CITC GLOBAL
Construction in the 21st Century
11th International Conference (CITC-11)
September 9-11, 2019, London, UK
Springer
SPRINGER NATURE

Enhancing Innovativeness in the Construction Sector: A System Dynamics Analysis

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Abstract. The construction industry has often been criticised for its lack of innovation and commitment to R&D. Using a systems approach, this study examined a number of construction innovation system scenarios and policy interventions within the context of four future plausible Russian construction industry transition scenarios. A system dynamics (SD) model was developed to incorporate the main actors of the construction innovation process, namely, industry, government and academia. The SD model provided insight into the complexity and inherent dynamics of innovation processes caused by multiple feedback loops, nonlinearity, and time delays in decision-making. The SD model also addressed the challenges of transforming Russia's construction industry into a highly developed sector by providing an understanding of how government policies and supportive programs could encourage industrialists to innovate, promote research and transfer technology. The transition scenarios were developed by considering the variation of two factors driving innovation in the construction sector, namely: (1) the conditions and level of government financial support; and (2) demand for innovation related to market expectations, largely dictated by traditional versus progressive procurement processes. One key finding was that the Russian construction industry preferences imitation-oriented innovation development.

Keywords: Construction Innovation, System Dnamics Modelling, Transition Scenarios.

1 Introduction

It is generally accepted that the construction industry worldwide does not have a coherent model of innovation development and shows a conservative attitude towards mass inclusion of cutting-edge technology into construction processes [1-4]. Nevertheless, a high level of innovation performance is extremely important for the industry's growth and the development a country economy. According to Seaden and Manseau [5], the innovation process is complex involving governmental and other institutional actors that interact by jointly and individually contributing to the development and diffusion of innovations. From this perspective, the innovation performance of the industry depends not only on how individual firms perform in isolation, but on how they interact with other actors. Hence, the current study is founded on the innovation system approach [6-9] which stresses that understanding the relationships among the actors involved in the innovation process is the key to improvement of innovation performance of an industry. Moreover, a systems modelling approach is applied for capturing dynamics within the construction innovation system. A robustly developed system dynamics (SD) model assists in understanding how government policies and supportive programs can encourage industrialists to innovate, promote research and transfer technology, which will ultimately improve industry productivity and competitiveness.

The overarching goal of this paper is to understand the mechanisms of innovation development in the context of four plausible scenarios of the Russian Federation construction industry. The built SD model integrates the concept of a construction innovation system with the notion of macro industry transition pathways [10-13]. The transition scenarios were developed considering the variation of key driving factors: (1) the conditions and level of government financial support; and (2) demand for innovation related to market expectations largely dictated by procurement processes.

2 Background

The Russian construction sector has been facing various challenges which hinder innovation processes. The industry's unwillingness to implement innovative technological advancements is primarily caused by a lack of innovative capabilities as a precondition for application of new building materials, structures, design methods and construction methods [14]. In the majority of cases, there are inadequate financial resources for contractors to support their innovative activities. In addition to weak investment activity, there are excessive administrative barriers, inappropriate technical regulation, and variance of construction norms and codes to international standards. Another top challenge in innovation integration is procurement methods based on price competition that lead to declining productivity and quality of construction works. It makes innovative companies hard to compete due to innovative solutions expansiveness at the initiation stage. Moreover, the 'cost over quality' purchasing practise may be a reason for the growth of corruption in the sector. The problem of significant underinvestment in R&D also holds true for the Russian construction innovation system. The conducted study [14] indicates weak interest in R&D on the side of the industry. Despite the promising scientific and research potential of research institutions and universities, the transfer of innovative laboratory ideas to the practical environment is only possible with the industry readiness to implement the results of R&D. Sufficient government incentive mechanisms would invoke firms to make long-term innovation investments and move away from only short-term profit considerations.

As mentioned above, the developed SD model integrates the concept of a construction innovation system with the notion of transition scenarios, i.e. a set of plausible 'futures' that ultimately incorporate different policies along with the industry views in a simplified way. The following scenarios emerge by crossing two influential and uncertain driving forces to illustrate represent four futures:

