A systemic approach to conceptualising a model of construction innovation system in Russia

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Abstract. This is an ongoing research employing an integrated method to identify variables forming a construction innovation system in Russia and to create an initial conceptual causal loop diagram supported by stakeholder-based techniques and structural analysis. Quantification of an innovation system generally and sectoral-specific such as construction is quite complicated. Systems are very complex and dynamic embracing a range of components such as information, performance, policies and strategies, resources and time. To overcome this challenge and conceptualise the system, systemic and participatory techniques have been utilised into a cohesive integrated approach. It included academic and industry consultation, stakeholder engagement (participatory interviews) and structural analysis (MICMAC). During the study, key variables were identified, influence/dependence map and graph (causal relationship) were created and finally a conceptual model was built as a causal loop diagram in order to understand and model the factors involved in the feedbacks, causes and impacts within the construction industry's innovation performance.

Keywords: construction innovation system in Russian Federation, model conceptualisation with stakeholders, participatory modelling, structural analysis, system dynamics.

1. Introduction

Construction industry has always been one of the most significant economic driving forces. Nevertheless, it has also been identified as an excessively conservative sector in relation to innovation implementation and diffusion. Hence, it is clear that the level of innovative activity within construction sector needs to be improved. A few studies have addressed innovation diffusion in the industry (Manley, 2008; Panuwatwanich *et al.*, 2009a, Panuwatwanich *et al.*, 2009b) mainly focusing at the project and firm level. However, little attention has been drawn to a complex approach exploring construction innovation performance at the industry and national level, in other words, studying construction innovation along the sectoral innovation system (Andersson and Widén, 2005).

"The laggard industry" is considered to be one of the most common characteristics of the global construction industry. According to the previously conducted exploratory study (Suprun and Stewart, 2015), in the case of the Russian Federation this problem is even more significant as it is a unique country, spread across a massive territory with an extraordinary variety of natural conditions unlike any other developed countries. For the last 25 years, it has been and continues to be a country that struggles to transform into an efficient market economy based on knowledge and innovation. Despite continuous efforts of the government to support innovative activity, the Russian construction sector still has been facing a lot of factors which hinder an increase of the current rate of innovation.

Following the background of the mentioned study (Suprun and Stewart, 2015) exploring the present situation in the Russian construction industry and the barriers, enablers and strategies that affect construction innovation diffusion most significantly, this research focuses on conceptualisation of a model encompassing a range of causal relations and feedbacks affecting construction innovation along the innovation system. Both studies are parts of an ongoing research study concerned with designing a simulation model of innovation system in the Russian construction industry using System Dynamics to create a range of scenarios and understand policies impact.

In this study the chosen research method combined a range of participatory and system-based approaches such as expert consultation, stakeholder participation and structural analysis of key variables built on expert knowledge. Some similar approaches has been used in projects dedicated to complex natural resources questions (Voinov and Gaddis, 2008), solid waste management (Torres and Olaya, 2010), climate change adaptation (Richards *et al.*, 2016) and water management (Sahin *et al.*, 2015; Sahin *et al.*, 2016). However, it has not been used before in the context of construction innovation system in general and with the focus on Russia in particular. The research team has chosen the systematic approach because the continuously developing innovation system of the construction industry is a complex system of innovation activities highly influences the development of construction. It involves innovative milieu, different policies, interactions and a range of participating system actors such as a government, organisations, universities and research institutes (Figure 1).

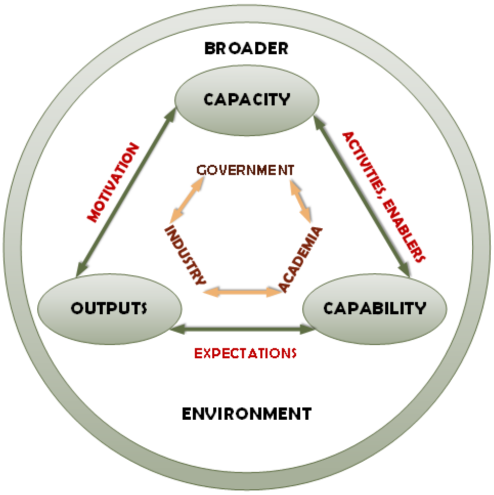

Figure 1. Theoretical model of innovation system in the construction industry

Capacity represents input resources such as human, financial, information and communication, scientific and technology resources. Activities and enablers involve interrelated actors' actions that shape innovation-related flows (e.g. financial and funding, human, knowledge, regulations, information and technology flows). Capability is an ability to transform input resources into outputs (e.g. quality of construction projects, final product cost, client's satisfaction and profit maximization) through the flows mentioned above.

Following the research approach section the results part is presented including the identification of the problem, relevant variables and stakeholders as well as construction of an initial causal loop diagram, which provides a basis for conceptualising the construction innovation system. Finally, the paper concludes with future research activities required to dynamic modelling.

