Project production flows in off-site prefabrication: BIM-enabled railway infrastructure

M. Arashpour[a], Y. Bai[a], V. Kamat[b], R. Hosseini[c] and I. Martek[c]

[a]Department of Civil Engineering, Monash University, Australia
[b]Department of Civil and Environmental Engineering, University of Michigan, USA
[c]School of Architecture & Built Environment, Deakin University, Australia

E-mail: mehrdad.arashpour@monash.edu, yu.bai@monash.edu, vkamat@umich.edu, reza.hosseini@deakin.edu.au, igor.martek@deakin.edu.au

Abstract – Railway infrastructure projects provide required physical and organizational facilities for transportation networks. Production flows in railway construction are complex especially when a hybrid of on-site and off-site processes is in progress. With railway projects still experiencing budget and time overruns, there is need to re-examine production flows. Towards this aim, a framework to investigate production flows in railway infrastructure projects is presented and discussed. A three-dimensional view of construction production including portfolio, process and operation aspects is found capable of improving performance measures in both design and construction. Such improvements include minimized rework and re-entrant flows, flexible prefabrication, enhanced multidisciplinary collaborations, and efficient planning of temporary works. This research contributes to the construction body of knowledge by examining production flows in a complex infrastructure setting. Construction managers would benefit from the presented model of production flows and its customization in the context of their projects to improve productivity and performance.

Keywords –

Building Information Modeling, Construction Management, Design Complexity, Infrastructure Project Management, Reentrant Flows, Rework Minimization, Robotics, Shop drawings, Three dimensional models (3D), Uncertainty in Decision Making

1 Introduction

Dynamics of workflow have been explored in the construction management literature [1-4]. However, there is need to investigate production flows in complex environments of infrastructure projects [5, 6]. Management of production flow in construction of railway, utility and energy projects is more challenging than residential and commercial construction [7, 8]. Among others, challenges are caused by involvement of many collaborating teams [9], lack of established frameworks for managing project production flows [10], and large numbers of stakeholders [11]. Recently, mainstream research in construction has been focused on Building Information Modeling (BIM) as a facilitator to support production flows in construction [12, 13]. Although useful, there are sparse studies aimed at improving the construction understanding of project production flows [14].

Off-site production, which is a hybrid of construction and manufacturing, has the potential to improve production flows in infrastructure projects [15], and increase flexibility in processes and operations [16]. The challenge, however, is the complexity of production flows within infrastructure project settings [17]. Not much research has been conducted to investigate project production flow dynamics in complex infrastructure construction where prefabrication is a major player [18].

The current study aims to bridge this gap by analyzing railway infrastructure projects within the framework of the production flow model developed by Sacks [19]. Towards this aim and in a similar approach to Liu, et al. [20], a case study approach was adopted as it is capable of responding to "how" and "why" types of research questions and allows retaining a holistic approach towards the research problem at hand [21]. Selected railway projects in Australia were deemed suitable to analyze production flows within infrastructure project settings. A purposeful selection of case studies targeted maximum level of complexity in project production flows. Main factors contributing to project complexity included the hybrid production mode (on-site and off-site), the concurrency of construction and train operations, numerous engineering scenarios and production alternatives, collaboration of many multidisciplinary teams, and complicated design and construction processes across several project modules.

To streamline complex production flows, railway infrastructure projects are often broken down to smaller manageable zones (modules). Geographic proximity and similarity of construction methods mainly drive the exercise of project modularization. The purpose-built production flow model in projects should realizes three dimensions of project portfolio (module), process and operations. The production flow model in infrastructure projects aims to maximize flow continuity for design and construction of on-site assembly and off-site prefabrication. This paper analyzes and discusses four major improvements resulting from the three-dimensional flow model in the following order. After describing the base model, most important improvements in terms of minimization of rework and reentrant flows are discussed. This is followed by series of performance enhancements including flexible prefabrication, improved multidisciplinary collaborations, and efficient planning of temporary works. Finally, conclusions are presented followed by discussion of limitations and opportunities for future research.