- 'Business as usual' (BAU) scenario. In this scenario, industry development and growth occur at a rate similar to today's. Namely, incremental performance improvements and innovation processes are hindered by tight financial situation, limited incentive schemes, outdated legislation, excessive administrative barriers and inappropriate technical regulation; financing for necessary R&D is restricted and scientific and human potential is scarce. The culture of 'lowest bid' takes place that forces contractors to focus on initial cost, but not on the life-cycle costs and the value of design, on order to win a tender [14].
- 'Market forces' (MF) scenario. In this scenario, innovativeness is mostly market-led and competition-driven under tight financial conditions. As a main client, government can significantly motivate decision-makers at construction firms to consider higher investment in innovation with driving demand for path-breaking processes and products (e.g. through procurement and tender policies). By following the multi-criteria tender evaluation procedure, construction companies are required to meet a range of criteria, such as overall projects' whole-life value, safety, and quality, to name a few. However, financing for incentive schemes and science is restricted.
- 'Conservative development' (CD) scenario. Government is in control of the industry development in this scenario. The high rate of public investments, emphasis on incentive mechanisms and improvement of regulations, standards and legislation stimulate innovation diffusion. Nevertheless, the industry is still cost-competitive. Only well-established leading organisations can support R&D. Thus, despite government's efforts to enhance innovativeness through additional investments, firms prefer to stay conservative and choose an imitative strategy which is far less costly and labour intensive.
- 'Innovation power' (IP) scenario. In this scenario the government drives and supports change by enforcing sustainable regulations and heavily investing in innovative infrastructure. At the same time, alternative procurement and tendering processes that aim to promote performance-based integrated delivery, induce companies to generate radical changes in creating know-how ideas; to invest a lot in R&D; to develop a variety of solutions in order to keep up with high demand for innovative products and processes. Overall, a strong will of both government and industry is necessary to ensure a successful transition.

3 Research Methodology

This research employed an integrated participatory systems modelling (IPSM) approach that is detailed in Suprun et al. [15]. This paper focuses on the scenario analysis derived from a comprehensively developed SD model that captures the complexity of the interactions between government, academia and industry within the construction innovation system. In general, SD modelling is a methodology that represents a set of conceptual and numerical methods that are used to examine and analyse the structure of a complex system and behavioural relationships between certain variables over time [16].

Active stakeholder engagement facilitated the formulation of the SD model. The study participants included researchers and academics specialising in construction management; civil and structural engineers; designers, project managers and directors of construction companies; and public servants with roles related to the construction industry and innovation development. Stakeholder consultations also resulted in the formulation of four future industry transition scenarios for this study, with each one attempting to encapsulate its relevant innovation conditions (e.g. government policy and incentives) and causal outcomes (e.g. innovation and R&D intensity). The simulation outcomes explore the system's behaviour in the context of different plausible futures on the horizon in 2045 to shed light on the transformation of the Russian construction sector based on different sets of assumptions.

Considering the specifics of this research, lack of empirical data, highly qualitative nature of the modelled system, and participatory nature of the implemented modelling approach, the following steps were implemented to evaluate the model: (1) engaging stakeholders throughout the modelling process via stakeholder workshops and expert consultations in order to achieve an agreed final model; (2) examining model parameters to check whether they had real world equivalents, and if not whether they were acceptable and acknowledged in theory; (3) performing sensitivity analysis to calibrate key input parameters and determine the importance of certain assumptions in order to generate a range of possible outcomes; (4) testing if the model confirmed the system boundary and the model behaviour was consistent with the real world; and (5) testing if the model behaved realistically under extreme conditions.

4 Results And Discussion

4.1 System Dynamics Model

The model is focused on the investigation of technological innovations (e.g. energy-efficient, soundproofing materials, BIM, off-site fabrication). According to the study previously conducted by the authors [14], the proportion of construction companies implementing technological innovations is less than 3% of the total market size compared to other sectors of Russia's economy such as energy (22%) and biomedical (29%) industries. The duration of the analysis is from 2015 to 2045. In 2015 the Russian government set national targets to facilitate innovative development of the industry by designing an "Innovative development strategy for the construction industry in Russia for the period up to 2030" [17]. Undoubtedly, a number of systematically targeted strategies and rational policies are required in order to achieve the set of government goals and shape successful transition of the construction sector in the innovative future. Hence, it was chosen to set the model time bound at 30 years to explicitly capture the long-term impact of various government policies on construction innovation performance.

The model distinguishes between two types of innovative companies: imitators and innovators [2, 18]. Imitators represent construction firms that introduce and implement technological innovations by adopting ideas from others and slightly improving construction materials, techniques, technologically advanced production methods, products and services. Such firms mainly implement innovations known as incremental. Innovators represent companies that implement technological innovations as a result of collaborative R&D. Such companies are constantly involved in R&D and implement newly introduced construction materials, techniques, goods, and services. Considered as radical, these innovations are new or significantly different from those inherent in earlier products in the case of: field of application, performance characteristics, features, and design performance. The SD model (Fig. 1) was developed in Vensim software [19]. Blue arrows labelled '+' point out causal influences that cause changes to an influenced variable in the same direction, whilst red '-' labels dictate changes in the opposite direction. The double lines across the arrows are a delay symbol which indicates that an effect would take longer to appear. It is noted that the representation of the stock and flow diagram is simplified in this paper, and only main variables and parameters are presented.

