Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

Article

Model of the Russian Federation Construction Innovation System: An Integrated Participatory Systems Approach

Emiliya Suprun [1], Oz Sahin [1,2,*], Rodney A. Stewart [1] and Kriengsak Panuwatwanich [1]

[1] Griffith School of Engineering, Griffith University, Gold Coast Campus, Queensland 4222, Australia; emiliya.suprun@griffithuni.edu.au (E.S.); r.stewart@griffith.edu.au (R.A.S.); k.panuwatwanich@griffith.edu.au (K.P.)

[2] GCCRP Griffith Systems Modelling Group, Griffith University, Gold Coast Campus, Queensland 4222, Australia

* Correspondence: o.sahin@griffith.edu.au; Tel.: +61-7555-27378

Abstract: This research integrates systemic and participatory techniques to model the Russian Federation construction innovation system. Understanding this complex construction innovation system and determining the best levers for enhancing it require the dynamic modelling of a number of factors, such as flows of resources and activities, policies, uncertainty and time. To build the foundations for such a dynamic model, the employed study method utilised an integrated stakeholder-based participatory approach coupled with structural analysis (MICMAC - Matrice d'Impacts Croisés Multiplication Appliquée à un Classement Cross-Impact Matrix). This method identified the key factors of the Russian Federation construction innovation system, their causal relationship (i.e., influence/dependence map) and, ultimately, a causal loop diagram. The generated model reveals pathways to improving construction innovation in the Russian Federation and underpins the future development of an operationalised system dynamics model.

Keywords: participatory modelling; causal loop diagram development; structural analysis; systems modelling; construction innovation; Russian Federation

1. Introduction

The 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 the construction sector needs to be improved. A few studies have addressed innovation diffusion in the industry [1–3], mainly focusing on 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 [4].

Globally, the construction industry is often described as being a "laggard" industry, with few exceptions. According to the previously conducted exploratory study of the authors [5], in the case of the Russian Federation, this problem is even more significant since it is a country spread across a massive territory with unique impediments to innovation diffusion. 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 faces impediments that hinder an increased rate of innovation activity. This prior study explored the present situation in the Russian construction industry and the barriers, enablers and strategies that affect construction innovation diffusion most significantly [5]. Findings indicated that the crucial obstacle to construction innovation is an inability of the government to build up a regulatory, legislative and institutional framework that would encourage construction firms to innovate. There is presently little economic incentive to innovate in the Russian construction industry. Economic and financial difficulties, the lack of research support and weak R&D collaboration were also identified as significant barriers to construction innovation diffusion. The study results suggested that construction firms and the industry in general require assistance and support from the government to cope with existing impediments and to improve the current lacklustre rate of construction innovation. Also identified was that it was extremely important to promote new collaborative partnerships between industry, government and academia.

This research is part of an ongoing study concerned with designing and operationalising a system dynamics model of the Russian Federation construction innovation system. In this present study, which aimed to create a qualitative model in order to represent interactions in a system, 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. Similar approaches have been used in projects dedicated to complex natural resources questions [6], solid waste management [7], climate change adaptation [8], water management [9,10] and innovation policies, concerning nanotechnology, biotechnology and ICT [11]. However, it has not been used before in the context of the construction innovation system in general and with a focus on the challenging Russian Federation context in particular.

In the next sections, a critical literature review is provided by focusing on the construction innovation system and the roles of key actors within the system. Following the literature review, the research approach is explained. The findings regarding the key factors affecting the construction innovation system in the Russian Federation and their causal relationship are then conferred, and a causal loop diagram of the innovation system is presented. Finally, the last section outlines the work completed herein and future research actions.

2. Literature Review

2.1. Innovation System

Early on, the concept of innovation activity was applied to the "system of innovation" concept at the national level at the end of the 1980s [12–17] and is widely used now [18–22]. The innovation system as a determinant of innovation processes is generally defined as the set of institutional actors that play a major role in influencing innovative performance at the national level [23]. According to Edquist [19], it involves important political, social, economic, institutional and organizational factors that influence the development, diffusion and use of innovation. Metcalfe [24] (p. 462–463) defines an innovation system as: "that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process".

2.1.1. Levels of Innovation Systems

The relationships of actors and knowledge flows are important for innovation at all levels of economic activity. Hence, the concept of the innovation system can be approached from various perspectives, for example national [13,14,24], regional [25–27] and sectoral [21,28,29].

At a national level, the national innovation systems (NIS) consist of four main actors: government, research institutions, educational institutions and industry [30]. The system itself expresses the various networks between the actors aiming to increase the innovation capability at the national level. The networks represent government policies, social and cultural practices, laws and norms, to name a few [12,13,15,17,19].

The regional innovation system (RIS) approach [26] focuses mostly on the interdependencies of clusters, firms and institutions within a region on its cultural base. The main goal of a regional approach is to increase regions' competence capacity and their degree of autonomy.

Meanwhile, the sectoral innovation systems (SIS) are specific characteristics defining an industrial sector's ability to develop and innovate [29]. According to Malerba [28] (p. 261), "sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out interactions for the creation, production and sale of those products". It depends on national and regional systems of innovation, which in turn mostly depend on government policy.

2.1.2. Complexity of Innovation Systems

The fundamental concept of observing a systems of innovation approach [12,19] is that innovation should be seen as a non-linear, interdisciplinary and interactive process, requiring intensive communication and collaboration between different actors who "create, store and transfer the knowledge, skills and artefacts which define new technologies" [24] (pp. 462–463). Turville [31] (p.4) points out that a country's innovation activity depends on inter-linked activities, which include: industrial research; publicly funded basic research; user-driven research; knowledge transfer; institutions governing intellectual property and standards; supply of venture capital; education and training of scientists and engineers; innovation policies of government departments; science and innovation policies of regional development agencies (RDAs); and international scientific and technological collaboration.

Obviously, the linear approach to conceptualising innovation does not offer a clear insight into the complexities of the innovation process over time. Hence, the innovation system in any context is perceived to involve mechanisms that govern the alignment of committed resources and interrelated innovation activities.

2.2. Construction Innovation System

A full analysis of innovation systems is outside the scope of this research. Very little research on national innovation systems has been sectoral specific [21,30], particularly for the construction industry [4,20]. There has been some research on national systems of innovation related to the construction industry at the macro level [32]. However, much of the work has not been on systems of innovation as such, but mostly on national public policies and their link to political systems, rather than the interrelations of all of the system's actors and innovation-related activities. Furthermore, Manseau and Seaden [32] argue that for such a traditional industry as construction, an NIS is a useful unit of analysis because of the common legal framework, education, customer preference and institutions that impact innovation. Nevertheless, NISs are traditionally designed for manufacturing industries, while innovations in the construction sector as a project-oriented industry are significantly different from the organisational context [33]. Our research focuses on the construction innovation system as a sector model with the structure of a systems analysis.

The innovation process in construction is an inherently complex, fragmented issue involving multiple actors and interactions in developing and adapting innovations [34]. Hence, the innovation system approach from a comprehensive and systemic construction industry-wide perspective appears to be appropriate to explain this multi-dimensional activity with its various options, problems and the consideration of the many influences of the institutional environment. The continuously-developing innovation system of the construction industry is a complex system of innovation activities highly influencing the development of construction [4]. It involves am innovative milieu, different policies, interactions and a range of participating system actors, such as a government, organisations, universities and research institutes (Figure 1).

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). The capability is an ability to transform input resources into outputs (e.g., quality of construction projects, final product cost, client's satisfaction and profit maximisation) through the flows mentioned above.

Bringing the concept of the sectoral innovation systems into the construction context, this study discusses the role of each of the main actors and the system's factors encompassed by each actor in the context of construction.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

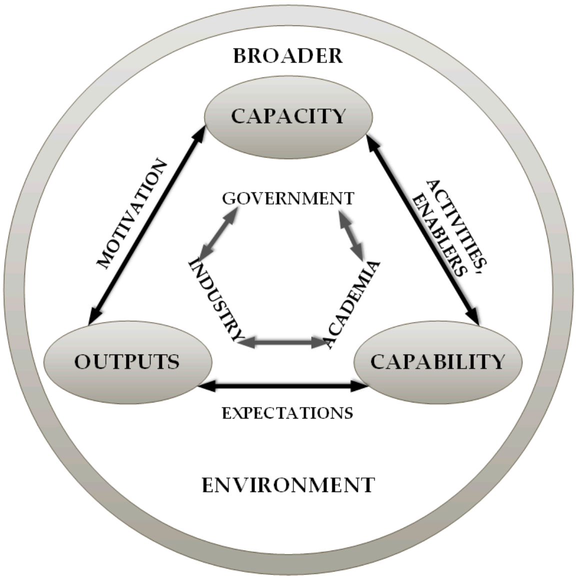

Figure 1. Theoretical model of the innovation system in the construction industry.

2.3. Actors Roles

As mentioned above, the construction innovation system is a very complex area that is closely connected to the national social structure. The environment in which construction firms operate is shaped by many actors, like clients, education providers and research centres, as well as industry associations, regulators and government agencies [35]. However, this environment changes with time, given the participation of a different group of firms in each project. Hence, the impact of construction development is highly influenced by a complex system of resources and activities flows, interactions and a range of actors participating in the system (Figure 2).

