International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13534-13540

The Methodology of Interactive Parametric Modelling of Construction Site Layout

Jozef Čabala[1], Mária Kozlovská[2] and Zuzana Struková[3]

[1,2,3] *Institute of Construction Technology and Management, Faculty of Civil Engineering, Technical University of Košice, Vysokoškolská 4, 042 00 Košice, Slovakia*.

[1,2,3] *Orcid: 0000-0002-7597-3523, 0000-0002-8125-4680, 0000-0003-3468-9697*

Abstract

The layout of an efficient construction site to ensure a congenial working space and to store, transport and deliver material and equipment and to and in the best and safest manner and within the shortest time belongs to leading factors and requirements in a complex construction project. The parametric modelling involves benefits for automated generation of alternatives of production area layout to select suitable one.

The methodology of interactive parametric modelling of construction site layout in 3D is presented and described in the paper. The methodology represents the foundation concept of 3D software tool for construction site layout designing through Information and Communication Technology. Moreover, the paper deals with a system of interactive parametric modelling of the construction site layout in 3D based on the study of the topological properties of construction site facilities. The creation of the proposed methodology has been conditioned by defining the mentioned system. Both, direct and indirect parameters, to be integrated into the interactive programming system of construction site layout, are specified and discussed.

Keywords: Construction Site Facility, Construction Site Layout, Information Technology, 3D Modelling System, Parametric Modelling.

INTRODUCTION

A construction site must be well-planned in terms of occupational health and safety demands, in terms of production demands and using time or its quality keeping, while its operation may not excessively disturb the surrounding environment. The site layout planning, as a critical step in construction planning, can be done more effectively through ICT systems supporting creation of 3D models, what is known as a virtual design. In this way, the 3D model of a construction site representing the real environment of the site operation before construction beginning may be created.

Demands on construction site operation change over time. This is limiting when solving a construction site layout. It makes requests on a continuous change of demands and construction site layout. Such changing requirements may be solved through parametric modelling in 3D. The parametric modelling involves benefits for automated generation of alternatives of production area layout to select one suitable option. A combination of three-dimensional and parametric modelling creates conditions for better processing of requirements and operating restrictions in proposal, installation and running of production area.

Recently, several research activities have focused on development of various construction site models [1]. Regarding construction site layout planning, the models may be divided into **static** and **dynamic**. The static models are presented through various planning methods and tools, as knowledge systems [2]-[4] computer simulation [5], [6], hybrid systems [7] and genetic algorithms [8]-[15]. The models of static construction site layout represent simple planning of production which must be newly developed in case of some changes. The dynamic models offer possibility enable relocation of temporary site facilities in dependence on changing need for space. The dynamic models are presented through various planning methods and tools, such as genetic algorithms [16] to find an optimal construction site layout in different construction phases to minimize transport distance between different temporary facilities. Another optimization model [17] has looked for an optimal construction site layout to cost of site reducing. Based on limiting conditions and linear programming, a hybrid model [18] has used the optimization of temporary facilities location to minimize transport and handling costs.

Other studies focused on construction site layout problems are based at knowledge systems and mathematical methods. The knowledge systems have been used to determine the rules for construction site layout before optimising. The mathematical methods usually involve an identification of one or more aims determining an optimal construction site layout. It is a mathematical programming for solution of optimizing problems (e.g. finding out an optimal solution based on specified criteria and compliance of specified restrictions.