2 Design and construction complexity-implications for production flows

In the context of infrastructure construction, project teams need to frequently evaluate and compare different engineering solutions to optimize performance measures [22-24]. In the case projects, an elevated rail solution was selected over a rail-under alternative. Elevated railways minimize construction impacts on local utilities and major gas, water and electricity transmissions across the rail corridor [25, 26]. Furthermore, risks of flooding and manipulation of water tables are minimized by using this engineering solution [27, 28]. Finally, elevated rail projects require lower amount of land acquisition as opposed to traditional open cut trench solutions [29, 30].

Design in infrastructure projects is more complex than other project types in which respective processes are often entirely completed before commencement of construction [31, 32]. In order to address complexity in railway infrastructure projects, design processes are split into different packages. The interdisciplinary design teams comprise architects, engineers, scientists and consultants. Detailed design drawings that are produced by design teams are reviewed by major stakeholders including local councils, road authority, electricity and gas distributors, public transport network, and government agencies. Considering the projects is a challenging task.

Production flows in large infrastructure projects are complex to manage with high levels of variability in both design and construction. For an effective management of production flows in railway infrastructure projects, a three-dimensional view of production, proposed by Sacks [19], is adopted. In this flow model, processes and operations of multiple project zones are managed in a three-dimensional (3D) space. The model has been customized to reflect the dynamism involved in design and construction of prefabricated elements in railway infrastructure projects. As can be seen in Figure 1, inclusion of the project portfolio (module) axis reflects the simultaneous occurrence of design and construction across several project modules. The model's objective is to achieve maximum production flow continuity at the project level.

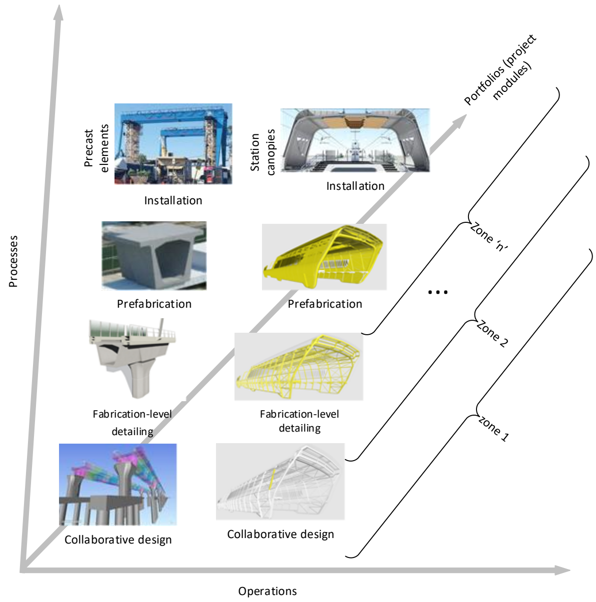

Figure 1. Three dimensional view of production flows in infrastructure projects

3 Robustness of the 3D view of project production flows

The balancing of production flows across different project modules results in several improvements that are discussed in the following sections. Improvements in the context of infrastructure projects include but are not limited to minimization of rework and re-entrant flows, maximization of flexibility in prefabrication, improvements in multidisciplinary collaborations, and efficient planning of temporary works.

3.1 Minimization of rework and re-entrant flows

In complex environments of infrastructure projects, resources often have to return to work locations more than once to complete processes. This creates reentrant flows resulting in delays and discontinuity of work [33, 34]. One contributor to reentrant flow is planning and management of process and operations without considering the production flow continuity at the project level [35]. For example, installation processes of station canopies in the investigated railway projects require teams to return to same work locations several times to complete assembly of canopy elements that have complex geometries and connections. Adoption of the customized 3D flow model resulted in real-time prioritization of installation processes across different project modules and minimization of reentrant flows.