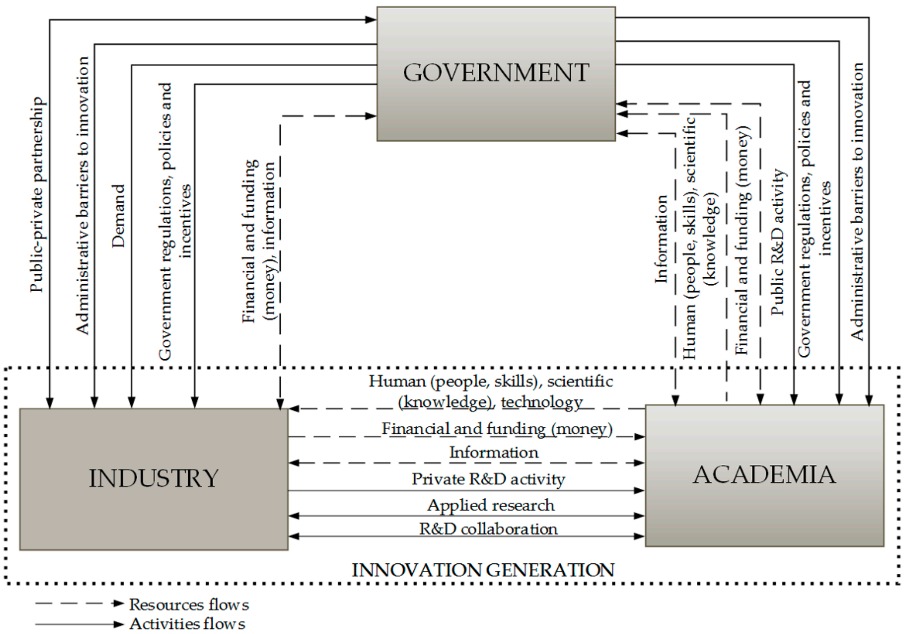

Figure 2. Theoretical framework for actors' relationships within the construction industry innovation system.

In this study, the scope is focused on the following three core actors involved in construction innovation that can undertake innovation activities and have different roles across the system:

1. Industry refers to private and public firms in the construction industry; design companies; related and supporting industries; building material and construction equipment suppliers; and service industry (e.g., contractors and consultants in building and civil infrastructure sectors).
2. Government as a highly influential participant in the construction industry.
3. Academia refers to technical colleges, higher education institutions and research institutions, responsible for conducting fundamental and applied research, training the next generation of industry professionals and acting as guardians of the inherited body of knowledge.

2.3.1. Industry

Private and public firms not only promote technology transfer, as well as commercialisation of innovative products, processes and services, but also preserve innovation strategies [20,33]. They are considered as mediators between R&D institutions to develop new technologies and knowledge [34].

2.3.2. Government

The public sector exercises a major influential role in several ways within the construction industry contributing to the system's balance by direct and indirect measures. As a client, it can significantly influence and motivate other actors along with driving demand for science and innovation (through procurement policies) [19,36]. As a policy-maker and legislator, it is responsible for overall public policies, laws, regulatory framework, aspects of collaboration and governance [32]. The significant challenge for a government is to make industry and research institutions collaborate in an innovation process. To achieve this, supporting funding aspects and incentive mechanisms should become more efficient.

2.3.3. Academia

Higher education institutions and research institutions are responsible for providing platforms for knowledge creation and diffusion through fundamental and applied research, training the next generation of innovators and acting as guardians of the inherited body of knowledge. It also improves overall national innovation capabilities, as knowledge is a component of innovation [20,32,34]. Moreover, academia enhances the ability of construction firms to assimilate knowledge from research laboratories to testing in an operational environment, which then can be put to commercial use [37,38]. Countries, such as Japan, South Korea, Germany and the USA, that have a strong collaborative culture between higher education and research institutions and industry have proven outcomes in terms of generating innovation capital [39].

2.3.4. Collaboration

Within the construction industry, actor collaboration has been traditionally very small. It mostly happens because very little formal R&D is undertaken in the construction sector [40]. Hence, the literature emphasises the importance of strong linkages among innovation system's actors in industry development. It is very important to promote the common interests of all actors in order to improve innovation performance [30,35,41,42]. R&D collaboration between industrial and academic and research partners, with high levels of engagement around a real-world problem, provides the basis for absorbing and applying research results. However, in the construction sector, technical and research support is needed for supporting human resources. In Russia, the majority of research institutions are public; hence, suitable incentive schemes might encourage collaboration and interactions between academia and industry in the process of innovation performance improvement [41].

3. Research Goal and Objectives

The overarching goal of an ongoing study is to design and operationalise a system dynamics model of the Russian Federation construction innovation system. To achieve this goal, the purpose

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

of the present research was to develop a qualitative systems model that can aid interpretation of the complex cause-and-effect relationships, along with the feedback mechanisms, that characterise the interaction and interdependencies of resources and activity flows within the innovation system. Considering this purpose, the present study sought to achieve the following objectives:

- To complete a literature review of the current state of knowledge regarding construction innovation systems, as well as the contextual factors specific to the Russian construction industry.
- To identify the main variables of the construction innovation system and relationships between them, as well as their influence on each other through structural analysis and stakeholder engagement.
- To develop a modelling framework that utilises a causal loop diagram to link relevant innovation factors.

4. Research Methodology

According to Sterman [43] (p. 85), "there is no cookbook recipe for successful system dynamics modelling, no procedure you can follow to guarantee a useful model". The modelling process, in general [44,45], is a very iterative step-by-step process. A predominant framework for system dynamics modelling, in particular, was developed by Sterman [43] and divided into five steps: the first two steps (i.e., problem articulation; formulating dynamic hypotheses) concern qualitative modelling, while the other three steps (i.e., formulating a simulation model; testing; policy design and evaluation) concern computer-based modelling for quantitative simulation. The overall research project will follow all five steps of the modelling process illustrated in Figure 3, but will be completed in two distinct stages with the more exploratory Stage 1 reported in this present paper. The Stage 1 scope consisted of two steps, namely: (a) Step 1, problem definition: scoping the problem to be addressed; and (b) Step 2, conceptual model development: designing a qualitative model that represents the problem and interactions in a system using stakeholder engagement and structural analysis. Herein, completed Stage 1 findings will support the future completion of Stage 2 activities (Figure 3), namely the building of a system dynamics model (Step 3), model testing (Step 4) and model simulation (Step 5).

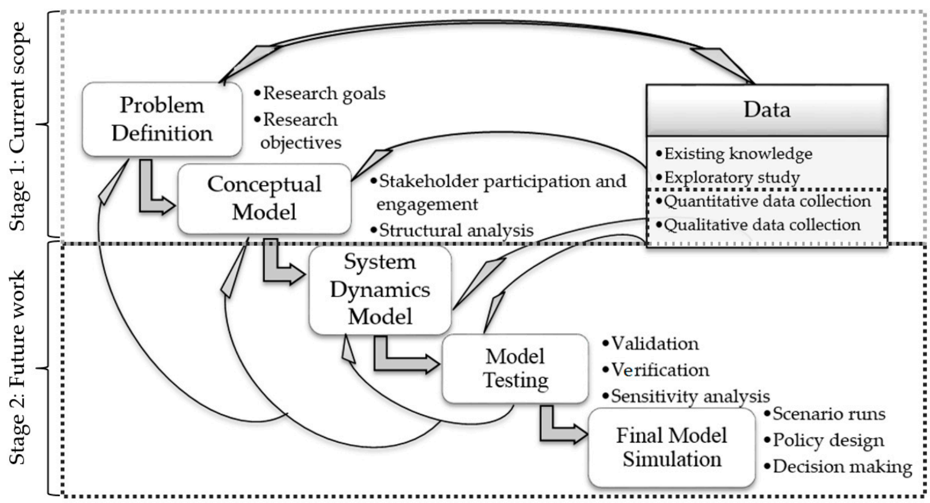

Figure 3. Stage 1 scope for the step-by-step modelling process (adapted from Sterman [43]).

Specifically, this research project is focused on research activities for the understanding and quantification of the relationships between system's components that are required to enable the eventual development of an operational systems model. The multi-actor innovation system in the construction industry is a complex topic requiring the use of a systems approach. This modelling approach will assist the understanding of important feedback mechanisms that characterise the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

dynamic behaviour of complex systems. The chosen systems approach also aims to overcome the disadvantages of traditional mind mapping by mitigating the number of insubstantial relationships. Generally, a collective and participatory approach limits the risks of incoherence. However, stakeholder engagement requires experts to volunteer considerable time to the research, which often limits the number of available participants. Nevertheless, it is not enough for this research to build and run computer models of such a complex multi-actor system using only desktop studies in order to support issues concerning innovation problems. The contribution of experts to structural analysis is useful due to the experts' knowledge of the situation and the problem addressed, which increases the level of validity of those findings. Incorporating stakeholder input in such models is essential to ensure that they facilitate effective decision making over the short-, medium- and long-term. Moreover, tacit knowledge of experts enables them to identify the variables that tend to have the greatest influence and dependency within the system. Participatory modelling often includes involving public representatives and decision makers into an analytic modelling process [6,8,9].

