

Implementation of automation and robotics: Benefits to the construction industry

Ayanda Boya¹, Opeoluwa Akinradewo¹, Clinton Aigbavboa¹ and Molusiwa Ramabodu²

¹ cidb Centre for Excellence & Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa, ayandabboya@gmail.com; opeakinradewo@gmail.com; caigbavboa@uj.ac.za

² Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa, molusiwar@uj.ac.za

Abstract:

With the advancement of technological equipment, understanding how technology influences the construction industry is essential. South Africa is expanding its use of technological innovation in the construction sector, primarily to solve issues particularly on building sites such as decline in quality and productivity, material wastage, injuries, project delays and poor working conditions. A solution to these issues is the adoption of implementation strategies of automation and robotics technologies, which have the potential to increase productivity, safety, and quality in the construction industry. This study aimed at evaluating the benefits of the implementation strategies of automation and robotics in the South African Construction industry. Corresponding literatures were reviewed, and a detailed quantitative research methodology was adopted to analyse the relationship between the variables. The cluster sampling technique was used and a survey questionnaire was distributed to a total of 111 valid construction professionals, who were situated in the Gauteng province of South Africa. The data collected presumed that the implementation of automation and robotics in the construction industry is beneficial as it increases productivity and efficiency. This was because technologies are generally more efficient than labourers as they can execute more work precisely without getting 'tired' as well as perform tasks well under hazardous conditions. The study concluded that the increase in productivity and efficiency by automation and robotics can reduce construction project delays and can ensure that certain goals are met during all phases of construction projects.

Keywords:

Automation, construction industry, 4IR, robotics, South Africa

1 Introduction

Due to the labour intensity of construction, different forms of automation and robotics have been executed to alleviate difficulties and to increase productivity and sustainability in the work environment. The implementation of these systems has given proof to be beneficial by establishing better and safer construction in terms of design and execution during the construction phase (Cai *et al.*, 2019). A rise in construction demand has been observed over the last few years and automation and robotics have been used to speed up the overall rate of construction completion (Bogue, 2017). Furthermore, construction has been described as an

industry with a higher rate of workplace injuries and fatalities where building collapse and falling from great heights are the leading causes of deaths in construction. Construction automation has shown to be necessary for carrying large materials, thus leading to injury prevention (Chonnaparamutt and Birk, 2006). According to Kamaruddin *et al.*, (2013), thoroughly embracing technologies such as robotics and building automation is the solution to labour shortages, workplace health and safety, and a decline in efficiency and productivity.

Due to labourers being at risk of injuries and facing casualties on construction sites (Cai *et al.*, 2019), the implementation of Automation and Robotics to perform high risk jobs through human supervision has proven to be highly advantageous when safely executing construction projects (Bahrin *et al.*, 2016). Over the years, construction has illustrated that the implementation of automation and robotics is necessary to lift hefty material e.g. cranes, for the reason that it is faster and safer for labourers unlike manual transportation, which could lead to serious injury. The cranes are programmed to evaluate the weighted material so that it does not fall due to the weight exceeding the carrying capacity of the crane (Chonnaparamutt and Birk, 2006). The magnitude of quality from using automation and robotics in construction is at a greater scale due to automated machines being able to work more precisely than labourers (Kwen and Cheong, 2005). Examples of quality of materials enhanced by the use of construction automation are pre-fabricated materials such as “pre-cast concrete, masonry and steel” (Kamaruddin *et al.*, 2013).

The main objective of this study is to investigate the benefits that can be obtained from the automation and robotics strategies that are implemented in the construction field. With all the problems that arise during the construction phase, there needs to be an exposure in the way automation and robotics assists with progress in the industry. This study will provide the necessary exposure to professionals and students in the construction field, so that they understand the importance of the implementation strategies used in the South African construction industry.

2 Automation and Robotics in the Construction Industry

Automation and robotics in construction is the mechanisation and digitalisation of human skills to aid in productivity as well as to resolve issues related to labor scarcity, safety factors etc. (Cai *et al.*, 2019). The rise of the industrial revolution 4.0 (4IR) has assisted in making people more mindful of the convenience of implementing automation and robotics in their daily tasks (Aghimien *et al.*, 2019). In the late nineties, automation and robotics studies began with the advent of sole-use robots (remote operated). Due to concerns regarding social dynamics, Japan pioneered this initiative, which indicated a potential shortage in construction labour force workers. The main related work in the United States consisted of designing wireless or remotely operated machines which needed specialised industrial equipment for carrying out dangerous tasks (Everett and Saito, 1994).