The second contributor to project reentrant flow is defective work and resultant rework [36, 37]. After identification of defects by successor trades or inspectors, responsible resources are called back to undertake rework in respective work locations [38]. Defects in construction are caused by inaccurate design and/or errors in completing the work [39]. Both issues in the analyzed railway projects were managed by using the 3D project production model. This along with the use of building information models facilitated collaborations in detecting design faults and clashes ahead of fabrication-level detailing. Furthermore, the model created continuous production flows for off-site manufacturers and on-site installation teams. As an example, collaborative review of initial design across project modules revealed several inconsistencies in the design of station canopies. Furthermore, frequent comparisons of planned and actual construction, resulted in early detection of errors in column locations for elevator shafts in railway stations.

Reduction of rework and reentrant flows by using the portfolio- process- operations model of production flows improves performance measures at the project level. This is due to the fact that reentrant flows often pass through bottleneck resources and cause further delays in completing activities on the project critical path [40, 41].

3.2 Flexible decision making for prefabrication

Implementation of the 3D model of project production facilitated the postponement of differentiation points in manufacturing of prefabricated elements such as viaduct segments, super T beams, precast piers, and elevated station canopies. The portfolio dimension facilitates continuity of process and operation flows at the project level and in accordance to unique requirements in each and every project module [42, 43]. Furthermore, the production flow structure provides required interfaces between preliminary design, prefabrication and on-site assembly. This allows completion of more design iterations before fabrication-level detailing and prototyping prior to mass manufacturing of non-standard elements.

The extraction of component data for fabrication can be deferred to optimize production of elements for different project modules. As an example, complex hyperboloid geometries and novel fabrication procedures to construct station canopies were developed by postponing decision making and achieving the maximum possible level of design maturity.

Furthermore, the production flow model allows temporal flexibility for consecutive design stages. As can be seen in Figure 2, preliminary design of the steel structure for station canopies significantly improved during detailed design stages and fabrication-level detailing. The final structure is lighter by removing excessive horizontal members and more stable because of increased number of braces.

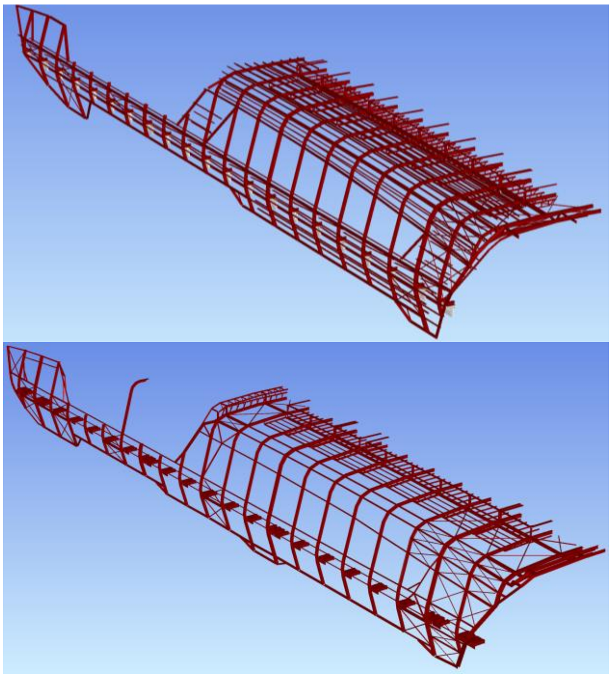

Figure 2. Flexible decision making- Initial design of canopy structure (top) and final design (down)

The continuity of production flow at the project level is maintained by considering the three dimensions of project portfolio, process and operations [44]. The modularity of project production in the railway case facilitated collaboration and information transfer amongst project teams. This is in line with findings of Williams, et al. [45] and confirms that a robust production flow structure should cover all project dimensions from design to fabrication to assembly. This holistic view maximizes temporal flexibility in decision making on downstream project processes that are often dependent to upstream work.

3.3 Improvements in multidisciplinary collaborations

Continuity of production flows across different project modules can only be achieved by efficient collaboration of multidisciplinary teams [46, 47]. This collaboration is essential for each and every project process including development of shop drawings. These drawings provide fabrication-level details of different structural and non-structural project elements. In the traditional approach to review and finalization of shop drawings, 2D documents sequentially pass through different discipline teams and necessary corrections are made [48]. This time consuming and error-prone process causes prolonged delays in downstream processes related to prefabrication and on-site installation [49, 50].