The present study was focused on the formulation of the causal loop diagram, which required the completion of the following research steps: (i) problem scoping and variables identification; (ii) stakeholder identification and engagement; (iii) structural analysis with cross-impact matrix multiplication applied to classification (MICMAC - Matrice d'Impacts Croisés Multiplication Appliquée à un Classement Cross-Impact Matrix); and (iv) the generation of a proposed qualitative model using a causal loop diagram (CLD). These research stages are outlined in further detail below.

4.1. Problem Scoping and Variables Identification

This step included understanding existing knowledge in the field based on a literature review, an exploratory study previously conducted by the authors and expert consultation. The next fundamental step was a selection of factors that affected the problem and therefore the system in general. Identification of interrelationships between such factors facilitated a better understanding of the complete system, which was necessary for the subsequent structural analysis stage and building of a causal loop diagram [46].

4.2. Stakeholder Identification and Engagement

As mentioned previously, many factors are involved in complex innovation systems. The list of the system's components must be approved by experts and stakeholders; this opinion ensures that all relevant elements are included and redundant variables removed. This process was completed through consultation with industry and academic professionals. The initial structural analysis matrix included the consideration of 80 factors and their importance to the process of construction innovation implementation and diffusion in Russia. As a result of consultation with the interviewees, a total of 30 of the 80 factors were retained based on their importance. The interactions between these 30 factors were considered as described later.

Further stakeholder engagement was conducted 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 an opinion survey on the construction innovation system and to discuss the key issues related to innovation in the industry.

Unstructured and highly interactive interviews were conducted with 14 experts who have played a role in managing the innovation implementation and diffusion process in construction and the innovation policy field in Russia.

4.3. *Structural Analysis with MICMAC*

According to Godet [47], 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

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

the system and to think about certain aspects of the system behaviour [47]. In our research, the structural analysis procedure was enriched by using the MICMAC approach to identify the key variables and the elements' interrelation web, as well as to quantify potential relationships. Moreover, the MICMAC method was selected because it provides a rigorous test to distinguish the rating of influences and the dependencies of variables, especially qualitative ones.

Generally, the structural analysis approach includes: (i) identification and description of the main variables; (ii) expert opinion about the relationships between variables within a structural matrix; (iii) classification of variables adopting the MICMAC method; and (iv) the design of the matrix of direct influences (MDI) and its corresponding influence maps, which provide all of the information needed for the analytical integration of culpable system parts and to build the causal chain of the system.

By studying these relations, the structural analysis enables researchers to highlight the variables that are essential to the system's evolution. Furthermore, the findings assist a modeller with revealing the dynamic characteristics of a system by identifying the influence and dependence of each of the factors in order to understand which variables to focus on while drawing the system boundary [7].

4.4. *Development of a Causal Loop Diagram*

Structural analysis with MICMAC is an effective tool for the construction of the qualitative model represented by a causal loop diagram. From the MICMAC analysis outcomes of the matrix of direct influences and its graphic representation, it is possible to evaluate the results and to obtain the key variables of the system. The interrelations between variables are crucial in the system interpretation, as they define the system's dynamics.

It is worth noting that the process of transferring MICMAC analysis outcomes into a causal loop diagram provides an advantage, as it allows researchers to know in advance the most important relationships between system's variables. Consequently, construction of the model is supported by a complete understanding of the system. A CLD is a tool for mapping a set of relationships forming the complex system. It provides a more visual understanding of the existing systemic relationships between the system's components. The CLD consists of both quantitative and qualitative variables.

5. Results and Discussion

5.1. Problem Scoping and Variables Identification

Innovation and innovation diffusion in the construction industry as a project-based sector should be seen in light of the specific characteristics of a dynamic systemic context. 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 the 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 systems model to create scenarios and to understand policies impact.

Most of the system's variables are qualitative and cannot be analysed quantitatively. Consequently, the variables (Table 1) need to be evaluated in order to develop a causal loop diagram and to better understand the behaviour of different factors that make up the system.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

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

No.	Variable	Short Title	Description	Theme	Resources involved	Actor	Qualitative/ Quantitative	References
1.	Level of innovation	LevInn	High innovation level is one the main characteristics of every industry development	Goal = expectation	Nil	Government Industry Academia	Qualitative	[4,21,48]
2.	Quality of construction projects	Qlt	Productivity and quality of construction projects (final product or service)	Output	Nil	Industry	Qualitative	[48–50]
3.	Final product cost	FinPCst	Final cost of a construction product or service	Output	Nil	Industry Government	Quantitative	[20,21,50,51]
4.	Client's satisfaction	ClSat	Client's satisfaction with final product or service quality	Output	Nil	Industry Government	Qualitative	[20,51]
5.	Profit maximisation	MaxPrft	Maximising profitability for private sector and maximising cost effectiveness for the public sector are key motivations for contractors and clients in the innovation implementation process	Output	Nil	Industry	Quantitative	[5,20,21,51]
6.	Level of public R&D activity	Pub_RDA	Public policies promoting science and R&D, investments in higher education, techno-parks, etc.	Enabler	Money People Skills Knowledge Information Technology Regulations	Government Academia	Qualitative	[20,21,39,50,51]
7.	Level of private R&D activity	Prvt_RDA	Private sector innovative activities for industry development	Enabler	Money People Skills Knowledge Information Technology	Industry Academia	Qualitative	[20,21,39,50,51]
8.	R&D expenditure (public)	Pub_RDE	Funds a government spends at universities and research institutes on STI	Resources	Money	Government	Quantitative	[20,21,37,39,51]
9.	R&D expenditure (industry)	Prvt_RDE	Firms investments on R&D	Resources	Money	Industry	Quantitative	[20,21,37,39,51]
10.	Client's demand	ClDem	As clients, government and local authorities, as well as private clients may significantly affect the use of new materials, technologies and methods	Enabler	Nil	Government	Qualitative	[5,20,50–52]

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

11.	Level of applied research	AppRes	Development of methods, products, systems, techniques, etc., which improve the industry and innovation performance	Resources	People Skills Knowledge Information Technology	Academia Industry	Qualitative	[20,39,50,51]
12.	Level of basic research	BasRes	Research in construction area developing its theoretical foundations	Resources	People Skills Knowledge	Academia	Qualitative	[20,39,51]
13.	Government regulations	Gov_Reg	Legislation, rules, building codes, certification procedure	Enabler*	Regulations	Government	Qualitative	[5,50,53,54]
14.	Government incentives	Gov_Inc	Public stimulating mechanisms for industry development (e.g., grants and awards for best practices and solutions)	Enabler	Money	Government Industry	Qualitative	[5,20,51,53,55]
15.	Level of government intervention	Gov_Inter	Public support and public policies (e.g., federal targeted programmes, direct financial investments, foundation of clusters)	Enabler	Money	Government Industry Academia	Qualitative	[5,20,51,53,55]
16.	PPP (Public-Private Partnership)	PPP	Cost sharing: public-private partnership	Enabler	Money Regulations	Government Industry	Qualitative	[5,37,56,57]
17.	Level of tax incentives	TaxInc	Fiscal arrangements and tax privileges	Enabler	Money Regulations	Government Industry	Qualitative	[5,37,53]
18.	UIG (University-Industry-Government) partnership	UIGPart	Partnerships between universities, research institutes, government and industry, mainly for supporting strategic innovative and pilot projects	Enabler	People Skills Knowledge Information Technology	Government Academia Industry	Qualitative	[4,20,37,51]
19.	UI R&D collaboration	UICol	Collaborative R&D with greater industry participation for testing and evaluating research results and new solutions	Enabler	People Skills Knowledge Information Technology	Industry Academia	Qualitative	[5,37,50,52,58]
20.	Level of technological cooperation	TechCoop	Technological cooperation with related and supporting industries; integrated R&D efforts are required for effective implementation of technology-using strategies	Enabler	People Skills Knowledge Information Technology	Industry	Qualitative	[5,20,50,51]
21.	New procurement approaches	Procur	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	Enabler	Information Technology Regulations	Government Industry	Qualitative	[5,54,56,57]

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

22.	Life cycle cost practice	LifeCyc	Assessment of construction project over its life cycle from the design stage, manufacturing, usage, maintenance and disposal	Enabler	Information Technology Regulations	Government Industry	Qualitative	[37]
23.	Awareness and training	AwTrain	All of 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	Enabler	People Skills Knowledge Information Technology	Government Academia Industry	Qualitative	[5,20,51,59,60]
24.	Level of IPR (Intellectual property rights) protection	IPRPr	Intellectual property rights protection supporting efficient flows of knowledge	Enabler	People Skills Knowledge Regulations	Government Academia Industry	Qualitative	[5,20,21,51]
25.	Level of innovation commercialisation	InnCom	Knowledge produced through R&D transforming into products with commercial value	Enabler	Money Knowledge	Government Academia Industry	Qualitative	[21,37,38]
26.	Quality of higher education	HighEdu	Government should support the development of educational programmes aimed at specialists engaged in the design process, construction and manufacturing	Enabler *	People Skills Knowledge Information	Government Academia	Qualitative	[5,55]
27.	Venture funding	VentFund	Investment funds in start-ups and small- and medium-sized enterprises	Enabler	Money	Government Industry Academia	Qualitative	Added from interview's results
28.	Import substitution	ImpSub	Nowadays, import substitution is Russia's response to imposed Western sanctions; it takes place in numerous areas, including building materials manufacturing and construction sectors	Enabler	People Skills Knowledge Information Technology Regulations	Government Industry Academia	Qualitative	Added from interview's results
29.	"Brain drain"	BrainDr	Russia's lack of support and incentives for innovation increase the level of "brain drain"	Broader environment	People Skills Knowledge	Government Industry Academia	Qualitative	Added from interview's results
30.	Level of administrative barriers to innovation	AdmBar	The variety of building codes and standards; low levels of government support for industry development; government contracts with inflexible fixed budgets, and so forth	Broader environment	Regulations	Government	Qualitative	Added from interview's results

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

5.2. Stakeholder Identification and Engagement

As mentioned above, the participation of stakeholders is crucial for this type of research, particularly during the analytic modelling process. Once the first set of 80 variables were identified through the literature review and the previously conducted study, an initial expert consultation involving academic and industry representatives was held. The interviewees from a diverse background and responsibility were selected, including managers (28.5%), designers (28.5%) and researchers (43%). The participants were provided with contextual information regarding the research and the initial list of relevant variables to discuss.