2.1 Benefits of implementing automation and robotics in construction

2.1.1 Material resource

In general, a machine can perform tasks with more precision and efficiency. In a variety of ways, automated systems can promote the effective use of materials. In prefabrication

facilities, for example, the use of resources can be optimised through methodical planning and automation under varying conditions. According to Neelamkavil (2009), sensor-based control does not just allow the monitoring of equipment and elements for easier interchanges but also identifies the structure of waste products for recycling. Construction Automation and Robotics (CAR) enables and coordinates the accumulation and categorisation of wastes in the prefabrication stage (Bock and Linner, 2015). According to previous sample tests, reduced waste is another advantage of “automated/robotic on-site factories” (AROFs). In addition, AROFs sanction easy reuse of constituents through the use of BIM and Construction Automation and Robotics (Lee *et al.*, 2015).

2.1.2 *Energy resource*

The excessive use of energy and emanation of Greenhouse gases are two of the most commonly used indicators in evaluating building sustainable development throughout the building operating phase (Berardi, 2013). Automation and robotics can help to create a streamlined work operation and reduce energy consumption (Bock and Linner, 2016b).

2.1.3 *Land resource*

Construction automation and robotics can have some form of impact on the efficient use of land resources. For instance, automated systems can simplify site layout and maximise area use (Balaguer *et al.*, 2002). Secondly, building and demolition frequently produce a great deal of waste and garbage disposal. Landfilling is still the major strategy in dealing with building and demolition waste in many countries (Yuan, 2013). Construction automation and robotics can help to reduce wastage by decreasing the need for landfill space and reducing land degradation. Thirdly, urban mining is facilitated by construction automation and robotics. For instance, AROFs can disassemble the structure when deconstructing instead of demolishing or using explosive devices, and steel elements do not require melting for heavy energy recycling use (de Beer *et al.*, 1998).

2.1.4 *Air resource*

Air pollution and noise disturbances from demolition operations can have a negative influence on neighbouring air quality (Yuan, 2013). As a result, CAR might help to mitigate the negative effects on air resources by taking steps like decreasing wastage (Cousineau and Miura, 1998), ensuring work surroundings are unpolluted and free of dust (Khoshnevis, 2004), and speeding up building projects (Bock and Linner, 2016b).

2.1.5 *Water resource*

Water is an essential part of construction work, consumed in tasks such as preparations for the mortar, concrete treatment and mixing, sanitation, etc. In comparison to human work, construction automation and robotics is designed to utilise water resources and recycling procedures more effectively (Cousineau and Miura, 1998).

2.1.6 *Environmental compliance*

Multiple countries have implemented environmental laws, regulations and requirements which facilitate compliance and ensure that the planned projects do not cause harm to the environment (Dunmade, 2002; Pan and Garmston, 2012; Qi, *et. al.*, 2010). The use of automation and robotics technology can be used as a significant enabler to ensure compliance

with environmental considerations aimed at legislation, politics and standards for projects or companies who seek to improve their sustainable development.

2.1.7 Economic benefits

The use of CAR to support, cooperate or replace human work can provide several direct and indirect economic advantages. Direct economic benefits mainly include labour cost reductions, resources and the cost of managing wastage, meanwhile indirect economic benefits include time reduction, reducing reworks, improving construction quality and potentially government subsidies for transformation (Bock and Linner, 2015; Mahbub, 2008). In automated prefabrication research, these benefits have been extensively recognised. Warszawski (2003), for instance, created technical guidelines to support industrialisation and proved the economic advantages of prefabricated mechanisation and automation. As per his studies, automation not only helps conserve work and accuracy, but also lowers design and transformation costs for smaller sized orders. Abbott (2013) suggested that the automation of manufacturing techniques when prefabricating can generate economic benefit by lowering cost of labour and project delays. With regards to indirect economic advantages, Kumar *et al.* (2016) discovered that automated instruments significantly cut the average time spent on main construction operations, resulting in significantly higher output quality and lower rework and scrap costs.