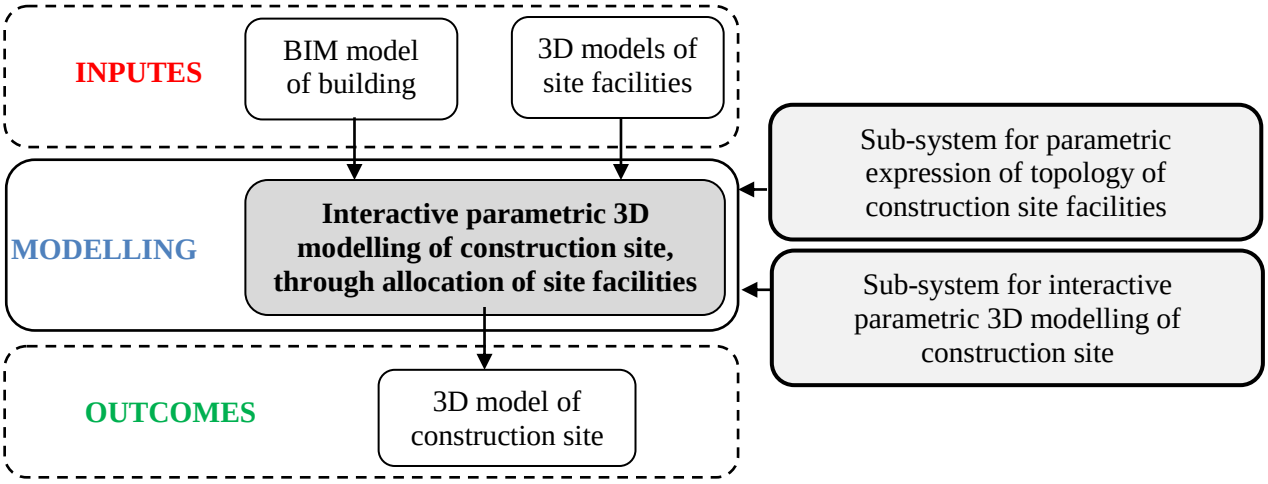


Figure 1: The concept of methodology of construction site modelling in 3D

These include methods as parametric programming, dynamic programming, linear programming, nonlinear programming, stochastic programming etc. The methods are aimed at minimization of in-site transport cost and at optimization of construction site layout in accordance with specific restrictions resulting from construction progress.

PROPOSAL OF METHODOLOGY OF INTERACTIVE PARAMETRIC MODELLING

It is not easy to find a comprehensive solution of optimal construction site layout. The construction activity requires the provision of conditions that give rise to a number of restrictions. Compared to a spatial solution of production in industrial factories, which is almost absolutely changeless, the production at the construction site requires continual spatial changes resulting from different phases of construction process.

The research in the field of mechanical engineering has long been concerned with virtual solution to the spatial formation of production systems. Various methodical procedures, algorithms and tools [21], [22] have been developed to design production systems. These methodical procedures, algorithms and tools have created assumptions for achievement of higher effectiveness of production process. The parametric models of topologic relations among production systems are used for detailed design and optimization of dispositional or spatial solution of production means.

The modelling itself is contingent on two crucial subsystems (Figure 1). The first subsystem is for parametric expression of topology of construction site facilities in 3D environment and the second one is for interactive parametric 3D modelling of a site. The application of these subsystems expects input background to create a virtual model of a site in 3D. The input background is represented by Building Information Modelling (BIM) model of a building and 3D models of construction site facilities.

Proposal of System of Parametric Construction Site Modelling

In the methodology of interactive parametric modelling of construction site facilities allocation, the term "system of interactive parametric construction site modelling" is defined as a 3D model of construction site consisting of elements (facilities) among which direct and indirect bonds exist. The bonds create a specific relation among facilities of the system, representing their interdependencies – interactions. The 3D model of construction site is made up of models:

- of buildings forming existing public infrastructure (e.g. surrounding built-up area, public road …),
- of planned constructions (e.g. media connections, driveway, pavements …),
- of temporary construction site facilities necessary for working, production and social purposes of building process (e.g. fencing, site roads, storing areas, cloakrooms, office etc.).

When modelling the construction site layout, allocation of construction site facilities is dependent on relations (interactions) among the objects of the system. These relations may be in programming systems expressed by parameters. The parameters may be represented as geometric parameters defining shapes and dimensions of construction site facilities and the site as a whole or text parameters describing interactions among site facilities (site objects). The geometrically expressed parameters may be defined through spatial dimensions – parameters, by which it is possible to set layout possibilities and restrictions when deciding on the allocation of an object in 3D model of the site. These parameters may be transformed into programming language in computer systems. The text parameters describe suitable allocation of an object at the site regarding interactions or conditionality of mutual spatial layout of construction site facilitates together with existing and building objects at the site. These parameters may not be transformed into

programming language but are useful for right construction site layout.