Based on the participants' feedback, the essential variables were identified, and some variables were grouped together as a single variable, while four new variables were added and some redundant variables removed from the list. As listed in Table 1, a total of 30 variables remained after this research step was completed (Table 1). Once the final list of variables was determined, structural analysis using MICMAC was completed by a group of 14 experts. They included researchers and academic staff, private and public construction companies' employees and contractors, design consultants (i.e., design engineers), building product manufacturers and public authorities' representatives. Researchers and academics (43% of the experts) focused on a range of topics in the broad field of civil engineering, architectural engineering, municipal and structural engineering, as well as construction management. Industry participants (36%) represented companies from civil infrastructure and building sectors. Involved public servants (21%) were specialised in innovation development programs.

5.3. Structural Analysis with MICMAC

The first step of the proposed 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 were required using a matrix linking all of the constitutive elements (Table 2).

The opinion survey aiming to identify the role of different factors in relation to the innovation system in the Russian construction industry was conducted 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 (Table 2).

After the relationships between variables were described, according to the exposed structural analysis, the MICMAC software [61] calculated the intensity of the influence and dependency between variables.

doi:10.20944/preprints201608.0143.v1

Table 2. An extract from 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	R&D Expenditure (Public)	R&D Expenditure (Industry)	Client's Demand	Level of Applied Research	Level of Basic Research	Government Regulations	Government Incentives	Level of Government Intervention	PPP	Level of Tax Incentives
Quality of construction projects	0	3	3	3	2	2	2	2	3	1	1	2	3	3	2	3
Final product cost	2	0	3	3	1	2	2	2	3	2	0	1	3	3	2	2
Client's satisfaction	3	2	0	2	1	2	2	3	3	2	0	1	2	2	3	1
Profit maximisation	2	3	2	0	1	2	1	3	1	2	0	1	2	2	2	3
Level of public R&D activity	3	2	3	1	0	3	3	2	2	3	3	2	2	2	1	2
Level of private R&D activity	3	2	3	2	2	0	1	3	2	3	1	2	3	3	1	2
R&D expenditure (public)	3	2	2	1	3	2	0	2	1	3	3	2	1	2	1	1
R&D expenditure (industry)	3	3	2	3	3	3	3	0	2	3	1	1	2	2	1	2
Client's demand	3	2	3	2	3	3	2	2	0	2	1	2	2	3	2	1
Level of applied research	3	2	2	2	3	3	3	3	1	0	2	2	2	2	1	2
Level of basic research	2	1	1	1	3	1	3	1	1	3	0	1	1	3	1	1
Government regulations	2	3	2	2	2	2	2	2	1	3	1	0	2	2	1	3
Government incentives	3	2	2	3	2	3	2	3	1	3	2	1	0	3	2	2
Level of government intervention	2	2	1	3	2	3	3	2	1	3	2	1	2	0	2	2
PPP	3	3	3	2	1	3	1	1	3	2	0	3	3	3	0	3
Level of tax incentives	3	3	3	3	1	3	1	3	1	2	1	2	2	2	2	0
UIG partnership	2	2	3	2	3	3	3	1	3	3	2	2	3	3	2	2

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

By cumulating the rows and the columns for each component, their individual roles within the system were established. Table 3 details the variables and their dependence and influence level rank. Structural analysis using MICMAC aids the necessary understanding of the role of each variable in the construction innovation system, which in turn assists in the further detailed System Dynamics (SD) modelling of particularly important system components. Moreover, using this approach as a precursor to the development of a system dynamics model ensures that it is based on a solid theoretical foundation.

Table 3. Direct influences/dependencies rating of variables according to the MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) method.

No.	Variable	Influence Rank	Dependence Rank
1	Level of innovation	3	1
2	Quality of construction projects	5	1
3	Final product cost	14	5
4	Client's satisfaction	13	3
5	Profit maximisation	16	7
6	Level of public R&D activity	1	8
7	Level of private R&D activity	4	1
8	R&D expenditure (public)	8	9
9	R&D expenditure (industry)	5	6
10	Client's demand	7	13
11	Level of applied research	4	1
12	Level of basic research	15	19
13	Government regulations	4	16
14	Government incentives	3	7
15	Level of government intervention	7	5
16	PPP	8	18
17	Level of tax incentives	8	11
18	UIG partnership	2	5
19	UI R&D collaboration	5	4
20	Level of technological cooperation	12	12
21	New procurement approaches	8	15
22	Life cycle cost practice	11	10
23	Awareness and training	9	8
24	Level of IPR protection	4	10
25	Level of Innovation commercialisation	5	4
26	Quality of higher education	10	14
27	Venture funding	17	16
28	Import substitution	5	2
29	"Brain drain"	11	17
30	Level of administrative barriers to innovation	3	15

All of 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.

 doi:10.20944/preprints201608.0143.v1

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

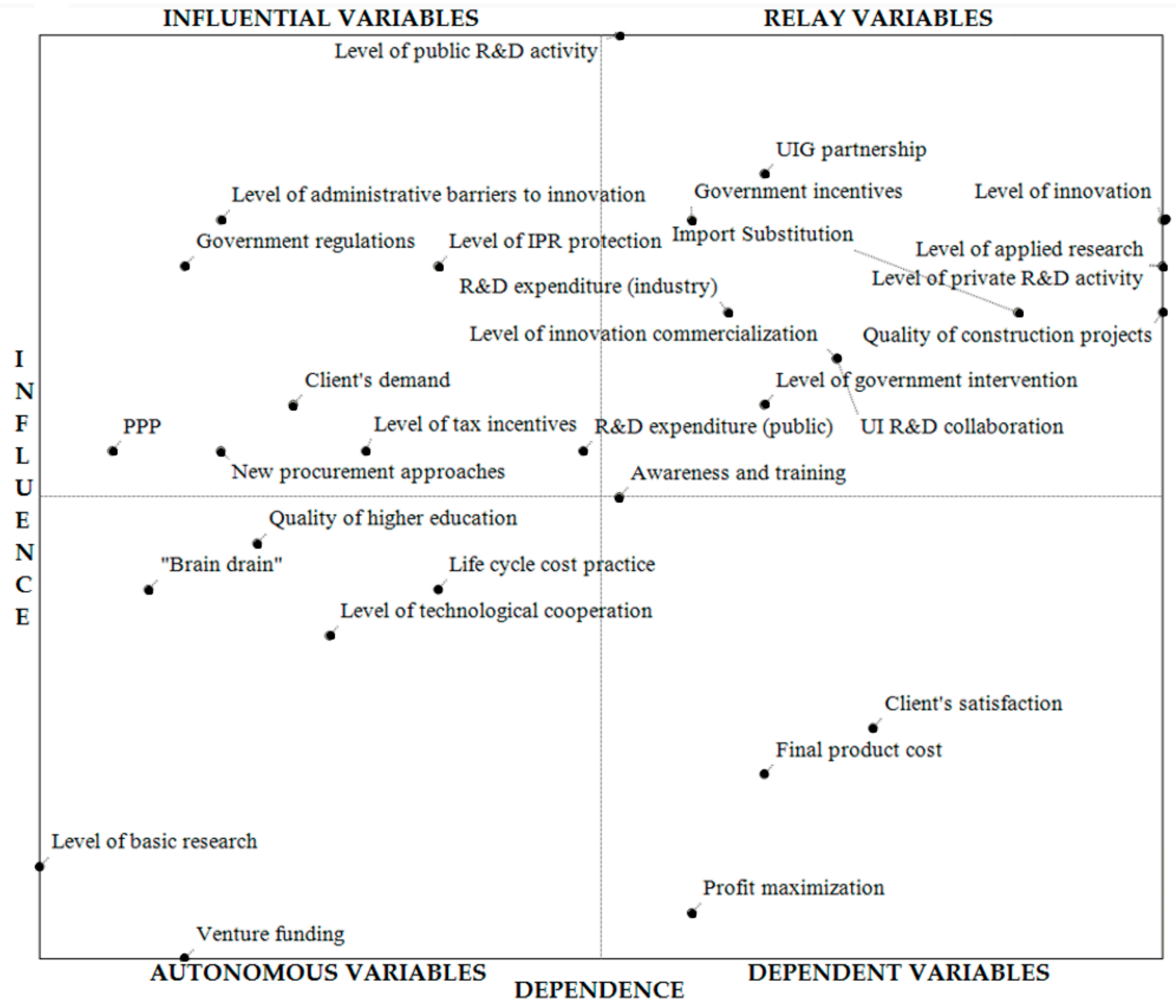

Figure 4. Direct influence and dependence map of the model variables.