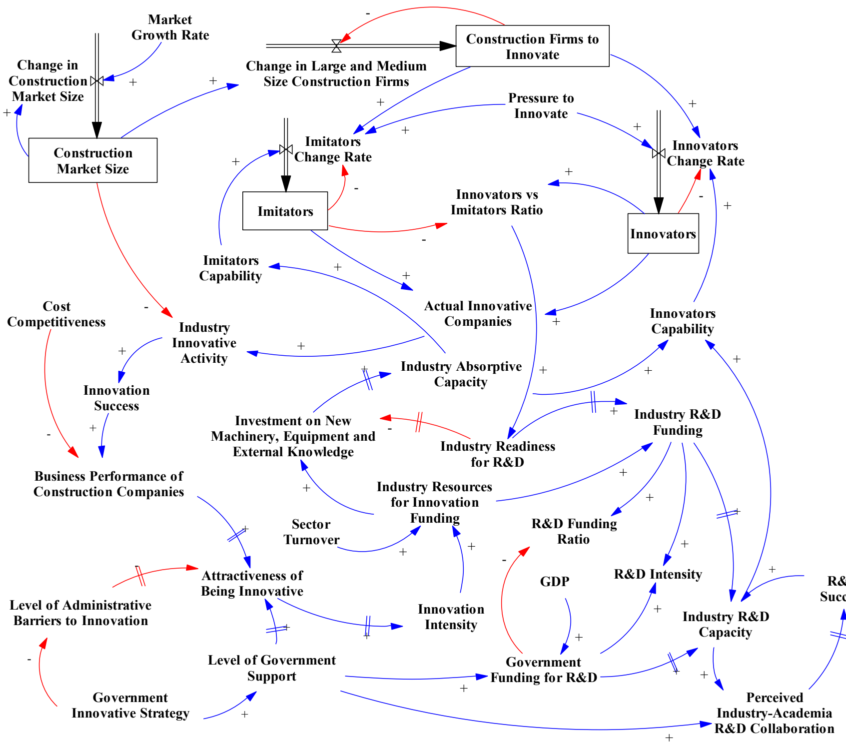

Fig. 1. Overview of the stock and flow diagram.

4.2 Scenario Analysis

Four scenarios were considered for the simulations to reveal insights about the construction innovation performance along with future transition pathways. The base case scenario represents business as usual (BAU) conditions, i.e. the continuation of current trends in the Russian construction sector. The base run was calibrated through sensitivity analyses and qualitative analysis in collaboration with stakeholders to reach relevant numbers and generate behaviours consistent with reality. Outcomes arising from simulations of the other three alternative scenarios are compared to the baseline scenario in which no policy interventions applied. We estimated the implications of the aforementioned scenarios and policy assumptions for a 30-year time period, from 2015 to 2045. The impacts in changes of key parameters on the dynamic behaviour of the outcome variables, were studied in every simulation run.

Fig. 2 illustrates the future growth trend for a number of innovative firms accompanied by the distribution between innovators and imitators across four scenarios until 2045. Fractions indicate ratio between innovators and imitators, measured as a proportion of innovators in the total amount of innovative construction companies which include both innovators and imitators. Fig. 3 shows the level of industry innovative activity as a proportion of companies that implement technological innovations.

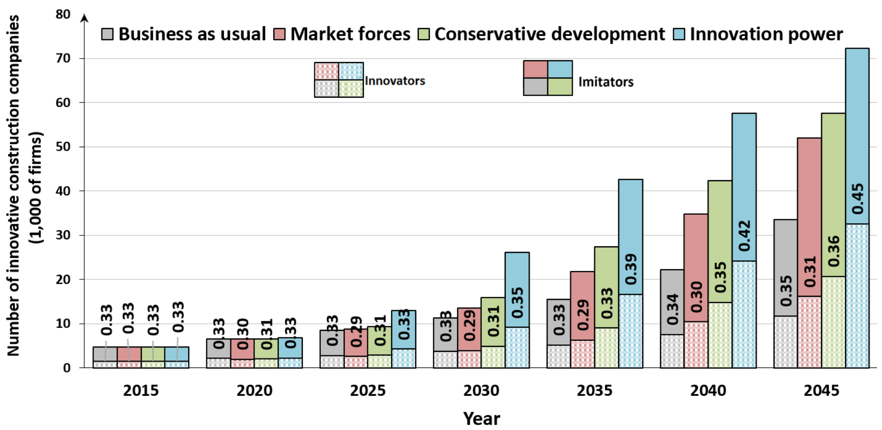

Fig. 2. Scenario results for cumulative innovative construction companies.

