Supplementary Materials

An integrated participatory systems modelling approach: Application to construction innovation

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Content of supplementary materials

SM-1. Stakeholder profile

Table SM-1.1. Stakeholder profile

Stakeholder engagement form	Number of participants	Participants
Modelling stage 1. Problem scoping		
Questionnaire survey	52	• Engineers and builders (28%) • Construction companies project and senior managers (21%) • Construction companies directors (18%) • Architects and designers (14%) • Manufacturers (11%) • Researchers and academics from the following fields: civil engineering, architectural engineering, municipal and structural engineering, construction management (8%).
One-on-one semi-structured post hoc interviews	12	• Researchers and academics (33%) • Construction companies project and senior managers (17%) • Engineers and builders (17%) • Architects and designers (17%) • Construction companies directors (8%) • Manufacturers (8%)
Modelling stage 2. Conceptualisation		
One-on-one expert consultations	7	• Researchers and academics (44%) • Construction companies project and senior managers (28%) • Designers (28%)
Opinion survey through one-on-one structured interviews	14	• Researchers and academics (44%) • Public servants working on innovation development programs (21%) • Engineers and builders (14%) • Construction companies project and senior managers (7%) • Construction companies directors (7%) • Architects and designers (7%)
Three facilitated 2-hour workshops	12	• Researchers and academics (33%) • Public servants working at the Department of Construction, Transport and Housing of the Belgorod region (17%) • Construction companies project and senior managers (17%) • Construction companies directors (17%) • Engineers and builders (8%) • Architects and designers (8%)
Modelling stage 3. Dynamic model formulation		
A facilitated 1-day workshop №1	6	• Researchers and academics (33%) • Public servants working at the Department of Construction, Transport and Housing of the Belgorod region (17%) • Public servants working on innovation development programs (17%) • Construction companies project and senior managers (17%) • Construction companies directors (17%)
A facilitated 1-day workshop №2	8	• Researchers and academics (37%) • Public servants working on innovation development programs (25%) • Construction companies directors (25%) • Construction companies project and senior managers (13%)
Modelling stage 4. Model analysis		
One-on-one expert consultations	8	• Researchers and academics (37%) • Construction companies directors (24%) • Public servants working at the Department of Construction, Transport and Housing of the Belgorod region (13%) • Public servants working on innovation development programs (13%) • Construction companies project and senior managers (13%)
Modelling stage 5. Model use and recommendations		
One-on-one expert consultations	8	• Researchers and academics (37%) • Construction companies directors (24%) • Public servants working at the Department of Construction, Transport and Housing of the Belgorod region (13%) • Public servants working on innovation development programs (13%) • Construction companies project and senior managers (13%)

SM-2. Background of the case study

In the Russian construction industry, 70% of the total implemented innovations are technological, involving the utilisation of technical approaches to either process or product innovation such as machinery and engineering equipment, cutting edge technology, software for architectural and construction design as well as information modelling. Such products aim to improve the efficiency of construction works and to accomplish high economic, technological and functional values to building operations.

The proportion of construction companies implementing technological innovations is less than 5% of the total market size compared to other sectors of Russia's economy such as the energy (22%) and biomedical (29%) industries (Gorodnikova et al., 2017). This low rate occurs mainly because micro and small companies make up around 90% of the construction industry. According to the Bureau of Statistics (FSSS, 2018), about half of the construction works in the country are completed by companies with an average number of employees up to 15 people and annual revenues of less than 100 million roubles (1.8 million USD at February 2018). It goes without saying that such firms are forcedly conservative and cannot afford to invest in innovation and take advantage of technological know-how.

According to the government forecast, the number of innovative construction companies is going to increase significantly over time (SM-2.1).

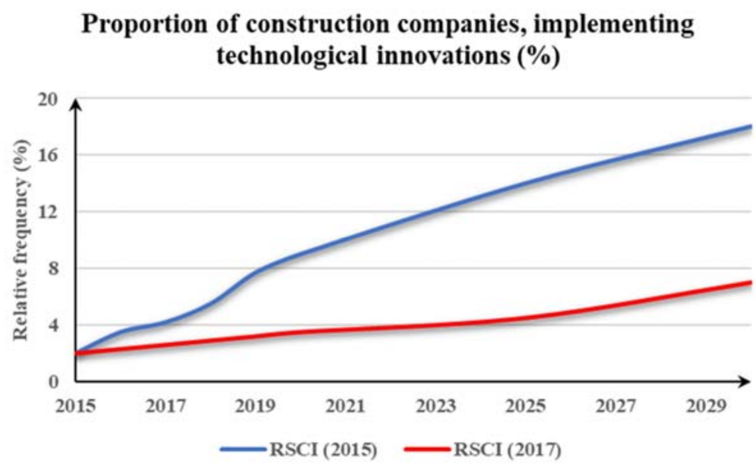

Figure SM-2.1. Reference mode diagram showing the government forecast (RSCI, 2015, RSCI, 2017)

As can be seen in Figure SM-2.1, there are two versions of an 'Innovative development strategy for the construction industry in Russia for the period up to 2030' (RSCI, 2015, RSCI, 2017). Initially, the Russian government was expecting ten-fold increase in the frequency of innovative construction companies by 2030. Nevertheless, it seemed to be a very ambitious plan given the relatively short period of time and current political and business issues that might affect innovation diffusion in the country and the industry, in particular, in a negative way. Undoubtedly, a number of systematically targeted strategies and rational policies is needed to achieve such results. However, the strategy was readjusted in 2017 showing a new trend (RSCI, 2017). According to the new forecast, the level of technological innovation is planned to be tripled by 2030. This change proves the observed complication of the manufacturing processes in the construction sector, including introduction of an innovative component.