As can be seen, each variable within the construction innovation system holds a unique position in the diagram in relation to all others. Depending on a 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 on the others. Consequently, any change in one of these variables will influence other variables and the system as a whole. Hence, they must have a priority when considering strategic actions or scenarios. These variables are: level of administrative barriers to innovation; government regulations; level of IPR (Intellectual property rights) protection; client's demand; PPP (Public-Private Partnership); new procurement approaches; level of tax incentives; R&D expenditure (public).
- Relay variables are also important as they both influence the system and are dependent on influential variables. Besides these variables have an unstable behaviour as they could change to be input or output variables. Hence, they are dynamic variables involved in the feedback loops of the system. These relay variables include: quality of construction projects; level of public R&D activity; level of innovation; import substitution; level of applied research; R&D expenditure (industry); level of innovation commercialisation; level of government intervention; government incentives; level of private R&D activity; UIG (University-Industry-Government) partnership; UI R&D collaboration.
- Dependent variables represent system's output variables that are the most impacted by other variables and the system. These variables are: client's satisfaction; final product cost; profit maximisation; awareness and training.

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

- Autonomous variables are neither influential nor dependent and do not significantly affect the system. Within the context of system dynamics modelling, these variables are associated with exogenous components that exist within the system, but are not controlled by the dynamics of the model. Although they can be excluded from any further analysis, their location near the axes of influence and dependence can mean a certain effect and should be taken into account. The stakeholders identified the following factors as independent: venture funding; level of basic research; level of technological cooperation; "brain drain"; life cycle cost practice; quality of higher education.

The next step was to identify the key variables where greater attention should be placed. As they are those included in the influential, relay and dependent groups of variables, 24 out of 30 analysed variables were determined as key variables for further SD model construction. These groups of variables are associated with endogenous variables that change based on the system's dynamics and are the basis for exploring how to improve system performance. However, the majority of the remaining autonomous factors involved in the system should not be excluded. Only two variables (venture funding and level of basic research) were identified as less essential components of the 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 into the system as a whole. The graphs assist a modeller in determining an initial reference for the building of a CLD.

The visual comparison of the level of influence and the dependence of key variables in the construction innovation system is presented in Figures 6 and 7, respectively.

The views of stakeholders representing construction firms where innovation takes place tended to support the relationships in these figures. In Figure 6, it can be seen from all three perspectives (i.e., government, industry and academia) that level of public R&D activity, level of applied research, government regulations, level of private R&D activity and UI R&D collaboration are ranked highly, which is in accordance with the outcomes of the exploratory study highlighting stakeholders' focus on public strategies and collaboration metrics. It is worth noting, that level of administrative barriers to innovation, government incentives, level of government intervention and level of IPR protection are seen to be more influential variables by industry and academia, as they are by the actors who generate innovation. As mentioned above, barriers related to government actions are the most significant impediments to innovation in the Russian construction industry. Consequently, these characteristics are fundamental for effective innovation system building. As for the government view, partnerships between universities, research institutes, the government itself and industry seem to be the most influential variables, mainly for supporting innovative pilot projects. Interestingly, public servants prefer the industry to take more initiatives in innovation performance improvement by increasing private R&D expenditure and undertaking more research activities. In addition, import substitution is a big issue in the development of many industries, including building materials manufacturing and construction sectors in Russia due to the imposed Western sanctions. In accordance with this, "brain drain" and quality of higher education are ranked as highly influential factors by government representatives. In terms of the variable dependency of key variables in the construction innovation system, stakeholders from all three groups agreed that the level of innovation and innovation system outputs (i.e., quality of construction projects, final product cost, client's satisfaction and profit maximisation) are highly dependent.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

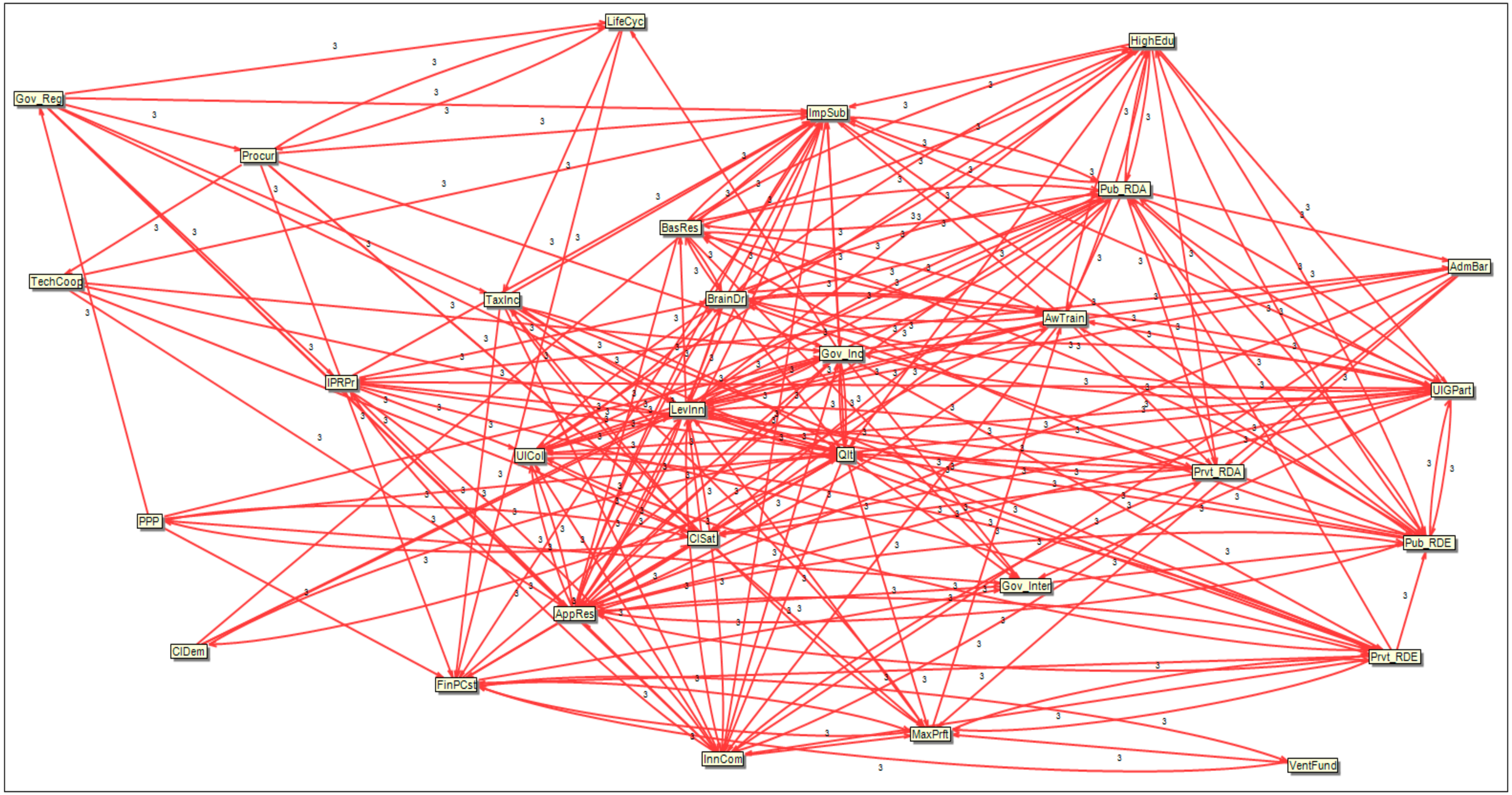

Figure 5. Direct influence graph representing the strongest influences of variables on each other.