2.1.8 Business development

Construction Automation and Robotics also leads to market distinctiveness, which may yield company development benefits such as new business prospects and long-term company value leading to more trading opportunities for the technology owners or investors (Brent *et al.*, 2006). Moreover, the reputation as a technological innovation company (Zavadskas, 2010) may be achieved and technical competitiveness may be realised that is conducive to a company's long-term commercial development (Bock and Linner, 2015).

2.1.9 Employees

Essentially, automation and robotics aid human workers in doing risky, monotonous, or illogical construction work (also known as “dull, dirty and dangerous activities”: DDD tasks) in a more structured and correct manner. These systems thus have a major effect on employee welfare. Performance factors like workplace health and safety, employee contentment, and workforce expansion are evaluated at the implementation level. Workers falling from rooftops or scaffolding, being electrocuted, and mechanical accidents are all common occurrences on construction sites, resulting in injuries and death (Castro-Lacouture, 2009).

2.1.10 Supply chain stakeholders

According to Bock and Linner (2012) and Mahbub (2008), relations with supply chains in the construction industry are sometimes complex and connected to unusual domino-effects. From the standpoint of the project, the implementation of advanced construction methods has the greatest impact on stakeholder satisfaction, which includes better client and end-user contentment with the increasing functioning and manageability of the project plan, and influences the cost of the final product. From a business standpoint, automation investments may have an influence on preserving long-term relations.

2.1.11 Construction monitoring

The construction manager needs to constantly monitor the construction process to guarantee that the client's needs are executed with quality. On-site safety and efficiency will also benefit from automation. When health and safety specialists and supervisors are absent on site, construction automation will track and document whatever occurs on site. Managers can access data directly because it can be saved and evaluated later (Struková and Líška, 2012).

2.1.12 Planning and estimating

Preparation and evaluation can be difficult, which will need the assistance of a professional project manager. During this stage of development, application software may be used. Applications that can schedule and make reliable cost forecasts are made possible by information technology. The project manager's likelihood of making a mistake are reduced with this software since an overview of required tasks can be generated through pre-programming from the layout, making approximations easier because all operations can be concentrated upon (Castro-Lacouture, 2009; Struková and Líška, 2012).

2.1.13 Designing

Construction has used manual designs with a two-dimensional plan over the decades. In the building industry, digital software can be used to assist architects and engineers build more efficiently. This programming helps the designer to see the design in three dimensions which is a faster way to design since the designer can look at all aspects of the model easily. More advanced software is used to design structures that provide a four-dimensional view. This software can be used as a prototype to help designers ensure that elements do not overlap (Castro-Lacouture, 2009).

2.1.14 Quality control

The construction industry is focused on producing high-quality goods. By using high tech inspection sensors and lasers, Robotics and Automation is implemented to increase the efficiency of the construction product. This technique is mostly used in pre-fabrication to validate work that has been examined by workers. Hydraulics can be used and test components to track their strength in construction, and they can be attached to a monitor to convey details about the components on that monitor. Lasers and sensors may be connected to a computer program to approve or reject a product if it fails the test. As a result, higher levels of automation are used to prevent structural failure and excessive cost (Balaguer and Abderrahim, 2008; Struková and Líška, 2012).

3 Research Methodology

The quantitative research approach was used for this study. A deductive logic approach was implemented where surveys/ questionnaires were gathered and issued to collect data. The explorative technique was most suitable with comparing the relationship between variables. The research was conducted in Gauteng, South Africa. Construction organisations as well as professionals (Quantity Surveyors, Construction Project Managers, Civil Engineers and Architects) in the engineering and construction sector were targeted respondents. The type of sampling employed for this research was random cluster sampling. Surveys were distributed to the above mentioned professionals in Gauteng. They represented organisations familiar with automation and robotics in the construction industry. This sampling technique was used

because was not be feasible to sample the whole population of construction professionals in South Africa. MIS – “Mean Item Score” and SD – “Standard Deviation” were used to analyse the data that was collected. A total of 111 valid responses were obtained and the data collected was examined using Microsoft Excel and Statistical Package for Social Science (SPSS). The study encountered limitations due to the fact that the targeted number of professionals did not complete the surveys and some individuals did not accurately complete the surveys. The reliability of the results was tested using Cronbach’s Alpha coefficient, which amounted to 0.903, meaning the findings of this study can be relied upon.