The industry grows steadily but very slowly under the BAU scenario, with no visible improvement in its innovative performance over time. In contrast, the innovative activity shows faster dynamics under MF and CD scenarios. Yet, this happens after almost a decade of the simulation horizon. It explains the necessity to accumulate enough capabilities to not only be involved in innovative projects successfully but also to encourage industrialists to consider investments in innovations in the long-run. Finally, under the IP scenario the sector grows rapidly up until 2040 and then slows down by reaching its steady state level of 12.5% by 2045, which is twice as high as in the BAU simulation (5.8%). It corroborates the main assumption of the scenario, i.e. priority in promoting R&D, investing more in cutting-edge ideas and eventually transforming the sector into a high-tech sector that is capable of supporting science and research. Even though the fraction of innovators almost equals the fraction of imitators in this scenario (0.45 and 0.55, respectively), it is apparent from the figures, in the simulated state of the construction sector in 2045, the industry will remain imitation-oriented under any circumstance. Moreover, under a market-driven scenario, companies give priority to maintaining the competitive advantage by trying to improve their absorptive capacity, i.e. investing primarily in new equipment and providing training to their personnel, but not collaborating with universities and research centres to develop new solutions. Thus, only 31% (approximately 16,000 firms) of innovative companies are innovators, which is even lower than those in the reference case. In other words, the mechanism of learning-by-using supersedes learning-by-searching, i.e. innovations are well diffused within the industry but developed to a very limited extent. It is consistent with the fact that the Russian economy is unprepared for the market-led regime to be able to compete worldwide [20, 21]. Therefore, this finding can be interpreted as the necessity to consider significant government support of the industry and academia in order to improve domestic R&D and science, in addition to policies targeting the growth of the construction industry itself. However, as can be seen in Fig. 2 and 3, providing financial incentives to boost innovative processes under the CD scenario is still not going to lead to the same results as when successful incentive schemes are accompanied by quality competitiveness driving the market.

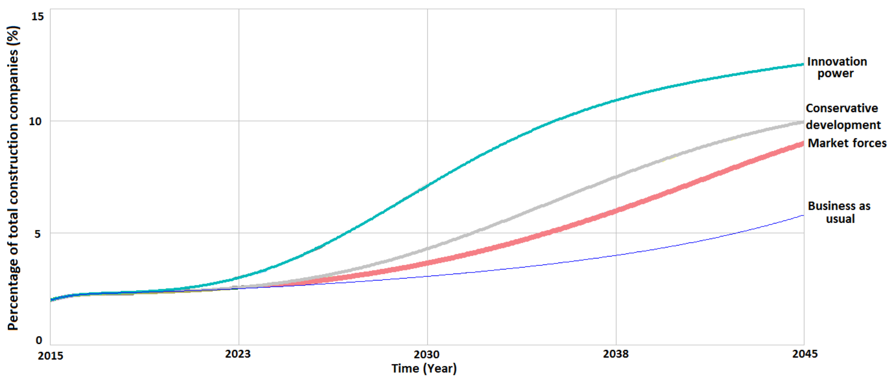

Fig. 3. Scenario results for percentage of companies that implement technological innovations

5 Conclusions

Effective strategies are required to overcome the challenges of transforming Russia's construction industry into one which is progressive and innovative. Nevertheless, innovation is only likely to occur if there is sufficient support for increased collaboration within the innovation system and research into new materials and technologies. In this paper, an SD model was developed as part of the IPSM approach to provide understanding on how construction innovation would evolve in the context of four plausible transition pathway scenarios of the Russian construction industry. Specifically, the research sought to explicitly capture the impact of various government policies, provide deeper understanding of how construction companies would behave in the context of different plausible 'futures', and enable decision makers to design rational policies to improve the chances of better futures actually occurring.

Various stakeholders with diverse backgrounds were involved in the SD model development, calibration and testing processes. The complex multi-actor nature of the system under investigation justified the IPSM approach for modelling the innovation processes and studying dynamic behaviour of the key parameters under different scenarios. The scenario analysis was performed with the notion of transition pathways to evaluate the possible futures of the Russian construction industry with regard to innovation development and diffusion. One key finding was that the Russian construction industry preferences imitation-oriented innovation development. The innovation power transition pathway does produce more truly innovative companies than the other scenarios, but even in this scenario it takes time to develop a sufficient proportion of them. Overall, simulation results under alternative scenario settings revealed that industry transformation requires sustained and coordinated innovation diffusion strategies that engages all innovation stakeholders. The versatility of the SD model allows for refinements to be made and new modules to be included in order to investigate the aforementioned research topics.

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