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 August 2016 doi:10.20944/preprints201608.0143.v1

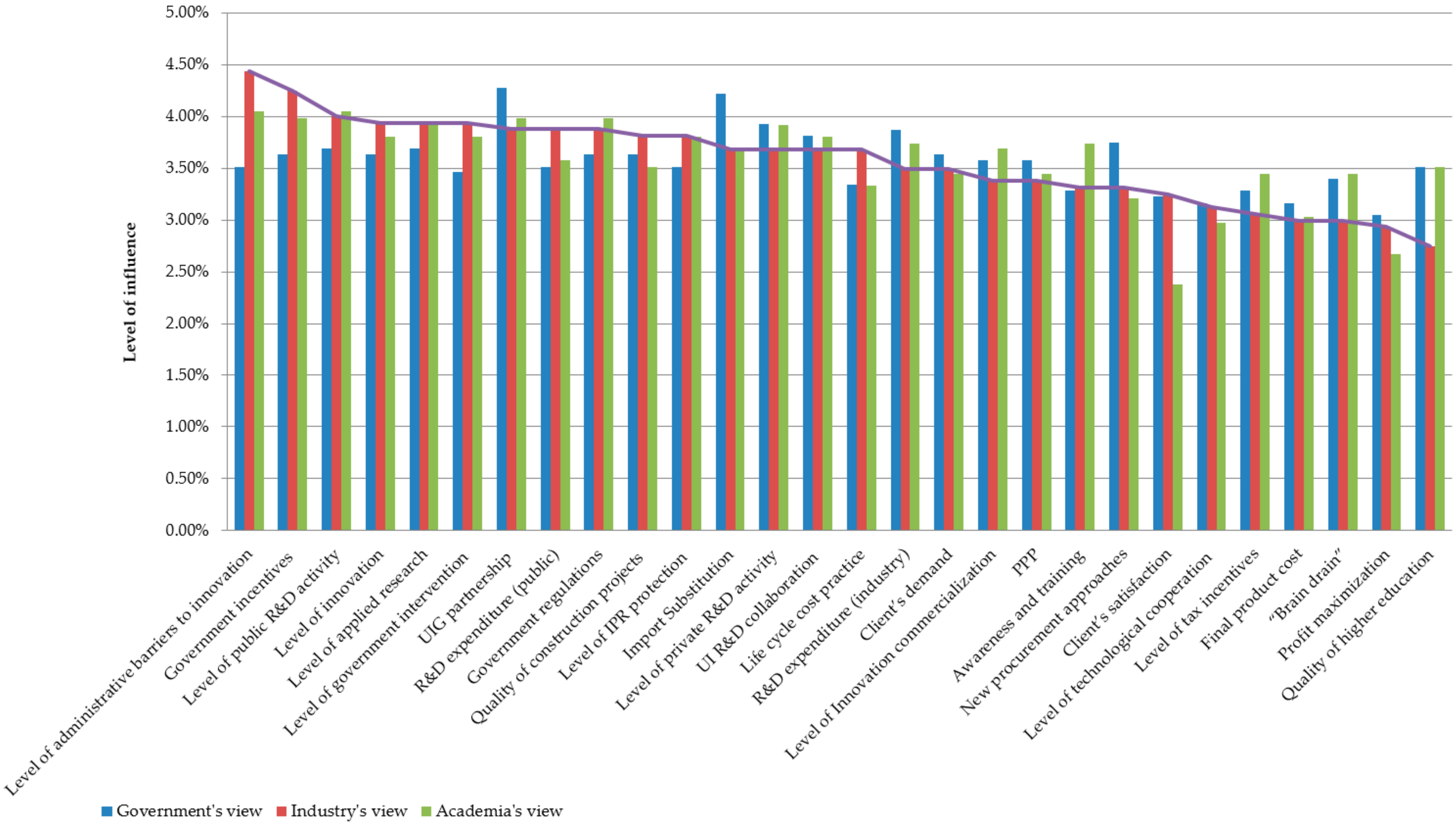

Figure 6. Level of influence of key variables within the construction innovation system from alternate stakeholder perspectives.

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

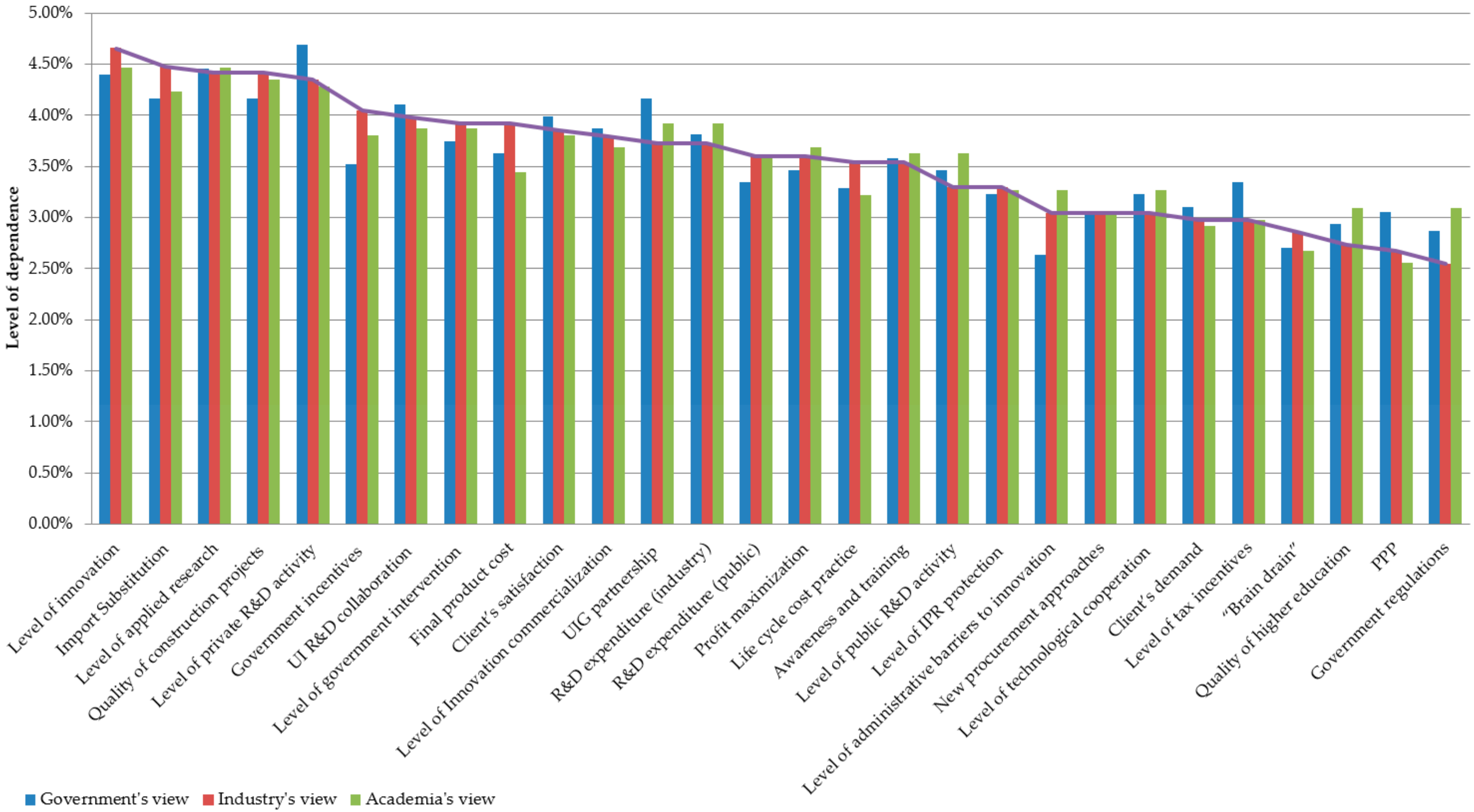

Figure 7. Level of dependence of key variables within the construction innovation system from alternate stakeholder perspectives.

Peer-reviewed version available at Systems 2016, 4, 29; doi:10.3390/systems4030029

5.4. Causal Loop Diagram

Once the structural analysis outcomes were incorporated from the direct and indirect influence graphs, as well as the completion of the 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 the level of public R&D activity in the case of our study.

A modeller develops a CLD in a similar manner to that of an MDI by asking the question: "What are the observed impacts of variable *i* on variable *j* at the present?" The next step is to identify the most important relationships that allow logical construction of the associated causal loop diagram. In this sense, the relationships between system variables can be displayed in 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 the case of modelling, the arrows describe the transition to a casual model and begin to represent the dynamics of the system. It also should be taken into account that some variables do not have a direct connection with each other, but influence can occur through other variables. Additionally, a modeller can enhance other meaningful interrelations between dynamic variables through taking into account the experts opinions during data collection, previous desktop study, as well as applying the tacit knowledge of researchers analysing the system.

The process of model construction is always subjective. However, the interactions of variables are supported by experts that provide a high degree of 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 qualitative model (Figure 8) 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.

The factors used in a CLD are both quantitative and qualitative. Obviously, qualitative elements, such as client's satisfaction, government regulations and quality of construction projects, are not generally measured directly; however, their inclusion adds considerable realism and power to the model. In order to visually convey the different components of the initial theoretical model of the Russian Federation construction innovation system to industry stakeholders, a CLD has been produced that categorises variables using different shapes and colours (Figure 8). Hexagons represent construction innovation outputs; boxes represent activities and enablers, system's resources and the broader environment; and finally, the circle represents the main goal. This CLD will be codified into an SD model applying conventional features in further research. In a CLD, the elements are linked together by arrows that indicate a causal relationship as a direct influence. A causal link between two variables implies the 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 or 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 8), which means a change in *X* produces an increase 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 8), which denotes that a change in *X* produces a decrease in *Y* in the opposite direction.