Departing from a file-based mode of reviewing and finalizing shop drawings, a cloud-based approach was used in the investigated infrastructure projects. Multidisciplinary collaborations were enhanced by the parallel use of commercial packages such as BIM360 Glue and Navisworks to facilitate reviewing fabrication-level details by collaborating multidisciplinary teams. As an example, in prefabrication of steel structures, comments from architecture, engineering and manufacturing teams were collaboratively addressed to finalize shop drawings.

The portfolio- process- operations view of production flows (Figure 1), provides a collaborative platform for exchanging fabrication-level information across different disciplines such as architecture, civil, rail and services. Modularity of the production flow structure and existence of the portfolio dimension (project modules) resulted in prefabrication of bespoke elements across different project modules.

3.4 Efficient planning of temporary works and structures

Temporary structures and works such as hoardings and scaffolding support construction of projects [51, 52]. Decision making on temporary structures and works requires consideration of both temporal and spatial limitations [53, 54]. Traditionally the decision making has been based on experience of design and construction teams, often causing delays and time-space conflicts [55, 56]. The portfolio- process- operations flow model facilitates decision making on temporary structures and works by considering multidisciplinary requirements across different project modules.

Temporary works are of great importance to the investigated project cases because of simultaneous operation of trains and construction. Hoardings next to rail tracks were designed considering safety of train users and construction crews, spatial limitations on worksites, duration of use, and possible workspace conflicts. After multidisciplinary analysis of optimum distance from hoardings to center of nearest tracks, project teams agreed on 2.1 meters to satisfy constraints. Understandably, this base distance is re-examined in different production scenarios to evaluate suitability to each project module.

Scenario analysis and evaluation of alternatives to temporary works often result in minimizing cost and maximizing performance measures at the project level [57]. For example, alternative use of scaffolding and scissor lifts as the work platform in the assembly process of elevated stations was deemed suitable in different project zones.

The portfolio-process-operation model of production flow facilitates consideration of multidisciplinary constraints in planning and design of temporary works with the aim of maintaining flow continuity at the project level.

4 Conclusions

Previous research has realized the complexity of managing production flows in large construction projects [58, 59]. However, studies that take holistic approaches to manage process and operations across different modules of infrastructure projects are sparse [60]. To bridge this gap, the current research analyzes railway infrastructure projects to evaluate the three-dimensional production flow model developed by Sacks [19].

The findings present significant improvements in terms of production flow continuity at the project level. Adopting the portfolio- process- operation view of project production resulted in minimization of rework and reentrant flows, flexible prefabrication, enhanced multidisciplinary collaborations, and efficient planning of temporary works. Results of the current analysis are in line with those of Mullens [61] and Sacks, et al. [62], confirming that all dimensions of production flow need to be holistically considered in order to maintain flow continuity at the project level.

This work contributes to the literature by analyzing dynamics of production flow in complex infrastructure projects where a hybrid of on-site and off-site processes across several project modules are in progress. Furthermore, the paper's approach to customize production flow model is of practical use to those planning and managing infrastructure construction. Early adoption of production flow model facilitates creation of a holistic approach to manage process and operations across different project modules.

5 Research limitations and further opportunities

Investigation of production flows in the current study is limited to infrastructure cases in the railway context. Future research would benefit from investigating other types of infrastructure projects to test the generalizability of findings. Furthermore, the results of this study are limited to four aspects of re-entrant flow, decision flexibility, collaboration and temporary works. With a more in-depth analysis of production data, there will be opportunities to investigate other production aspects.

References

[1] R. Sacks, M. Treckmann, and O. Rozenfeld, "Visualization of Work Flow to Support Lean Construction," *Journal of construction engineering and management,* vol. 135, no. 12, pp. 1307-1315, 2009.