In terms of integration of the parameters into programming system that ensures interactivity of an site facility allocation, the parameters can be divided into two groups:

- direct parameters (geometric)
- indirect parameters (text)

Specification of direct (geometric) parameters

In interactive projection, allocation of each object is based on a set of geometric and spatial interactions existing among them. The interactions create a set of complex functional relations. The range of interactions that define possibilities, restrictions and changes of allocation, plays a key role. The interactions among objects are expressed as parametric bonds. It is possible to create an interactive connection for 3D modelling in CAD systems through determination of parametric bonds among different objects. Such interactive connection brings an added value. The geometric and spatial interactions reflect:

- minimal/maximal distance between objects,
- area enabling intersections of different objects,
- area creating restrictions of allocation of objects.

To specify the direct interaction among models of construction site objects, an operating area of object is designed (Figure 2).

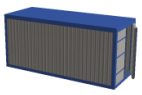
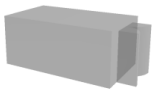
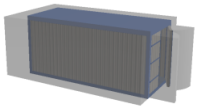
Model of object(O)	Operating area (P)	Model of object + operating area
		

Figure 2: An example of the model of object with its operating area

The operating area of a construction site object is expressed as the area required for the object to fulfil its purpose. This area specifies a minimal/maximal necessary area around the object which is needed to insure the distance from other objects, to insure manipulation with objects or with moving parts of the object (e.g. doors opening, windows opening etc.).

Specification of indirect (text) parameters

When solving the construction site layout, not only minimal/maximal distances between different site objects should be considered. The space interactions of all construction site objects must be respected. These spatial interactions determine the construction site layout within all its conception. In designing software (e.g. ArchiCAD), the parameters may be expressed as indirect parameters providing information in text form. In this way, information about construction site objects allocation from using methods and conditions point of view may be provided. Moreover, the indirect parameters may inform about quantities and dimensions of construction site objects (e.g. number of office and sanitary containers) and about cost of construction site facilities (purchase cost, rental cost, cost of installation and removal etc.). Based on this information decision about suitable allocation of each construction site facility may be done. So, the indirect parameters are helpful in construction site modelling since they carry information about conditions and principles of selection and allocation of construction site facilities in a site model.

The method to allocate 3D construction site facilitates models in 3D construction site model

The nature of interactive parametric modelling of a site rests in allocation of different interacting construction site facilities that interact with existing and just being constructed buildings. All the facilities may be classified into certain groups. Direct and indirect parameters expressing the interaction of facilities models may be determined among the groups. These parameters represent interaction of spatial characteristics (shapes and dimensions) of different construction site facilities as well as spatial characteristics of all objects within the whole construction site model and its environs. A construction site layout depends on these interactions. Based on these geometric and spatial characteristics of a construction site layout, four principal models of construction site facilities are defined:

- models of building objects that are under construction in the solved construction project (e.g. central building object, media connections, driveway, pavements…),
- models of before and still existing objects at the site (e.g. buildings, roads, greenery…),
- models of temporary construction site facilities (e.g. fencing, cloakrooms, washrooms, office containers, material and products in storage…),
- model of construction site objects incorporating models of different building objects under construction, models of existing objects and models of temporary construction site facilities.

Models of construction site facilities in 3D

To create a model of construction site layout through interactive parametric modelling in 3D, the model of site and its facilities must be expressed by spatial zones. These zones

may identify the site and its facilities horizontally and vertically. In the proposed methodology of construction site layout, the spatial zones may be defined as:

- a site zone comprising space of site,
- objects zones comprising construction site facilities including their operation spaces and existing objects and buildings,
- handling zone to support allocation of construction site facilities in the site model; it is space inevitable especially for construction material handling.

A high level of these zones overlay is typical in construction site layout. For example, when considering a place of material storing, the crane must reach the take-off point of material, whole building under construction and whole storing place too. Theoretically, the material could be stored anywhere within reach of the crane. The transport way in the site represents the space for material take-off point and for unloading material from trucks by crane. Its allocation also results from above mentioned consideration.

Based on direct and indirect parameters, the spatial zones define bounded space for allocation of particular type of construction site facilities or define limits influencing construction site layout (e.g. zone defining set of construction site facilities, where it is not appropriate to allocate any construction site facility which interferes the space of other facility). In essence, the zones define the space possibilities and restrictions (horizontally and vertically) for construction site facilities grouping in 3D model of construction site layout (Figure 3).