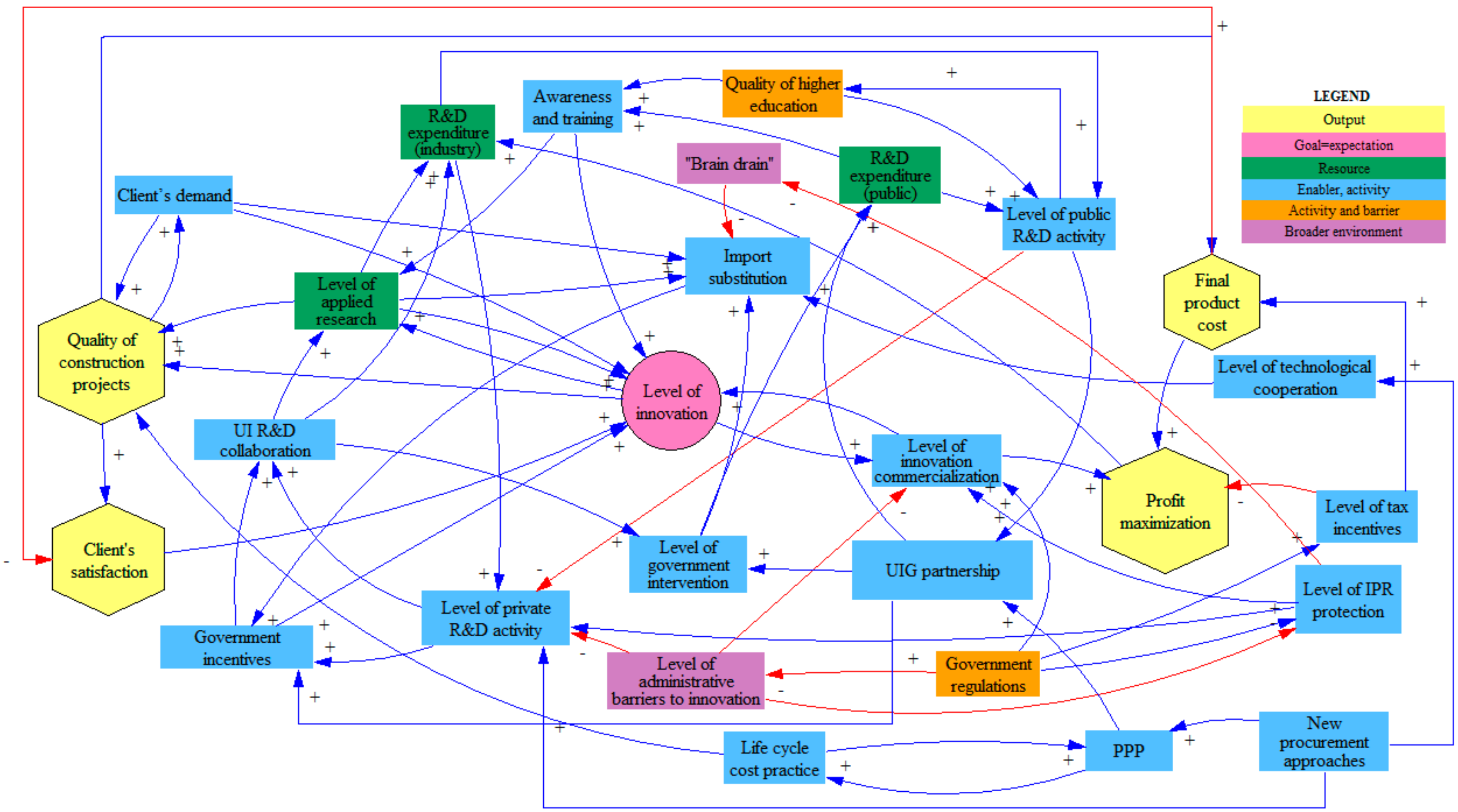

Figure 8. Construction innovation system causal loop diagram based on a MICMAC analysis.

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

For instance, in Figure 8, the link between level of tax incentives and final product cost indicates a 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 the level of applied research influencing the quality of construction projects and ultimately client's satisfaction and final product cost. Client's satisfaction would also provide assistance for increasing the level of innovation while final product cost provides sufficient room to adjust prices' level to improve the resulting maximise profitability for the private sector and maximise cost effectiveness for the public sector, as shown (Figure 8).

6. Conclusions

The one overarching goal of this study was to present the Russian Federation construction innovation system as a model. Considering the qualitative nature of the model and the complexity of the system, a systemic approach was demanded to visualise its elements and to quantify the relevance of relationships between them. A participatory and integrated modelling approach was deemed to be effective in building an initial casual loop diagram.

The first stage consisted of the identification of essential system's factors undertaken through an expert consultation with industry and academic representatives in order to validate the list of variables. The following step employed stakeholder engagement to determine the degree of influence that different variables have on each other within the system. The contribution of experts representing three groups of innovation system's actors was undoubtedly useful due to the knowledge they have of the situation and problem addressed. Then, the structural analysis was carried out using the MICMAC technique for generating the required information about interrelations between key variables in order to identify causal loops between them. This final step systematically assists the modelling of complex innovation system through creating an initial causal loop diagram (CLD) integrating both qualitative and quantitative variables.

Based on the information derived from the structural analysis using the MICMAC method, the construction innovation system's variables were classified into different groups. It revealed eight influential variables that have a priority when considering strategic actions or scenarios for the industry development. They included the level of administrative barriers to innovation, government regulations, PPP, level of tax incentives, level of IPR protection, client's demand, new procurement approaches and public R&D expenditure. It has been found that the key influential and dependant variables are the level of public and private R&D activity, import substitution, government incentives and collaboration between higher education and research institutions with industry. It is becoming clear that the public sector plays a major influential role within the construction industry in Russia. Variable rankings based on their driving power also indicated client's satisfaction, final product cost and profit maximisation as dependent variables, which are directly associated with the construction innovation system's outputs. The identification and classification of key variables were essential for developing a framework suited for the Russian Federation construction innovation system, while the causal loop diagram revealed potential strategic pathways to overcome innovation diffusion challenges in the Russian Federation construction sector.

7. Limitations and Future Research

The research findings should be interpreted in light of several limitations:

- The CLD explains interactions and interrelations. However, it may be considered as a didactic tool in order to understand the complexity of the system under study because the changes over time cannot be seen. Moreover, it is unable to capture the levels (stocks) and rates (flows) in the system's behaviour and to represent its dynamics. Stock and flow diagrams are required to overcome this limitation. Hence, this constructed CLD provides a

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

roadmap for reference and is the basis for refinement and further building of a simulation model using the system dynamics technique.

The chosen integrated approach is heavily reliant on participant choices. However, the participatory method significantly limits the risks of incoherence. Moreover, it offers researchers the opportunity to build up a model together and using experts' experience and knowledge, despite the lack of engaged stakeholders' understanding of the research methods.

As previously mentioned, this paper is part of ongoing research, which consists of two intertwined research stages. The outcomes of this present study provides a foundation for continuing with the Stage 2 scope of work (Figure 3), which will focus on building, testing and simulating a comprehensive system dynamics model. A casual loop diagram is relevant as an initial step in modelling. Nevertheless, it is unable to identify which variables are flows and which ones are stocks (two central concepts of SD theory). Consequently, future modelling will focus on the use of the system dynamics technique after "quantifying" and translating the CLD into a system dynamics model based on the stock and flow concepts. Such a model enables decision makers to explore potential innovation outcomes resulting from a range of different innovation planning strategies and uncertain situational context scenarios.

Once the stock and flow model is developed, it can be simulated by populating it with data. Software simulations will allow the identification of the system's behaviour over time or to redesign the system's structure by using the key system's variables as leverage. 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 a 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 the system structure. It is especially relevant in the case of the Russian construction industry where high uncertainty and lack of data are involved. Moreover, stakeholder participation is important for validating and checking the model consistency and usefulness, as well as providing information about whether the model needs to be revised. Finally, different scenarios related to the construction industry development, innovation diffusion, policies impacts, and so forth, will be considered.

Author Contributions: Emiliya Suprun performed the review of the pertinent literature, collecting and analysing the data, conceptualising the model and drafting the paper. Oz Sahin, Rodney A. Stewart and Kriengsak Panuwatwanich revised the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Manley, K. Implementation of innovation by manufacturers subcontracting to construction projects. *Eng. Constr. Archit. Manag.* **2008**, *15*, 230–245.
2. Panuwatwanich, K.; Stewart, R.A.; Mohamed, S. Critical pathways to enhanced innovation diffusion and business performance in Australian design firms. *Autom. Constr.* **2009**, *18*, 790–797.
3. Panuwatwanich, K.; Stewart, R.A.; Mohamed S. Validation of an empirical model for innovation diffusion in Australian design firms. *Constr. Innov.: Inf. Process. Manag.* **2009**, *9*, 449–467.
4. Andersson, N.; Widén, K. Construction innovation systems—A sector approach. In Proceeding of the Conference in Advancing Facilities management and Construction through Innovation, Helsinki, Finland, 13-16 June 2005; pp. 203–213.
5. Suprun, E.V.; Stewart, R.A. Construction innovation diffusion in the Russian Federation: Barriers, drivers and coping strategies. *Constr. Innov.* **2015**, *15*, 278–312.
6. Voinov, A.; Gaddis, E.J.B. Lessons for successful participatory watershed modelling: A perspective from modelling practitioners. *Ecol. Model.* **2008**, *216*, 197–207.
7. Torres, N.; Olaya, C. Tackling the mess: System conceptualization through cross-impact analysis. In Proceeding of the 28th International Conference of the System Dynamics Society, Seoul, Korea, 25–29 July 2010.