[2] M. Arashpour, R. Wakefield, N. Blismas, and T. Maqsood, "Autonomous production tracking for augmenting output in off-site construction," *Automation in Construction,* vol. 53, pp. 13-21, 2015.

[3] M. Arashpour, R. Wakefield, N. Blismas, and J. Minas, "Optimization of process integration and multi-skilled resource utilization in off-site construction," *Automation in Construction,* vol. 50, pp. 72-80, 2015.

[4] M. Arashpour, Y. Bai, G. Aranda-mena, A. Bab-Hadiashar, R. Hosseini, and P. Kalutara, "Optimizing decisions in advanced manufacturing of prefabricated products: Theorizing supply chain configurations in off-site construction," *Automation in Construction,* vol. 84, pp. 146-153, 2017.

[5] I. C. Cardenas, H. Voordijk, and G. Dewulf, "Beyond theory: Towards a probabilistic causation model to support project governance in infrastructure projects," *International Journal of Project Management,* vol. 35, no. 3, pp. 432-450, 4// 2017.

[6] A. Van Os, F. Van Berkel, D. De Gilder, C. Van Dyck, and P. Groenewegen, "Project risk as identity threat: explaining the development and consequences of risk discourse in an infrastructure project," *International Journal of Project Management,* vol. 33, no. 4, pp. 877-888, 2015.

[7] A. Bradley, H. Li, R. Lark, and S. Dunn, "BIM for infrastructure: An overall review and constructor perspective," *Automation in Construction,* vol. 71, Part 2, pp. 139-152, 11// 2016.

[8] A.-M. Mahamadu, L. Mahdjoubi, and C. A. Booth, "Critical BIM qualification criteria for construction pre-qualification and selection," *Architectural Engineering and Design Management,* pp. 1-18, 2017.

[9] K. Choi, Y. Kwak, J. Pyeon, and K. Son, "Schedule Effectiveness of Alternative Contracting Strategies for Transportation Infrastructure Improvement Projects," *Journal of Construction Engineering and Management,* vol. 138, no. 3, pp. 323-330, 2012/03/01 2011.

[10] J. Larsson, P. E. Eriksson, T. Olofsson, and P. Simonsson, "Industrialized construction in the Swedish infrastructure sector: core elements and barriers," *Construction Management and Economics,* pp. 1-14, 2013.

[11] K. Y. Mok, G. Q. Shen, R. J. Yang, and C. Z. Li, "Investigating key challenges in major public engineering projects by a network-theory based analysis of stakeholder concerns: A case study," *International Journal of Project Management,* vol. 35, no. 1, pp. 78-94, 1// 2017.

[12] H. Abdirad, "Metric-based BIM implementation assessment: a review of research and practice," *Architectural Engineering and Design Management,* vol. 13, no. 1, pp. 52-78, 2017/01/02 2017.

[13] B. Abdulaal, A. Bouferguene, and M. Al-Hussein, "Benchmark Alberta's architectural, engineering, and construction industry knowledge of building information modelling (BIM)," (in English), *Canadian Journal of Civil Engineering,* Article vol. 44, no. 1, pp. 59-67, 2017.

[14] U. Gurevich and R. Sacks, "Examination of the effects of a KanBIM production control system on subcontractors' task selections in interior works," *Automation in Construction,* vol. 37, pp. 81-87, 2014.

[15] M. Arashpour, R. Wakefield, N. Blismas, and E. W. M. Lee, "Framework for improving workflow stability: Deployment of optimized capacity buffers in a synchronized construction production," (in English), *Canadian Journal of Civil Engineering,* vol. 41, no. 12, pp. 995-1004, 2014.

[16] T. Gunawardena, T. Ngo, P. Mendis, and J. Alfano, "Innovative Flexible Structural System Using Prefabricated Modules," (in English), *Journal of Architectural Engineering,* Conference Paper vol. 22, no. 4, 2016, Art. no. 05016003.