4 Findings and Discussion

4.1 Findings

The background data that was collected from the targeted respondents was analysed. Results showed that 18.9% hold a post matric certificate or Diploma, 41.4% hold a Bachelor’s Degree, 29.7% hold an Honour’s Degree, 8.1% hold a Master’s Degree, and 1.8% hold a Doctorate. Results also indicated that 8.1% are Architects, 49.5% are Quantity Surveyors, 11.7% are Civil Engineers, 0.9% are Industrial Engineers, 10.8% are Mechanical Engineers, 8.1% are Construction Managers, 8.1% are Construction Project Managers, and 2.7% fall under Other professions.

Through the application of the 5-point Likert scale of ‘Strongly Disagree’ (SD) – ‘Strongly Agree’ (SA), the respondents were required to specify the extent at which they agree with regards to the benefits of the strategies adopted in the implementation of automation and robotics in the industry.

Table 1 indicates the respondent’s rankings of the benefits of the strategies adopted. The results indicate that “Increase in productivity and efficiency” was ranked first position, with a MIS of 4.38 and a SD of 0.843; “Advancement in 3D drawings and designs” was ranked second position, with a MIS of 4.32 and a SD of 0.896, “Reduction in project duration” was ranked third position, with a MIS of 4.19 and a SD of 0.848, “Reduction in material wastage” and “Efficiency in pre-fabrication of material” were both ranked fourth position, with a MIS of 4.18 and a SD of 0.907 and 0.789 respectively.

Additionally, “Improvement in measurements and estimations” was ranked sixth, with a MIS of 4.16 and a SD of 0.804; “Reduction in site injuries” was ranked seventh position, with a MIS of 4.07 and a SD of 0.860; “Increased safety of site” was ranked eighth position, with a MIS of 4.04 and a SD of 0.904, “Reduction in labour costs” was ranked ninth position, with a MIS of 3.97 and a SD of 0.986, “Improvement in site monitoring” was ranked tenth position, with a MIS of 3.91 and a SD of 0.848; and lastly, “Reduction in project risks” was ranked eleventh position, with a MIS of 3.80 and a SD of 0.952.

Table 1: Benefits of the strategies adopted in the implementation of automation and robotics

Benefits of the strategies adopted	MIS	SD	R
Increase in productivity and efficiency	4,38	0,843	1
Advancement in 3D drawings and designs	4,32	0,896	2
Reduction in project duration	4,19	0,848	3
Reduction in material wastage	4,18	0,907	4
Efficiency in pre-fabrication of materials	4,18	0,789	4
Improvement in measurements and estimations	4,16	0,804	6
Reduction in site injuries	4,07	0,860	7
Increased safety of site	4,04	0,904	8
Reduction in labour costs	3,97	0,986	9
Improvement in site monitoring	3,91	0,848	10
Reduction in project risks	3,80	0,952	11

Mean Item Score (MIS); Standard Deviation (SD); Ranking (R)

4.2 Discussion

Through the observation of the ranking, it is evident that the most beneficial strategy adopted in the implementation of automation and robotics is ‘Increase in productivity and efficiency’. These findings are congruent with literature presented by (Bock *et al.*, 2012; de Looze *et al.*, 2016), that robotics can assist labourers by lessening the elevated nature of their labour and increase productivity. Other literatures that tally with this finding are Bock and Linner (2015) who stated that prefabrication automation allows multifunctional units to significantly improve efficiency. Struková and Líška (2012) mentioned that on-site safety and efficiency will also benefit from automation. The beneficial strategy ‘Advancement in 3D drawings and designs’ can be substantiated by Castro-Lacouture (2009), who stated that digital software can assist designers to see their designs in three dimensional formats which is a faster way to design since the designer can look at all aspects of the model easily. Direct and indirect economic benefits from literature confirm that automation and robotics lead to ‘Reduction in project duration’ and ‘Reduction in material wastage’ (Bock and Linner, 2015; Mahbub, 2008).