Peer-reviewed version available at *Systems* **2016**, *4*, 29; doi:10.3390/systems4030029

8. Richards, R.G.; Sano, M.; Sahin, O. Exploring climate change adaptive capacity of surf life saving in Australia using Bayesian belief networks. *Ocean. Coast. Manag.* **2016**, *120*, 148–159.
9. Sahin, O.; Stewart, R.A.; Porter, M.G. Water security through scarcity pricing and reverse osmosis: A system dynamics approach. *J. Clean. Prod.* **2015**, *88*, 160–171.
10. Sahin, O.; Stewart, R.A.; Giurco, D.; Porter, M. Renewable hydropower generation as a co-benefit of balanced urban water portfolio management and flood risk mitigation. Available online: http://www.sciencedirect.com/science/article/pii/S1364032116001817 (accessed on 10 April 2016).
11. Almeida, M.F.L.; Moraes, C.A.C.; Melo, M.A.C. Technology Foresight on Emerging Technologies: Implications for a National Innovation Initiative in Brazil. *J. Technol. Manag. Innov.* **2015**, *10*, 183–197.
12. Lundvall, B.A. Innovation as an Interactive Process: From User-producer Interaction to the National System of Innovation. In *Technical Change and Economic Theory*; Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L., Eds.; Pinter Publisher: London, UK; New York, NY, USA, 1988.
13. Nelson, R. National Innovation Systems: A Retrospective on a Study. *Ind. Corp. Chang.* **1992**, *1*, 347–374.
14. Niosi, J.; Saviotti, P.P.; Bellon, B.; Crow, M. National systems of innovations: In search of a workable concept. *Technol. Soc.* **1993**, *15*, 207–227.
15. Freeman, C. The "National System of Innovation" in Historical Perspective. *Camb. J. Econ.* **1995**, *19*, 5–24.
16. Amable, B; Barré, R.; Boyer, R. *Les Systémes D'innovation a L'ére De La Globalization*; Economica: Paris, France, 1997. (In French)
17. OECD. *National Innovation Systems*; OECD: Paris, France, 1997.
18. Carlsson, B. Innovation Systems: A Survey of the Literature from a Schumpeterian Perspective. In Proceeding of the International Schumpeter Society Conference, Milan, Italy, 9–12 June 2004.
19. Edquist, C. Systems of Innovation: Perspectives and Challenges. In *The Oxford Handbook of Innovation*; Oxford University Press: Oxford, UK, 2004.
20. Na, L; Ofori, G.; Park, M. Stimulating construction innovation in Singapore through the National System of Innovation. *J. Constr. Eng. Manag.* **2006**, *132*, 1063–1082.
21. Uriona, M.; Pietrobon, R.; Varvakis, G.; Carvalho, E. A preliminary model of innovation systems. In Proceeding of the 30th International Conference of the System Dynamics Society. St. Gallen, Switzerland, 22–26 July 2012.
22. Sun, Y.; Grimes, S. The emerging dynamic structure of national innovation studies: A bibliometric analysis. *Scientometrics* **2016**, *106*, 17–40.
23. Nelson, R.; Rosenberg, N. Technical innovation and national systems. In *National Innovation Systems: A Comparative Analysis*; Nelson, R., Ed.; Oxford University: New York, NY, USA; Oxford, UK, 1993.
24. Metcalfe, S. The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives. In *Handbook of the Economics of Innovation and Technological Change*; Stoneman, P., Ed.; Blackwell Publishers: Oxford, UK, 1995.
25. Autio, E. Evaluation of RTD in Regional Systems of Innovation. *Eur. Plan. Stud.* **1998**, *6*, 131–140.
26. Cooke, P. Regional innovation systems, clusters, and the knowledge economy. *Ind. Corp. Chang.* **2001**, *10*, 945–974.
27. Iammarino, S. An evolutionary integrated view of regional systems of innovation. Concepts, measures and historical perspectives. *Eur. Plan. Stud.* **2005**, *13*, 495–517.
28. Malerba, F. Sectoral Systems of Innovation and Production. *Res. Policy* **2002**, *31*, 247–264.
29. Carlsson, B. *Technological Systems in the Bio Industries: An International Study*; Kluwer Academic Publishers: Boston, MA, USA, 2002.
30. Bartholomew, S. National Systems of Biotechnology Innovation: Complex Interdependence in the Global System. *J. Int. Bus. Stud.* **1997**, *28*, 241–266.
31. Turville, L.S. *The Race to the Top;* HM Treasury: London, UK, 2007.
32. Manseau, A.; Seaden, G. *Innovation in Construction—An International Review of Public Policies*; Spoon Press: New York, NY, USA, 2001.
33. Slaughter, E.S. Implementation of construction innovations. *Build. Res. Inf.* **2000**, *28*, 2–17.
34. Winch, G. Zephyrs of creative destruction: Understanding the management of innovation in construction. *Build. Res. Inf.* **1998**, *26*, 268–279.
35. Van Egmond, E. Innovation, Technology and Knowledge Transfer for Sustainable Construction. In *Construction Innovation and Process Improvement*, 1st ed.; Akintoye, A., Goulding, J.S., Zawdie, G., Eds.; Wiley-Blackwell: London, UK, 2012, pp. 95–123.

36. Andersson, N. A Mesoeconomic Analysis of the Construction Sector. Ph.D. Thesis, Lund University, Lund, Sweden, 2003.
37. Seaden, G.; Manseau, A. Public policy and construction innovation. *Build. Res. Inf.* **2001**, *29*, 182–196.
38. Dulaimi, M.F.; Nepal, M.P.; Park, M. A hierarchical structural model of assessing innovation and project performance. *Constr. Manag. Econ.* **2005**, *23*, 565–577.
39. Hampson, K.D.; Kraatz, J.A.; Sanchez, A.X. *R&D Investment and Impact in the Global Construction Industry*; Routledge: Oxon, UK, 2014.
40. Milford, R.V. National Systems of Innovation With Reference to Construction in Developing Countries. In Proceedings of the 2nd International Conference on Construction in Developing Countries, Gaborone, Botswana, 15–17 November 2000.
41. Gann, D.M. How does innovation link to research? *Build. Res. Inf.* **2001**, *29*, 250–252.
42. Aouad, G.; Ozorhon, B.; Abbott, C. Facilitating innovation in construction. *Constr. Innov.* **2010**, *10*, 374–394.
43. Sterman, J. *Business Dynamics: Systems Thinking and Modelling for a Complex World*; McGraw-Hill: Boston, MA, USA, 2000.
44. Forrester, J.W. *Industrial Dynamics*; MIT Press: Cambridge, MA, USA, 1961.
45. Voinov, A.A. *Systems Science and Modelling for Ecological Economics*; Elsevier: Amsterdam, The Netherlands, 2008.
46. Cole, A.; Allen, W.; Kilvington, M.; Fenemor, A. Participatory modelling with an influence matrix and the calculation of whole-of-system sustainability values. *Int. J. Sustain. Dev.* **2007**, *10*, 382–401.
47. Godet, M. *Creating futures: Scenario Planning as a Strategic Management Tool*; Économica: London, UK, 2006.
48. Gann, D.M.; Salter, A. Innovation in project-based, service-enhanced firms: The construction of complex products and systems. *Res. Policy* **2000**, *29*, 955–972.
49. Goodrum, P.M.; Haas, C.T.; Caldas, C. Model to predict the impact of a technology on construction productivity. *J. Constr. Eng. Manag.* **2011**, *137*, 678–688.
50. Xue, X.; Zhang, R.; Dai, J. Innovation in construction: A critical review and future research. *Int. J. Innov. Sci.* **2014**, *6*, 111–126.
51. Na, L.J.; Ofori, G.; Ling, F.Y.Y.; Hua, G.B. Role of national institutions in promoting innovation by contractors in Singapore. *Constr. Manag. Econ.* **2007**, *25*, 1021–1039.
52. Gumba, K.M. *Efficient Control over Development of Innovative Processes at Enterprises of the Construction Industry*; ASV Publishing House: Moscow, Russia, 2009.
53. Blayse, A.M.; Manley, K. Key influences on construction innovation. *Constr. Innov.* **2004**, *4*, 143–154.
54. De Valence, G. Competition and barriers to entry in the construction industry. In *Modern Construction Economics: Theory and Application*; Taylor&Francis: Oxford, UK, 2011; pp. 100–116.
55. Gokhberg, L.; Kuznetsova, T.; Ryud, V. Analysis of innovative modes at Russian economy: Methodological approaches and some results. *Foresight* **2010**, *3*, 18–30.
56. Li, B.; Akintoye, A. An overview of public-private partnership. In *Public-Private Partnerships: Managing Risks and Opportunities*; Akintoye, A., Beck, M., Hardcastle, C., Eds.; Blackwell Science: Oxford, UK, 2003.
57. Leiringer, R. Technological innovation in the context of PPPs: Incentives, opportunities and actions. *Constr. Manag. Econ.* **2006**, *24*, 301–308.
58. Dulaimi, M.F.; Ling, Y.; Bajracharya, A. Enhancing integration and innovation in construction. *Build. Res. Inf.* **2002**, *30*, 237–247.
59. Stewart, R.A.; Mohamed, S.; Marosszeky, M. An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry. *Constr. Innov.: Inf. Process. Manag.* **2004**, *4*, 155–171.
60. Grigoryev, Y.V. Obstacles of innovative activity. *Innov. Ind. Policy Econ.* **2011**, *4*, 5–14.
61. MICMAC. Structural Analysis. Methods of Prospective website. Available online: http://en.laprospective.fr/methods-of-prospective/softwares/59-micmac.html (accessed on 20 February 2016).