[17] P. E. D. Love, D. J. Edwards, H. Watson, and P. Davis, "Rework in civil infrastructure projects: determination of cost predictors," *Journal of*

construction engineering and management, vol. 136, no. 3, pp. 275-282, 2010.

[18] T. M. Rose and K. Manley, "Revisiting the adoption of innovative products on Australian road infrastructure projects," *Construction Management and Economics,* vol. 32, no. 9, pp. 904-917, // 2014.

[19] R. Sacks, "What constitutes good production flow in construction?," (in English), *Construction Management and Economics,* Article vol. 34, no. 9, pp. 641-656, 2016.

[20] M. Liu, G. Ballard, and W. Ibbs, "Work flow variation and labor productivity: Case study," *Journal of Management in Engineering,* vol. 27, no. 4, pp. 236-242, 2011.

[21] J. W. Creswell, *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications, 2013.

[22] M. Arashpour, R. Wakefield, B. Abbasi, M. Arashpour, and R. Hosseini, "Optimal process integration architectures in off-site construction: Theorizing the use of multi-skilled resources," (in English), *Architectural Engineering and Design Management,* Article vol. 14, no. 1-2, pp. 46-59, 2018.

[23] M. Arashpour, E. Too, and T. Le, "Improving productivity, workflow management, and resource utilization in precast construction," in *9th International Structural Engineering and Construction Conference: Resilient Structures and Sustainable Construction, ISEC 2017*, 2017: ISEC Press.

[24] M. Arashpour and G. Aranda-Mena, "Curriculum renewal in architecture, engineering, and construction education: Visualizing building information modeling via augmented reality," in *9th International Structural Engineering and Construction Conference: Resilient Structures and Sustainable Construction, ISEC 2017*, 2017: ISEC Press.

[25] D. Murià-Vila, A. R. Sánchez-Ramírez, C. H. Huerta Carpizo, G. Aguilar, J. Camargo Pérez, and Y. López Casillas, "Field tests of a curve in an elevated urban railroad," in *9th International Conference on Structural Dynamics, EURODYN 2014,* 2014, vol. 2014-January, pp. 1175-1182: European Association for Structural Dynamics.

[26] H. Xia, Y. Deng, Y. Zou, G. De Roeck, and G. Degrande, "Dynamic analysis of rail transit elevated bridge with ladder track," (in English), *Frontiers of Architecture and Civil Engineering in China,* Article vol. 3, no. 1, pp. 2-8, 2009.

[27] Z. Junwei, L. Lei, M. Xiaojie, Z. Yi, and Q. Honglue, "Prevention problem progress of underground water disaster under large railway tunnel construction," (in English), *Electronic Journal of Geotechnical Engineering,* Article vol. 19, no. Q, pp. 4281-4292, 2014.

[28] L. Dong, B. Niu, S. Hu, and Y. Su, "Research on the influence law of bridge foundation settlement with seasonal underground water level change on high speed railway," in *15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, ARC 2015*, 2015, pp. 1407-1411: Asian Regional Conference on Soil Mechanics and Geotechnical Engineering.

[29] J. Lee and K. Sohn, "Identifying the Impact on Land Prices of Replacing At-grade or Elevated Railways with Underground Subways in the Seoul Metropolitan Area," (in English), *Urban Studies,* Article vol. 51, no. 1, pp. 44-62, 2014.

[30] J. Shi, K. Zou, A. J. Gu, H. Jiang, and Q. H. Liang, "Research on effect of train running on elevated line of high-speed railway on existing railway subgrade," (in Chinese), *Yantu Lixue/Rock and Soil Mechanics,* Article vol. 34, no. SUPPL.2, pp. 285-290, 2013.

[31] H. W. Lee, I. D. Tommelein, and G. Ballard, "Design of an infrastructure project using a point-based methodology," *Journal of Management in Engineering,* vol. 28, no. 3, pp. 291-299, // 2012.

[32] Y. Li and T. R. B. Taylor, "Modeling the impact of design rework on transportation infrastructure construction project performance," (in English), *Journal of Construction Engineering and Management,* vol. 140, no. 9, 2014, Art. no. 04014044.