‘Reduction in labour costs’ being ranked one of the least beneficial strategies corresponds with findings from Oke *et al.*, (2019), where the benefit in their literature - ‘Reduces labour costs’- was ranked eleventh out of a total of twelve. ‘Improvement in site monitoring’ was ranked one of the least which does not correlate with literature presented by (Struková and Líška, 2012; Rakha and Gorodetsky, 2018) and other literature which proclaim that automation and robotics significantly improve monitoring of sites. ‘Reduction in project risks’ was ranked least among the respondents and this correlates with literature from Oke *et al.*, (2019), which showed that the benefit ‘Reduces construction accidents’ was ranked tenth out of a total of thirteen.

4.3 Implication of findings

Based on the discussion of the findings, it can be deduced that the strategies adopted in the implementation of automation and robotics show increase in productivity and efficiency. Due to the complexity of certain projects, robotics can carry more workload, minimise exhaustion, and execute more work than labourers normally can. On the contrary, on multiple occasions the literature review mentions that automation and robotics assist with site and equipment monitoring yet the rankings illustrate that ‘Improvement in site monitoring’ is the second least beneficial strategy chosen. This could be due to lack of access to site monitoring equipment, lack of excess knowledge on how to use site monitoring equipment or personal experiences where automation and robotics did not monitor efficiently. It is perceptible that automation and robotics strategies can be used to monitor and assess risks on site. Nevertheless, this does not entail that the monitoring of risks and accidents results in a decrease in those risks and accidents. This could be the reason for ‘Reduction in project risks’ being the least beneficial strategy.

5 Conclusion and Further Research

In the study, the research objectives were identified and met. The scope limited the population of the questionnaire survey to professional individuals in the South African construction industry. Therefore, the findings of this study enhanced the existing methodology and provided useful recommendations for automation and robotics implementation strategies. The study was successful in identifying that the most beneficial strategy adopted in the implementation of automation and robotics was increase in productivity and efficiency. The increase in productivity and efficiency can reduce project delays and ensure that certain goals are met during all phases of construction projects. Technologies are generally more efficient than labourers as they can execute more work precisely without getting ‘tired’ as well as perform tasks well under hazardous conditions. A suggestion for further research or recommendation can therefore be the increase in accessibility of technologies – technologies need to be easily accessible for organisations to be able to obtain them and effectively utilise them. For further studies, this research recommends an investigation in the scale of adoption of automation and robotic technologies in the South African construction industry.

6 References

- Abbott, L.F., 2013. Political barriers to house building in Britain: a critical case study of protectionism and its industrial-commercial effects. *Ind. Syst. Res.* 3.
- Aghimien, D.O., Aigbavboa, C.O., Oke, A.E. and Thwala, W.D., 2019. Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. *Journal of Engineering, Design and Technology.*
- Bahrin, M.A.K., Othman, M.F., Azli, N.H.N. and Talib, M.F., 2016. Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi*, 78(6-13).
- Balaguer, C., Abderrahim, M., 2008. Trends in robotics and automation in construction. In *Robotics and Automation in Construction*. InTech.
- Balaguer, C., Abderrahim, M., Navarro, J., Boudjabeur, S., Aromaa, P., Kahkonen, K., Slavenburg, S., Seward, D., Bock, T., Wing, R., 2002. Future Home: an integrated construction automation approach. *IEEE Robot. Autom. Mag.* 9, 55e66.