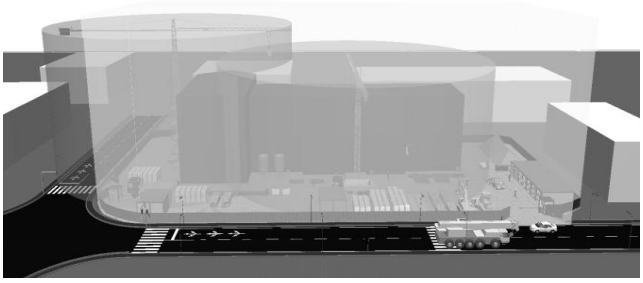


Figure 3: The spatial zones in 3D model of construction site layout

The model of construction site consists of a set of zones where other zones may also be in one zone. These zones may be called sub-zones. The sub-zones create a certain hierarchy of influence of interactions of objects forming the model of construction site. Thus, the defined zones can support the decision-making process of allocation of a construction site facility in 3D site environment through interactive colour signalisation indicating the space possibility of a facility allocation in the site environment.

The principle of signalisation of allocated construction site facilities in 3D construction site model

In the proposal of methodology of interactive parametric modelling, identification of possibility of spatial allocation of a construction site facility in a construction site model is indicated by a colour representation.

The green colour indicates that the allocation of the construction site facility in the considered area (zone) is appropriate. In the case of an orange colour, the allocation of the construction site facility in the considered area (zone) conditionally appropriate. This means that the workspace of the allocated facility overlaps with the workspace of the construction site facility or with this site facility respectively with other facilities, what may reduce their functionality. In this case, the designer of the 3D construction site model must assess the degree of constraints. In case of a red colour, the allocation of the construction site facility is not possible in the considered area (zone). So, there was a direct overlapping of the allocated facility with the facility already been placed at the site.

The methodology of interactive parametric modelling of construction site layout in 3D

The methodology of interactive parametric modelling of construction site in 3D is based on interactive signalisation of allocated construction site facility depending on identification of the construction site zone and the zones of the facilities forming the model of the building. Just precise identification of the zones is a prerequisite for the proper colour signalisation of the construction site facility when it is allocated in the construction site model. Based on this requirement, creation of the 3D model of construction site in the Building Information Modelling (BIM) environment is based on two tasks:

- identification of space of construction site and objects in the site
- grouping of construction site facilities in the space of construction site

It is important to note that the first task is to be done only one, even before allocation of models of construction site facilities. The second task is carried out during the whole designing of the model of construction site. The identification of space of site and facilities in the site is detected by the spatial zones expressed horizontally and vertically. The zones specify the shape and dimensions of the construction site contours of the space of site and facilities at the site. Based on the above-mentioned approaches and principles, it is possible to generalize the methodology of interactive parametric 3D modelling of the construction site. The methodology is presented in the algorithm in Figure 4.