2. Approach

As mentioned above, construction innovation system is a very complex and dynamic area that is closely connected to the national social structure. Hence, the impact of construction development is highly influenced by a complex system of innovation activities, interactions and a range of actors participating the system. The purpose of the research is to develop a systems model that can be particularly useful to facilitate the understanding of important complex cause and effect relationships along with feedback mechanisms that characterise interaction and interdependencies of resources and activities flows; and affect the dynamic behaviour of the construction innovation system, due to the actors working together (Figure 2).

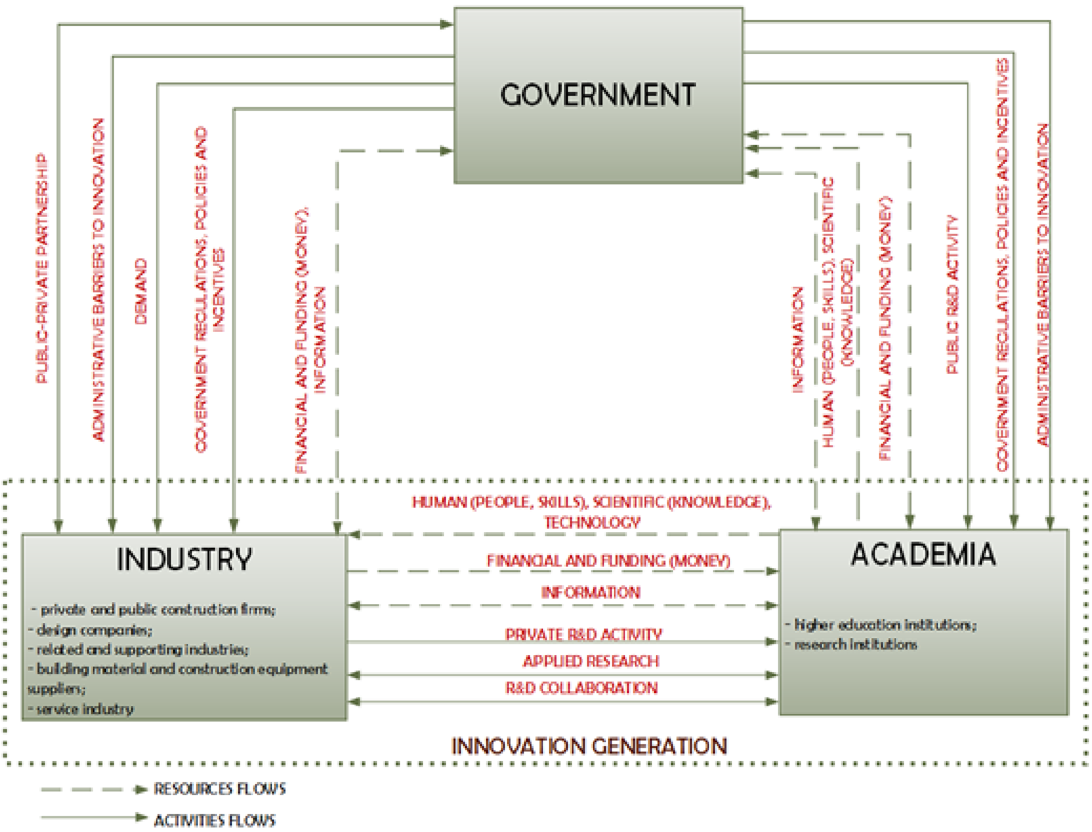

Figure 2. Theoretical framework for actors' relationships within the construction industry innovation system

Building a system dynamics model is a very iterative step-by-step process that involves multiple cycles (Sterman, 2000). The phases incorporated in the modelling process of the whole research project are presented at Figure 3.

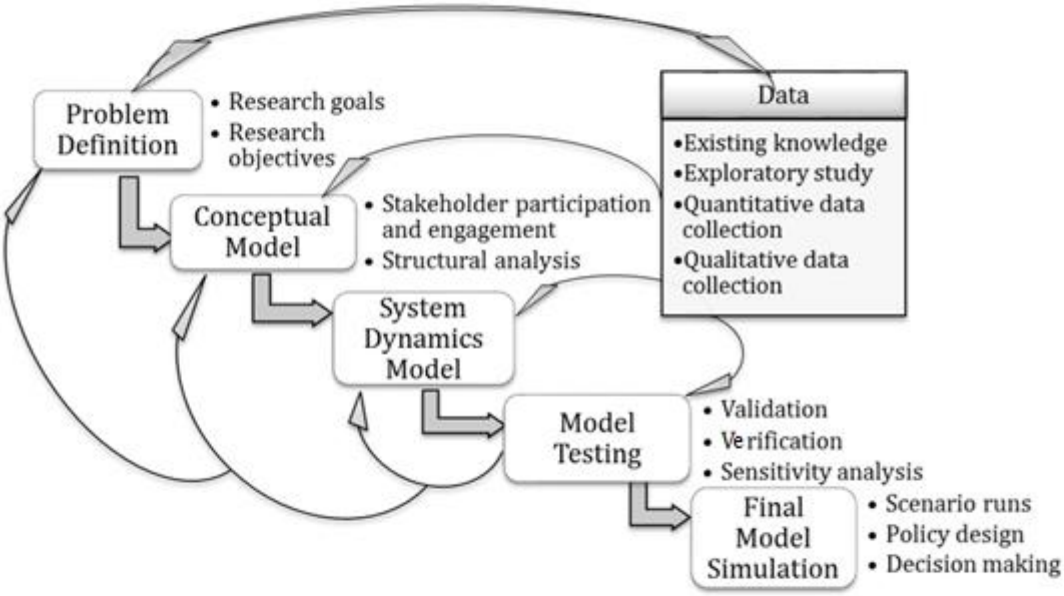

Figure 3. Systems approach step-by-step modelling process (Adapted from Sterman, 2000)