[33] I. Brodetskaia, R. Sacks, and A. Shapira, "Stabilizing Production Flow of Interior and Finishing Works with Reentrant Flow in Building Construction," *Journal of Construction Engineering and Management,* vol. 139, no. 6, pp. 665-674, 2013.

[34] V. Priven and R. Sacks, "Impacts of the Social Subcontract and Last Planner System Interventions on the Trade-Crew Workflows of Multistory Residential Construction Projects," (in English), *Journal of Construction Engineering and Management,* Article vol. 142, no. 7, 2016, Art. no. 4016013.

[35] M. Arashpour, R. Wakefield, N. Blismas, and B. Abbasi, "Quantitative analysis of rate-driven and due date-driven construction: Production efficiency, supervision, and controllability in residential projects," (in English), *Journal of*

Construction Engineering and Management, vol. 142, no. 1, p. 04015006, 2016, Art. no. 05015012.

[36] M. Arashpour, R. Wakefield, N. Blismas, and E. W. M. Lee, "Analysis of disruptions caused by construction field rework on productivity in residential projects," *Journal of Construction Engineering and Management*, vol. 140, no. 2, p. 04013053, 2014.

[37] P. E. D. Love, D. J. Edwards, Z. Irani, and N. Forcada, "The latent causes of rework in floating production storage and offloading projects," (in English), *Journal of Civil Engineering and Management*, vol. 20, no. 3, pp. 315-329, 2014.

[38] P. E. Love, D. J. Edwards, and J. Smith, "Rework Causation: Emergent Theoretical Insights and Implications for Research," *Journal of Construction Engineering and Management*, p. 04016010, 2016.

[39] M. Taggart, L. Koskela, and J. Rooke, "The role of the supply chain in the elimination and reduction of construction rework and defects: an action research approach," *Construction Management and Economics*, vol. 32, pp. 829-842, 2014.

[40] B.-G. Hwang and S. Yang, "Rework and schedule performance: A profile of incidence, impact, causes and solutions," *Engineering, Construction and Architectural Management*, vol. 21, no. 2, pp. 190-205, // 2014.

[41] L. Ben-Alon and R. Sacks, "Simulating the behavior of trade crews in construction using agents and building information modeling," (in English), *Automation in Construction*, Article vol. 74, pp. 12-27, 2017.

[42] M. Arashpour and M. Arashpour, "Analysis of Workflow Variability and Its Impacts on Productivity and Performance in Construction of Multistory Buildings," *Journal of Management in Engineering*, vol. 31, no. 6, p. 04015006, 2015.

[43] L. Ma and R. Sacks, "Agent-based simulation of construction workflows using a relational data model," in *24th Annual Conference of the International Group for Lean Construction, IGLC 2016*, 2016, pp. 73-82: National Pingtung University of Science and Technology.

[44] V. Priven, R. Sacks, O. Seppänen, and J. Savosnick, "A lean workflow index for construction projects," in *22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014*, 2014, pp. 715-726: The International Group for Lean Construction.

[45] N. Williams, J. Burry, D. Davis, B. Peters, A. Pena De Leon, and M. Burry, "FabPod: Designing with temporal flexibility & relationships to mass-customisation," (in English), *Automation in Construction*, Article vol. 51, no. C, pp. 124-131, 2015.

[46] N. P. Garcia-Lopez and M. Fischer, "A Construction Workflow Model for Analyzing the Impact of In-Project Variability," in *Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan, CRC 2016*, 2016, pp. 1998-2007: American Society of Civil Engineers (ASCE).

[47] F. R. Hamzeh, E. Zankoul, and C. Rouhana, "How can 'tasks made ready' during lookahead planning impact reliable workflow and project duration?," *Construction Management and Economics*, pp. 1-16, 2015.

[48] M. Arashpour, R. Wakefield, B. Abbasi, E. W. M. Lee, and J. Minas, "Off-site construction optimization: Sequencing multiple job classes with time constraints," *Automation in Construction*, vol. 71, pp. 262-270, 2016.