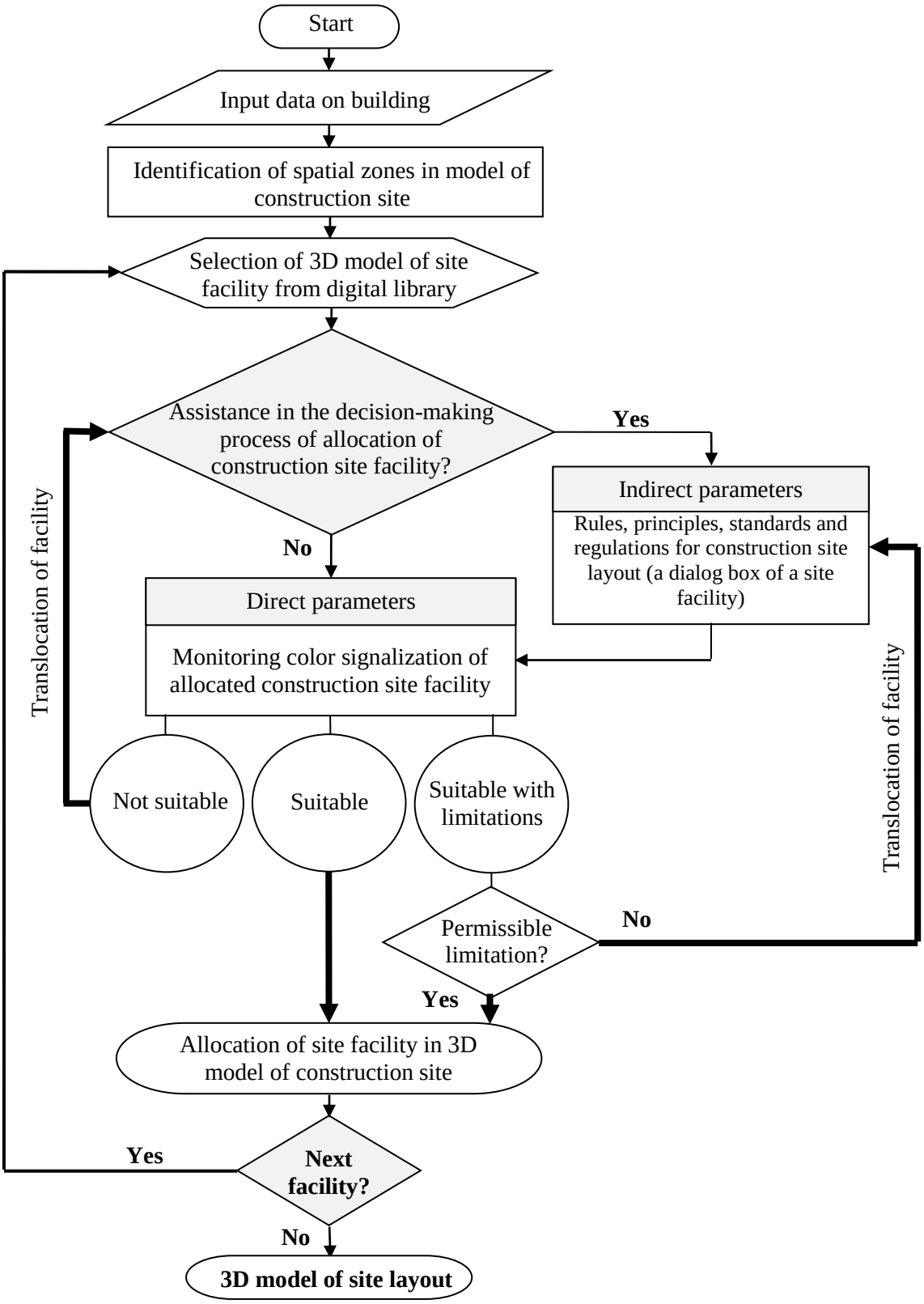


Figure 4: The methodology of interactive modelling of construction site layout in 3D

CONCLUSION

The proposal of interactive parametric modelling of construction site layout in 3D was preceded by the review of the development of information technologies and the review of scientific research on the support of design of construction execution conditions. Based on the outcomes of the review, the proposal of the methodology of interactive parametric modelling of the construction site layout in 3D was developed. The design of the methodology has been conditioned by defining a system of interactive parametric modelling of the construction site layout in 3D based on the study of the topological properties of construction site facilities. The proposed methodology is based on interactive parametric modelling based on colour signalisation of appropriate allocation of construction site facilities.

The methodology represents the innovative approach into construction site layout designing, based on 3D modelling of topology of construction site facilities, controlled by parameters that can be modified using a mathematical apparatus. The methodology presents the foundation concept of 3D software for construction site layout designing. The software allows the automated selection of construction site facilities and their subsequent allocation in the site. The construction site layout processed by the software allows evaluation of construction site facilities capacities, identification of construction work risks or determination of the objective size of the area necessary for building site development. Since the methodology is based on BIM, its potential for use in practice is significantly increased. Its integration in the software systems supporting 3D Building Information Modelling is inevitable for undepreciated use of the proposed methodology in practice.

ACKNOWLEDGEMENTS

The article presented a partial research result of project: CE II, ITMS: 26220120037, Excellent integrated research centre of progressive building construction, material and technology

The article is the result of the Project implementation: University Science Park TECHNICOM for Innovation Applications Supported by Knowledge Technology, ITMS: 26220220182, supported by the Research & Development Operational Programme funded by the ERDF.

REFERENCES

[1] Khaled, El-Rayes, and Hisham, S. Dynamic Site Layout Planning Using Approximate Dynamic Programming. In: Journal of Computing in Civil Engineering, Vol. 23, No. 2, March 1, 2009, ISSN 0887-3801/2009/2-119–127/.

[2] Tam, C. M., Tong, T. K., Leung, A. W., and Chiu, G. W. “Site layout planning using nonstructural fuzzy decision support system.” 2002, J. Constr. Eng. Manage., 128_3_, 220–231.