Obviously, it is not enough for researchers to build and run the computer models of complex systems using only desktop studies in order to support issues concerning innovation problems. Stakeholder incorporation is needed to support decisions involving complex questions and to improve the value of a built model. Participatory modelling often includes public representatives and decision makers into an analytic modelling process (Voinov and Gaddis, 2008; Sahin *et al.*, 2015; Richards *et al.*, 2016). Consequently, the present study dedicated to the conceptual model construction flowed through the following multi stage process:

- *Problem scoping and variables identification*
  Includes understanding of the existing knowledge in the field based on literature review, exploratory study previously conducted by the authors and expert consultation. The next fundamental step is selection of factors which affect the problem and therefore the system in general. Identification of interrelationships between them and description of aspects that clearly addresses the system understanding are necessary for the structural analysis and further building of a conceptual model (Cole *et al.*, 2007).
- *Stakeholder identification and engagement*
  Stakeholder engagement through facilitated interviews where interactions between variables were established. Steps were then undertaken to: (i) identify relevant stakeholders (e.g. representatives from construction and related industries, the public sector, universities and the research community), (ii) contact nominated stakeholders and invite them to interviews; and (iii) conduct opinion survey on construction innovation system and discuss the key issues related to innovation in the industry.

- *Structural Analysis with MICMAC*
  According to Godet (2006), there is a relationship between the structural analysis and dynamics of systems. Structural analysis is a research method supported by people (stakeholders) with proven experience in a certain area who participate in a multi-phase process allowing participants to describe the system and to think about certain aspects of the system behaviour (Godet, 2006). In our research, the structural analysis was enriched using the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) approach to identify key variables and the elements' interrelations web. Generally, the structural analysis approach includes: (i) identification and description of main variables; (ii) expert opinion about the relationships between variables within a structural matrix; (iii) classification of variables adopting the MICMAC method; and (iv) design of the Matrix of Direct Influences (MDI) and its corresponding influence maps, that provide all the information needed to for the analytical integration of culpable system parts and to build the causal chain of the system.
- *Generation of a proposed conceptual model using a causal loop diagram (CLD)*
  From the MICMAC analysis outcomes of the cross-impact matrix creating and its graphic representation, it is possible to evaluate the results and obtain the key variables of the system. The interrelations between variables are crucial in the system interpretation as they define the system's dynamics. A CLD is a tool for mapping a set of relationships forming the complex system. It provides a more visual understanding of the existing systematic relationships between the system's components.

3. Results

3.1. Problem Scoping and Variables Identification

The construction industry is closely connected to the national social structure and therefore, is highly influenced by governmental and other institutional actors (Figure 2). In order to improve the level of innovative activity within construction sector, it is fundamental to identify how the interrelations among these key actors and variables of the innovation system can be combined into a complex dynamic model to create scenarios and understand policies impact.

The variables need to be evaluated in order to develop a conceptual model and better understand the behaviour of different factors that make up the system.

Table 1. List of variables identified through literature review, exploratory study and expert consultation

N°	Variables	Description	Source
1.	Level of innovation	High innovation level is one the main characteristics of every industry development	Gann and Salter (2000), Andersson and Widén (2005), Uriona *et al.* (2012)
2.	Quality of construction projects	Productivity and quality of construction projects (final product or service)	Gann and Salter (2000), Goodrum *et al.* (2011), Xue *et al.* (2014)
3.	Final product cost	Final cost of a construction product or service	Na *et al.* (2006), Uriona *et al.* (2012), Xue *et al.* (2014)
4.	Client's satisfaction	Client's satisfaction with final product or	Na *et al.* (2006)

