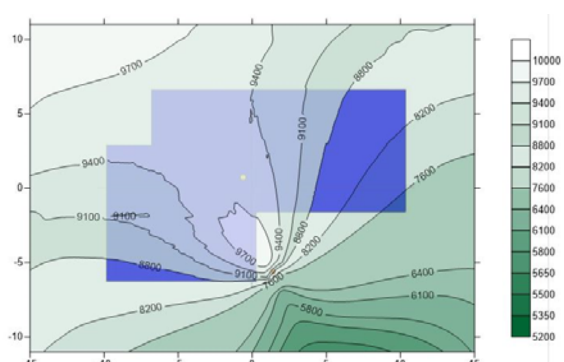

Figure 4 Time of transport according to the crane location

After precise calculation of all criteria, they are evaluated in order to define the ordered list of optimal positions. Dark indicated parts at Figure 3 are preferred in terms of location.

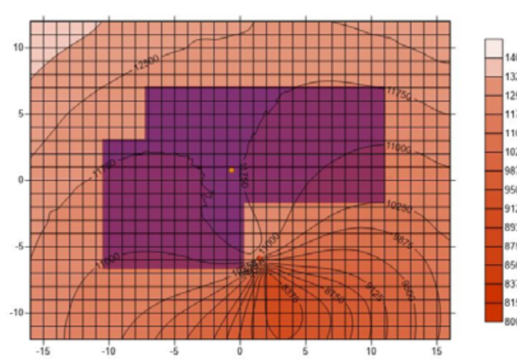

Figure 5 Contour map of the sum of all criteria

The basis of the methodology is an export of the data from a virtual model, which are crucial in designing the position and type of a crane. Location of a crane is further analyzed in each variant position in terms of capacity of selected types of cranes and their bearing capacity. The first step is verified by a particular type of crane capacity required for reaching the supply area and the location of all elements – demand point. Based on the distance of the point of supply, optimal jib is defined taking into consideration the module of a manufacturer.

Individual elements are defined by location and weight and by comparison with the database of the crane load it is verified whether it is possible to use selected type of crane for construction, i.e. whether a crane is capable of delivering all the elements from point of supply to all demand points and therefore it is guaranteed that selected crane is able to reach and deliver all elements.

Figure 6 Optimal position of tower crane after evaluation of all criteria

Based on a comparison of crane capacity data, the reserve between required and available capacity of a crane is calculated. Total reserve is the sum of all reserves and it allows for the optimal crane selection within the closest range of weights.

4 CONCLUSION

Due to complexity of projects and the resulting amount of manual work needed to obtain necessary information relevant for the proper selection of a tower crane type and its location by traditional methods it is common to examine only the heaviest and farthest element. This may lead not only to improper crane selection but also it makes it impossible to automate the whole process. The proposed methodology addresses the benefits of a functional link building information modeling and deployment issues of tower cranes. Methodology itself is more complex than other methods that are currently in use because it is possible to evaluate all elements distributed in 3D space of a construction and verify that they are within the capacity diagram of a crane. The methodology also defines the procedure for choosing the appropriate crane for fast, smooth and cost optimal solution.

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