[3] Chau, K. W., and Anson, M. “A knowledge-based system for construction site level facilities layout.” Lect. Notes in Artif. Intell., 393–402.

[4] Sadeghpour, F., Moslehi O., and Alkass, S. “Computer-aided sit layout planning.” J. Constr. Eng. Manage., 132_2_, 143–151.

[5] Retik, A., and Shapira, A., 1999. “VR-based planning of construction site activities.” Autom. Constr., 8, 671–680.

[6] Dawood, N., and Marasini, R., 2002. “Visualization of a stockyard layout simulator “SimStock:” A case study in precast concrete products industry.” Autom. Constr., 12, 113–122.

[7] Zhang, J. P., Liu, L. H., and Coble, R. J., 2002. “Hybrid intelligence utilization for construction site layout.” Autom. Constr., 11, 551–519.

[8] Hegazy, T., and Elbeltagi, E., 1999. “EvoSite: Evolutionary-based model for site layout planning.” J. Comput. Civ. Eng., 13_3_, 198–206.

[9] Mawdesley, M. J., Al-Jibouri, S. H., and Yang, H., _2002_. “Genetic algorithms for construction site layout in project planning.” J. Constr. Eng. Manage., 128_5_, 418–426.

[10] Zouein, P. P., Harmanani, H., and Hajar, A., 2002. “Genetic algorithms for solving site layout problem with unequal-size and constrained facilities.” J. Comput. Civ. Eng., 16_2_, 143–151.

[11] Cheung, S., Tong, T. K., and Tam, C., 2002. “Site pre-cast yard layout arrangement through genetic algorithms.” Autom. Constr., 11, 35–46.

[12] Tam, C. M., Tong, T. K., and Chan, W. K. W., 2001. “Genetic algorithms for optimizing supply locations around tower crane.” J. Constr. Eng. Manage., 127_4_, 315–321.

[13] Osman, H., Georgy, M. E., and Ibrahim, M. E., 2003, “A hybrid CADbased construction site layout planning system using genetic algorithms.” Autom. Constr., 12, 749–764.

[14] Khalafallah, A., and El-Rayes, K., 2005. “Trade-off between safety and cost in planning construction site layouts.” J. Constr. Eng. Manage., 131_11_, 1186–1195.

[15] Khalafallah, A., and El-Rayes, K., 2006. “Minimizing constructionrelated hazards in airport expansion projects.” J. Constr. Eng. Manage., 132_6_, 562–572.

[16] Elbeltagi, E., Hegazy, T., and Eldosouky, A., 2004. "Dynamic layout of construction temporary facilities considering safety." J. Constr. Eng. Manage., 130_4_, 534–541.

[17] Osman, H., Georgy, M. E., and Ibrahim, M. E., _2003a. "An automated system for dynamic construction site layout planning." Proc., 10th Int. Colloquium on Structural and Geotechnical Engineering, Ain Shams University, Cairo, Egypt.

[18] Zouein, P. P., and Tommelein, I. D., 1999. "Dynamic layout planning using a hybrid incremental solution method." J. Constr. Eng. Manage., 125_6_, 400–408.

[19] Funtík, T., and Gašparík, J.. Site plan development: Tower crane placement based on data obtained from IFC file. In ISARC 2016 : proceedings of the 33rd International Symposium on Automation and Robotics in Construction and Mining. Auburn, Alabama, USA, July 18-21, 2016. [s.l.] : International Association for Automation and Robotics in Construction (I.A.A.R.C), 2016, S. 33-37. ISBN 978-1-5108-2992-3

[20] Kantova, R., and Motyčka, V.. Construction Site Noise and its Influence on Protected Area of the Existing Buildings. 9th International enviBUILD Conference Location: Brno, CZECH REPUBLIC Date: SEP 18-19, 2014. Univ Technol, Fac Civil Engn. ENVIBUILD 2014 Book Series: Advanced Materials Research Volume: 1041, 2014, S. 419-423.

[21] Rudy, V.. Virtuálne riešenia priestorovej štruktúry strojárskych výrob. In: Transfer inovácií. Č. 13 (2009), s. 231-235. - ISSN 1337-7094.

[22] Kováč, J.. Projektovanie výrobných procesov a systémov. Technická univerzita v Košiciach, Strojnícka fakulta, 2006.128 s. ISBN 80-8073-720-7.