N°	Variables	Description	Source
		service quality	
5.	Profit maximization	Profit maximization is a key motivation for contractors in innovation implementation process	Na *et al.* (2006), Uriona *et al.* (2012), Suprun and Stewart (2015)
6.	Level of public R&D activity	Public policies promoting science and R&D, investments in higher education, techno-parks etc.	Na *et al.* (2006), Uriona *et al.* (2012), Hampson *et al.* (2014), Xue *et al.* (2014)
7.	Level of private R&D activity	Private sector innovative activities for industry development	Na *et al.* (2006), Uriona *et al.* (2012), Hampson *et al.* (2014), Xue *et al.* (2014)
8.	R&D expenditure (public)	Funds a government spends at universities and research institutes on STI	Seaden and Manseau (2001), Na *et al.* (2006), Uriona *et al.* (2012), Hampson *et al.* (2014)
9.	R&D expenditure (industry)	Firms investments on R&D	Seaden and Manseau (2001), Na *et al.* (2006), Uriona *et al.* (2012), Hampson *et al.* (2014)
10.	Client's demand	As clients, government and local authorities as well as private clients may significantly affect the use of new materials, technologies and methods	Na *et al.* (2006), Gumba (2009), Xue *et al.* (2014), Suprun and Stewart (2015)
11.	Level of applied research	Development of methods, products, systems, techniques etc. which improve the industry and innovation performance	Na *et al.* (2006), Hampson *et al.* (2014), Xue *et al.* (2014)
12.	Level of basic research	Research in construction area developing its theoretical foundations	Na *et al.* (2006), Hampson *et al.* (2014)
13.	Government regulations	Legislation, rules, building codes, certification procedure	Blayse and Manley (2004), de Valence (2011), Xue *et al.* (2014), Suprun and Stewart (2015)
14.	Government incentives	Public stimulating mechanisms for industry development (e.g. grants and awards for best practices and solutions)	Blayse and Manley (2004), Na *et al.* (2006), Gokhberg *et al.* (2010), Suprun and Stewart (2015)
15.	Level of government intervention	Public support and public policies (e.g. federal targeted programmes, direct financial investments, foundation of clusters)	Blayse and Manley (2004), Na *et al.* (2006), Gokhberg *et al.* (2010), Suprun and Stewart (2015)
16.	PPP	Cost sharing: Public-Private Partnership	Seaden and Manseau (2001), Li and Akintoye (2003), Leiringer (2006), Suprun and Stewart (2015)
17.	Level of tax incentives	Fiscal arrangements and tax privileges	Seaden and Manseau (2001), Blayse and Manley (2004), Suprun and Stewart (2015)
18.	UIG partnership	Partnerships between universities, research institutes, government and industry, mainly for supporting strategic innovative and pilot projects	Seaden and Manseau (2001), Andersson nd Widén (2005), Na *et al.* (2006)
19.	UI R&D collaboration	Collaborative R&D with greater industry participation for testing and evaluating research results and new solutions	Seaden and Manseau (2001), Dulaimi *et al.* (2002), Gumba (2009), Xue *et al.* (2014), Suprun and Stewart (2015)
20.	Level of technological cooperation	Technological cooperation with related and supporting industries. Integrated R&D efforts are required for effective implementation of technology-using strategies	Na *et al.* (2006), Xue *et al.* (2014), Suprun and Stewart (2015)
21.	New procurement approaches	PPPs and other concession projects, build and maintain (B&M) which transfer back to the government at the end of the contract and create the industry alliances that eventually influence the marketplace	Li and Akintoye (2003), Leiringer (2006), de Valence (2011), Suprun and Stewart (2015)

N°	Variables	Description	Source
22.	Life cycle cost practice	Assessment of construction project over its life-cycle from design stage, manufacturing, usage, maintenance and disposal	Seaden and Manseau (2001)
23.	Awareness and training	All the actors involved in the research and construction process need to have access to the best available information on technologies and tools in order to introduce and implement innovation	Stewart *et al.* (2004), Na *et al.* (2006), Grigoryev (2011), Suprun and Stewart (2015)
24.	Level of IPR protection	Intellectual property rights protection supporting efficient flows of knowledge	Na *et al.* (2006), Uriona *et al.* (2012), Suprun and Stewart (2015)
25.	Level of innovation commercialization	Knowledge produced through R&D transforming into products with commercial value	Seaden and Manseau (2001), Dulaimi *et al.* (2005), Uriona *et al.* (2012)
26.	Quality of higher education	Government should support the development of educational programmes aimed at specialists engaged in the design process, construction and manufacturing	Gokhberg *et al.* (2010), Suprun and Stewart (2015)
27.	Venture funding	Investment funds in start-ups and small- and medium-size enterprises	Added from interview‘s results
28.	Import substitution	Nowadays import substitution is Russia's response to imposed Western sanctions. It takes place in numerous areas including building materials manufacturing and construction sectors	Added from interview‘s results
29.	“Brain drain”	Russia’s lack of support and incentives for innovation increase the level of “brain drain”	Added from interview‘s results
30.	Level of administrative barriers to innovation	The variety of building codes and standards; low levels of government support for industry development; government contracts with inflexible fixed budgets and so forth	Added from interview‘s results

3.2. Stakeholder identification and engagement

As mentioned above, participation of stakeholders is crucial for analytic modelling process. Once the first set of 80 variables were identified through literature review and previously conducted study, an initial expert consultation involving academic and industry representatives was held. Participants were provided with contextual information regarding the research and the initial list of relevant variables to discuss. After agreement on the essential components, many variables were grouped together or removed from the list as redundant ones while 4 new factors were added (see the list of variables – Table 1). The next step was to provide the stakeholders with a simplified structural analysis matrix to complete. Unstructured and highly interactive interviews including opinion survey aimed to capture the information related to specific components of the construction innovation system by rating relation between different variables with respect to the criteria and the research goal.