[49] Y. H. Chen and T. K. Yang, "Lapping pattern, stock length, and shop drawing of beam reinforcements of an RC building," (in English), *Journal of Computing in Civil Engineering*, Article vol. 29, no. 1, 2015, Art. no. 04014028.

[50] T. Nath, M. Attarzadeh, R. L. Tiong, C. Chidambaram, and Z. Yu, "Productivity improvement of precast shop drawings generation through BIM-based process re-engineering," *Automation in Construction*, vol. 54, pp. 54-68, 2015.

[51] J. Duntemann, "Design specifications for bridge temporary works in the United States," in *19th IABSE Congress Stockholm 2016: Challenges in Design and Construction of an Innovative and Sustainable Built Environment*, 2016, pp. 2804-2810: International Association for Bridge and Structural Engineering (IABSE).

[52] R. Jongeling, J. Kim, M. Fischer, C. Mourgues, and T. Olofsson, "Quantitative analysis of workflow, temporary structure usage, and productivity using 4D models," (in English), *Automation in Construction*, Article vol. 17, no. 6, pp. 780-791, 2008.

[53] M. Arashpour, B. Abbasi, M. Arashpour, M. Reza Hosseini, and R. Yang, "Integrated management of on-site, coordination and off-site uncertainty: Theorizing risk analysis within a hybrid project setting," *International Journal*

of Project Management, vol. 35, no. 4, pp. 647-655, 2017.

[54] M. Arashpour, R. Wakefield, E. W. M. Lee, R. Chan, and M. R. Hosseini, "Analysis of interacting uncertainties in on-site and off-site activities: Implications for hybrid construction," *International Journal of Project Management,* vol. 34, no. 7, pp. 1393-1402, 2016.

[55] J. C. Rubio-Romero, M. C. Rubio, and C. García-Hernández, "Analysis of construction equipment safety in temporary work at height," (in English), *Journal of Construction Engineering and Management,* Article vol. 139, no. 1, pp. 9-14, 2013.

[56] Y. Shin, H. Cho, and K. I. Kang, "Simulation model incorporating genetic algorithms for optimal temporary hoist planning in high-rise building construction," (in English), *Automation in Construction,* vol. 20, no. 5, pp. 550-558, 2011.

[57] X. Yuan, C. J. Anumba, and M. K. Parfitt, "Cyber-physical systems for temporary structure monitoring," *Automation in Construction,* vol. 66, pp. 1-14, 6// 2016.

[58] M. Arashpour and R. Wakefield, "Developing an uncertainty analysis model for off-site building production," in *Y.X. Zhang (ed.) Proceedings of 8th International Structural Engineering and Construction Conference, ISEC 2015*, 2015, pp. 1121-1125, DOI: 10.14455/ISEC.res.2015.7: ISEC Press.

[59] M. Arashpour, A. Sagoo, D. Wingrove, T. Maqsood, and R. Wakefield, "Single capstone or multiple cornerstones? Distributed model of capstone subjects in construction education," in *Y.X. Zhang (ed.) Proceedings of 8th International Structural Engineering and Construction Conference, ISEC 2015*, 2015, pp. 971-976, DOI: 10.14455/ISEC.res.2015.27: ISEC Press.

[60] D. H. T. Walker, P. R. Davis, and A. Stevenson, "Coping with uncertainty and ambiguity through team collaboration in infrastructure projects," *International Journal of Project Management*, vol. 35, no. 2, pp. 180-190, 2// 2017.

[61] M. Mullens, "Production flow and shop floor control: Structuring the modular factory for custom homebuilding," in *Iris Tommelein (ed.) Proceedings of the NSF Housing Research Agenda Workshop; ISBN: 9780784407547* 2004, vol. 2, pp. 12-14.

[62] R. Sacks, O. Seppänen, V. Priven, and J. Savosnick, "Construction flow index: a metric of production flow quality in construction," *Construction Management and Economics,* vol. 35, no. 1-2, pp. 45-63, 2017/02/01 2017.