- Berardi, U., 2013. Clarifying the new interpretations of the concept of sustainable building. *Sustain. Cities Soc.* 8, 72e78.
- Bock, T., Linner, T., 2012. Evolution of large-scale industrialisation and Service - innovation in Japanese prefabrication industry. *J. Construct. Innov. Inf. Process Manag.* 12, 1471e1475.
- Bock, T., Linner, T., 2015. *Robotic Industrialisation: Automation and Robotic Technologies for Customized Component, Module and Building Prefabrication*. Cambridge University Press, Cambridge.
- Bock, T., Linner, T., 2016b. *Site Automation: Automated/Robotic On-site Factories*. Cambridge University Press, Cambridge.
- Bock, T., Linner, T., Ikeda, W., 2012. Exoskeleton and humanoid robotic technology in construction and built environment, *The Future of Humanoid Robots-Research and Applications*, InTech.
- Bogue, R., 2017. What are the prospects for robots in the construction industry? *Industrial Robot: An International Journal*.
- Brent, A.C., Van Erck, R.P., Labuschagne, C., 2006. Sustainability Cost Accounting Part 1: a Monetary Procedure to Evaluate Sustainability of Technologies in the South African Process Industry.
- Cai, S., Ma, Z., Skibniewski, M., & Bao, S., 2019. Construction automation and robotics for high-rise buildings over the past decades: A comprehensive review. *Adv. Eng. Informatics*, 42.
- Castro-Lacouture, D., 2009. Construction automation. In *Springer handbook of automation* (pp. 1063-1078). Springer, Berlin, Heidelberg.
- Chonnaramutt, W. and Birk, A., 2006. Using rescue robots to increase construction site safety. In *International Symposium of Automation and Robotics in Construction (ISARC)* (pp.241-245).
- Cousineau, L., Miura, N., 1998. *Construction Robots: the Search for New Building Technology in Japan*. ASCE Publications.
- De Beer, J., Worrell, E., Blok, K., 1998. Future technologies for energy-efficient iron and steel making. *Annu. Rev. Energy Environ.* 23 (1), 123e205.
- De Looze, M.P., Bosch, T., Krause, F., Stadler, K.S., O'Sullivan, L.W., 2016. Exoskeletons for industrial application and their potential effects on physical work load, *Ergonomics* 59, 671–681.
- Dunmade, I., 2002. Indicators of sustainability: assessing the suitability of a foreign technology for a developing economy. *Technol. Soc.* 24, 461e471.
- Everett, J. G., Saito, H., 1994. Automation in Construction: Social and Culture Difference between Japan and the United States, *Automation and Robotics in Construction XI*, 223-229.
- Kamaruddin, S. S., Mohammad, M. F., Mahhub, R., Ahmad, K., 2013. Mechanisation and Automation of the IBS Construction Approach: A Malaysian Experience, *Asian Pacific International Conference on Environment Behavior Studies*, 105:106-114, 2013.
- Khoshnevis, B., 2004. Automated construction by contour crafting-related robotics and information technologies. *Autom. Constr.* 13, 5e19.
- Kwen, H.N., and Cheong, Y. W., 2005. Quality Control in Precast Production: A Case Study on Tunnel Segment Manufacture, *Dimesi Teknik Arsitektur*, 33(1):153-164.

- Lee, S., Pan, W., Linner, T., Bock, T., 2015. A framework for robot assisted deconstruction: process, sub-systems and modelling. In: Proceedings of the 32nd International Symposium on Automation and Robotics in Construction and Mining (ISARC2015), Oulu, Finland.
- Mahbub, R., 2008. An Investigation into the Barriers to the Implementation of Automation and Robotics Technologies in the Construction Industry. Queensland University of Technology.
- Neelamkavil, J., 2009. Automation in the Prefab and Modular Construction Industry, 26th Symposium on Construction Robotics ISARC.
- Oke, A., Akinradewo, O., Aigbavboa, C. and Akinradewo, O., 2019, November. Benefits of construction automation and robotics in the South African construction industry. In *IOP Conference Series: Earth and Environmental Science* (Vol. 385, No. 1, p. 012063). IOP Publishing.
- Pan, W., Garmston, H., 2012. Building regulations in energy efficiency: compliance in England and Wales. *Energy Policy* 45, 594e605.
- Qi, G., Shen, L., Zeng, S., Jorge, O.J., 2010. The drivers for contractors' green innovation: an industry perspective. *J. Clean. Prod.* 18, 1358e1365.
- Rakha, T., Gorodetsky, A., 2018. Review of Unmanned Aerial System (UAS) applications in the built environment: towards automated building inspection procedures using drones, *Autom. ConStruct.* 93, 252–264.
- Struková, Z., Líška, M., 2012. Application of automation and robotics in construction work execution. *AD ALTA: Journal of Interdisciplinary Research*, 2:121-5.
- Warszawski, A., 2003. *Industrialized and Automated Building Systems: a Managerial Approach*. Routledge.
- Yuan, H., 2013. Key indicators for assessing the effectiveness of waste management in construction projects. *Ecol. Indic.* 24, 476e484.
- Zavadskas, E.K., 2010. Automation and robotics in construction: international research and achievements. *Autom. Constr.* 19, 286e290.