Interviews were conducted with experts who have played a role in managing the innovation implementation and diffusion in construction and innovation policy field in Russia: researchers and academic staff, private and public construction companies’ employees and contractors, consultants (design engineers), manufacturers and public authorities’ representatives who were willing to share their experience and opinions. Details of stakeholder analysis are out of the scope of this paper.

3.3. Structural Analysis with MICMAC

The first step of the proposed systemic conceptualisation and model development involved a structural analysis of the system which came in the form of a group of interrelated elements (variables/factors). At this research stage a detailed understanding and quantification of the potential relationships was required using a matrix linking all the constitutive elements (Table 2).

Table 2. Example fragment of the structural analysis matrix completed by participants

	Quality of construction projects	Final product cost	Client's satisfaction	Profit maximization	Level of public R&D activity	Level of private R&D activity	Client's demand	Government regulations	Government incentives	Level of government intervention
Quality of construction projects	0	3	3	3	2	2	3	2	3	3
Final product cost	2	0	3	3	1	2	3	1	3	3
Client's satisfaction	3	2	0	2	1	2	3	1	2	2
Profit maximization	2	3	2	0	1	2	1	1	2	2
Level of public R&D activity	3	2	3	1	0	3	2	2	2	2
Level of private R&D activity	3	2	3	2	2	0	2	2	3	3
Client's demand	3	2	3	2	3	3	0	2	2	3
Government regulations	2	3	2	2	2	2	1	0	2	2
Government incentives	3	2	2	3	2	3	1	1	0	3
Level of government intervention	2	2	1	3	2	3	1	1	2	0

The opinion survey aiming to identify the role of different factors in relation to the innovation system in the Russian construction industry was held through interviews with the stakeholders. All experts represented three groups of actors interacting in the system: government, industry, and universities and research institutes. The participants answered the question "If variable *i* changed, what would be its direct impact on variable *j*?" The relationship evaluation included four intensities: no influence (0), weak influence (1), medium influence (2) and strong influence (3). Once the grading was done for all variables it was possible to observe the sum of each row that would show the influence level. Similarly, the sum of each column would indicate the dependency level. Eventually, the aggregated structural analysis matrix was created using the geometric mean. The matrix is not shown due to its size.

After the relationships between variables were described, according to exposed structural analysis, the MICMAC software (MICMAC, 2014) calculated the intensity of influence and dependency between variables. As a result, all the variables could be characterised by both direct and indirect influences and represented in the Direct (Figure 4) or Indirect influence/dependence map. The maps' axes are obtained from the row and column sum of the direct or indirect matrix and represent dependence and influence level. We could see that each variable among the factors of construction innovation system holds a unique position in the diagram in relation to all other system's elements. Depending on variable's location on the matrix, every factor was classified into Influential, Relay, Dependent and Autonomous variables, as described below:

- *Influential variables* represent input variables that exert some influence on other elements, but are not dependent from the others. Consequently, any change in one of these variables will reflect the other variables and the system as a whole. Hence, they must have a priority when considering strategic actions or scenarios.
- *Relay variables* are significantly important as they are both influence the system and are dependent from influential variables. Besides these variables have an unstable behaviour as they could change to be input or output variables.
- *Dependant variables* represent system's output variables that are the most sensitive in terms of other variables behaviour.
- *Autonomous variables* are neither influential nor dependent and do not significantly affect the system. Although they tend to be excluded from the further analysis, their location near the axes of influence and dependence can mean a certain effect and should be taken into account.

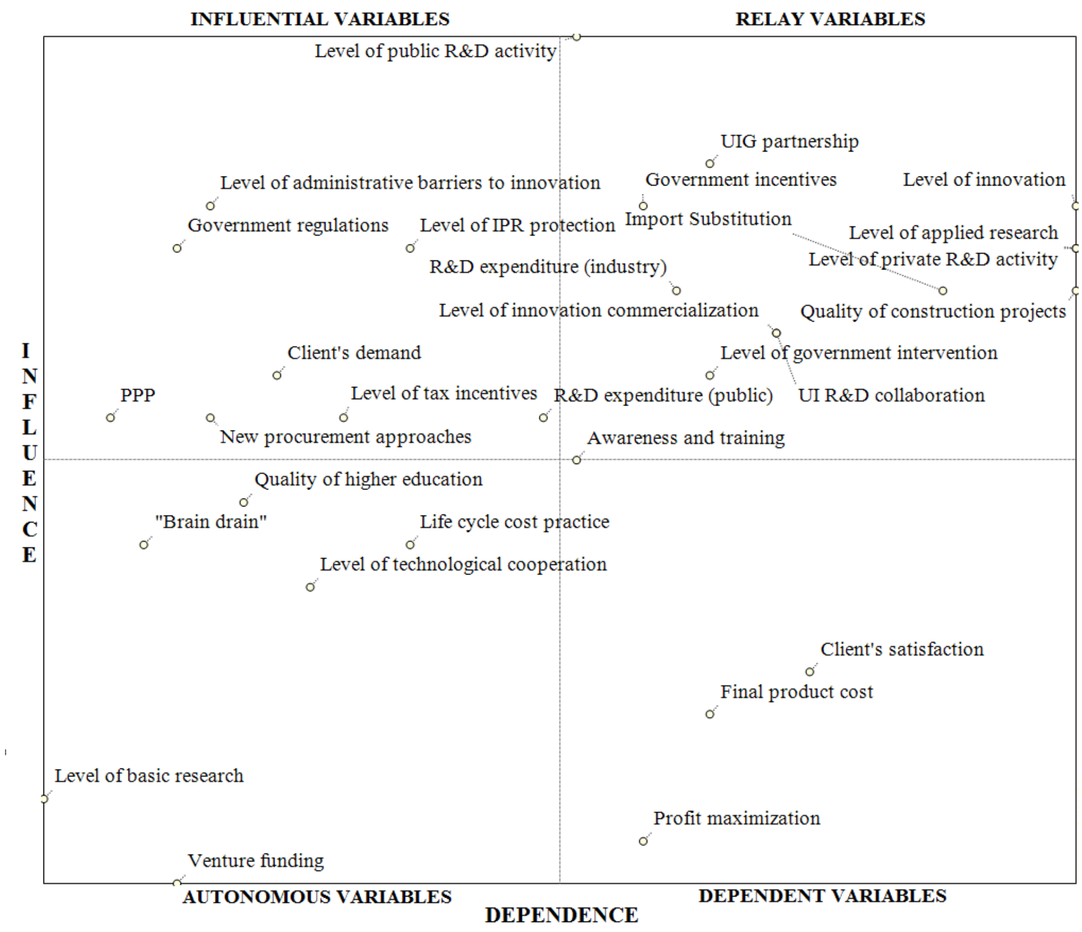

Figure 4. Direct influence and dependence map of the model variables

The next step was to identify the key variables on which greater attention should be placed. As they are those included in Influential, Relay and Dependent groups of variables, 24 out of 30 analysed variables were determined as key variables for the further model conceptualisation. However, the majority of the remaining Autonomous factors involved in the system should not be excluded. Only 2 variables (Venture funding and Level of basic research) were identified as less essential components of construction innovation system in Russia by all three groups of experts.

Elements alone cannot be inspected but only through the identification of interrelations between them. Therefore, the MICMAC software generates direct (Figure 5) and indirect influence graphs to provide an insight about the system as a whole. The graph assists a modeller in determining an initial reference for building of a conceptual CLD.

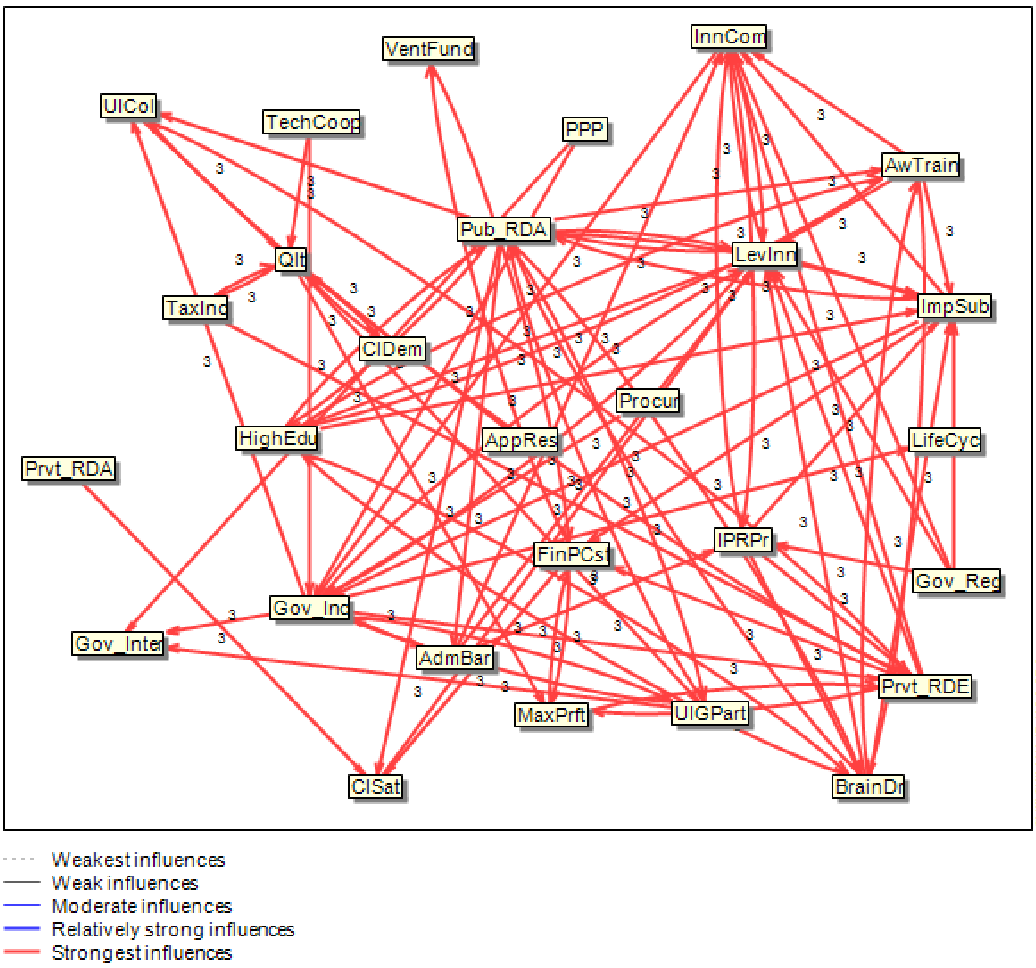

Figure 5. Direct influence graph representing 10% of interrelations between variables

3.4. Generation of a proposed conceptual model using a causal loop diagram (CLD)

Once the structural analysis outcomes were incorporated from the direct and indirect influence graphs as well as completed cross-impact matrix, the identification of causal feedback loops between variables became possible. Generally, it presents only the most significant interrelations which have been assessed at least as medium or strong in the MDI. However, low impacts are shown sometimes in cases of current importance, such as quality of higher education affects level of public R&D activity in case of our study. Furthermore, causal logic of influence may be likewise or contrariwise.

Analogically to MDI building a modeller develops a conceptual model by answering the question: "Which impact of variable *i* on variable *j* can be observed at present?" The next step is to identify the most important relationships that allow logical construction of the associated causal diagram. In this sense, the relationships between system variables can be displayed at the Direct and Indirect influence graphs created with the MICMAC software (see Figure 5).

The graphs include arrows of different types indicating the level of impact of the variables on each other and reflecting both direct and indirect influences. In case of modelling the arrows describe the transition to a casual and represent the dynamics of the system. It also should be taken into account that some variables do not have direct connection but can be related through other variables that lead to the same result. Additionally, a modeller can enhance other meaningful interrelations between dynamic variables taken into account the experts opinions during data collection, previous desktop study and knowledge of those who analyse the problem.

The process of model conceptualisation is always subjective. However, interactions of variables are supported by experts that provide a high degree reliability. Furthermore, the influence diagrams illustrate dynamic behaviour of the construction innovation system by linking the various elements and therefore work as a reference for building a CLD. As a result, the generated conceptual model (Figure 6) was built using a rigorous and comprehensive analysis of the different factors involved. As can be seen, the finalised causal loop diagram reveals the systemic relationships and provides a broad vision of interactive factors that are part of the complex construction innovation system.

In a CLD, the elements are linked together by arrows that indicate a causal relationship, either direct influence or change. A causal link between two variables implies direction of change between the cause and effect pairs. The polarity is '+' when two elements increase or decrease together and the polarity is '-' when one variable increases while the other decreases, and vice versa. In other words:

- If a causal link from one element (X) to another (Y) is positive, it is denoted by "+" (blue arrows in Figure 6), which means X adds to Y, or a change in X produces a change in Y in the same direction.

- If a causal link from one element X to another element Y is negative, it is denoted by "-" (red arrows in Figure 6), which X subtracts from Y or a change in X produces a change in Y in the opposite direction.

For instance, in Figure 6, the link between *Level of tax incentives* and *Final product cost* indicates change (or movement) in the same direction. In contrast, an opposite direction change occurs between *Level of administrative barriers to innovation* and the *Level of innovation commercialisation*; hence, while one increases, the other decreases. As can be seen, *Government incentives* as one of the most influential enablers identified by all three groups of stakeholders directly influences the system's goal *Level of innovation* and another enabler *UI R&D collaboration*, which has an influence on the state of *Level of applied research* influencing *Quality of construction projects* and ultimately *Client's satisfaction* and *Final product cost*. *Client's satisfaction* would also provide assistance to increases in *Level of innovation*, while *Final product cost* provides sufficient room to adjust prices level to improve the resulting maximise profitability for private sector and maximise cost effectiveness for public sector as shown (Figure 6).

As mentioned above, barriers related to government actions are the most significant impediments to innovation in the Russian construction industry. Consequently, these characteristics are the fundamental for effective innovation system building. *Level of public R&D activity*, *Level of applied research*, *Government regulations*, *Level of private R&D activity* and *UI R&D collaboration* are the most influential variables, which is in accordance with the outcomes of the exploratory study highlighting stakeholders focus on public strategies and collaboration metrics. In addition, *Import substitution* is a big issue in development of many industries including building materials manufacturing and construction sectors in Russia due to imposed Western sanctions.

The CLD explains interactions and interrelations. However, it is unable to capture the levels (stocks) and rates (flows) in the system's behaviour and represent its dynamics. Moreover, the changes over time cannot be seen. Hence, this constructed CLD provides a roadmap for reference and is the basis for refinement and further building of a simulation model using System Dynamics technique.

4. Next research stage

The conducted research is an ongoing project and further activities and results are expected. A casual loop diagram is relevant as an initial step in modelling. Nevertheless, it is unable to identify which variables are flow and which ones are stocks. Consequently, future modelling will focus on the use of System Dynamics technique after "quantifying" and translating the CLD into system dynamics model based on the stock and flow concepts. Stock and flow diagram is a more powerful modelling tool represented by mathematical parallels of integration and derivation where stocks denote accumulation while flows reflect the change in the level of a variable.

Once the stock and flow model is developed it can be simulated by populating it with data. Available quantitative data will be collected. Nevertheless, the innovation system is very complex and consists of many relationships that are too qualitative to be expressed trustworthily by a mathematical formula. Hence, the next round of data collection will employ participatory modelling approach in the form of workshops. Stakeholders from all three groups of the innovation system actors will discuss the outcomes of the present research analysis and focus on portraying system structure. It is especially relevant in the case of Russian construction industry where high uncertainty and lack of data is involved. Finally, different scenarios related to construction industry development, innovation diffusion, policies impacts and so forth will be created.

5. Conclusion

The goal of the research was to present construction innovation system as a conceptual model. The complexity of the system demanded a systematic approach to visualise its elements and quantify the relevance of relationships between them.

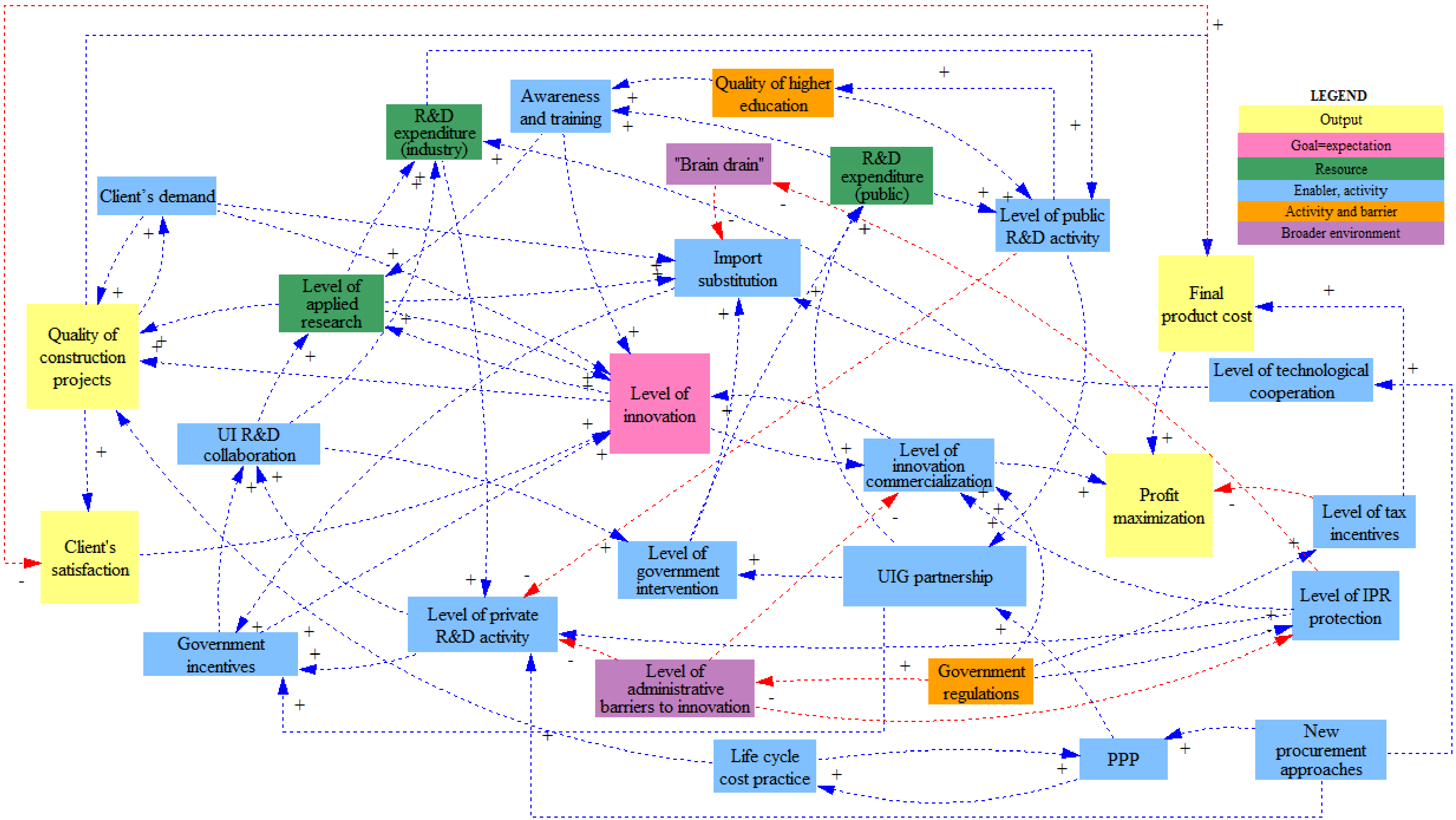

Figure 6. Construction innovation system Causal Loop Diagram based on a MICMAC analysis

Participatory and integrated modelling approach demonstrated to be effective in building an initial casual loop diagram. The identification of essential system's factors was undertaken through an expert consultation with industry and academic representatives followed by stakeholder engagement to present the influence different variables have on each other within the system. Then the structural analysis was carried out using MICMAC technique for generating the required information about interrelations between key variables in order to identify causal loops between them.

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