In addition to weak investment activity, there are excessive administrative barriers, inappropriate technical regulation, and variance of construction norms and codes to international standards. Coordination of construction procedures, time, and cost, are considered to be the primary problems of the Russian construction sector (Suprun and Stewart, 2015). Due to a number of measures taken by the government to simplify the process of obtaining building licenses and documentation, Russia takes 115th place out of 186 for the time and ease of such procedures, compared to 156th place in 2015 (Doing Business, 2018). Nevertheless, 230 days are still spent dealing with the construction permits while for Europe and Central Asia it is 168 days on average. In comparison, it takes 27.5 days in South Korea (28th place), 86 days in the UK (14th place), 121 days in Australia (6th place), and 161 days in the Netherlands (76th place).

Business confidence in the construction industry has remained negative since the mid-1990s, which in turn significantly hinders innovation implementation. An exception was in 2008, when the business confidence index reached 5%. By 2014, the index had approached zero and continued to show negative dynamics during the crisis of 2014-2016 (FSSS, 2018). In 2017 the Ministry of Economic Development had forecasted a 4.2% increase in the industry turnover by the end of the year. However, according to the department's reports, the construction fell by 1.9%, and the confidence index reached -15% (IZ, 2018). Nevertheless, experts forecast the increase of the index to -4% in 2018. In other words, there is a potential for the development of the construction sector despite the market instability.

Industry, government, and academia contribute to and benefit from the introduced innovations as they constitute part of the system's environment in their role as innovation generators, policy makers and knowledge brokers. It is clear, that construction development is highly influenced by the variety of complex interactions between these three actors. For instance, the government plays a major influential role within the construction industry contributing to the system's balance as a policy-maker and legislator. Innovation generators represented by construction firms, design companies and knowledge developers need to be encouraged to innovate through public policies, laws and incentive mechanisms (Miozzo and Dewick, 2002, Slaughter, 1993). In addition, government as a client significantly influences and motivates other actors by driving demand for research and innovation through regulatory frameworks and procurement schemes.

Public funds comprise institutional funding granted specifically to universities and research centres, meanwhile, industrial and scientific organisations contribute to the country's GDP.

Research organisations and universities are responsible for training the next generation of innovators and diffusing knowledge within the innovation system. Furthermore, academia improves overall national innovative capabilities by assisting construction companies in testing and evaluating research results and innovative solutions (Hampson et al., 2014). Hence, the industry may be considered as a mediator between R&D institutions by investing in research.

SM-3. Summary of feedback loops within the extended causal loop diagram

Sixteen main feedback loops emerged from the extended causal loop diagram representing involvement of the industry, government and academia in the innovation process within the construction innovation system (Table SM-3.1). The assembled causal loop diagram (CLD) consists of seven themes.

Innovation diffusion. The innovation diffusion process takes two forms in the construction industry representing different dynamics (Suprun and Stewart, 2015). Development of innovative solutions is performed by actual innovators involved in the R&D activity that introduce and implement product and process innovations that are new to the industry or market (Figure SM-3.1). The second group of innovative companies is represented by imitators that adopt already known technological innovations (Bass, 1969, Kunc, 2004).

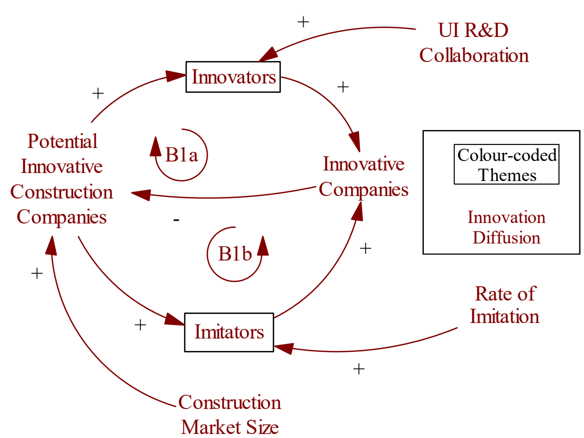

Figure SM-3.1. CLD: Layer 1

Table SM-3.1. Summary of feedback loops

Loops	Loop name	Structure	Theme
B1a	Market saturation	Potential innovative construction companies → Innovators → Innovative companies → Potential innovative construction companies	Innovation diffusion
B1b	Market saturation	Potential innovative construction companies → Imitators → Innovative companies → Potential innovative construction companies	Innovation diffusion
B2a	Client satisfaction driven motivation in short-term prospective	Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Quality of construction projects → Construction cost to a client → Client satisfaction → Business performance of construction companies → Attractiveness of innovation → Innovative companies	Attractiveness of being innovative
B2b	Profit driven motivation in short-term prospective	Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Quality of construction projects → Construction cost to a company → Profitability → Business performance of construction companies → Attractiveness of innovation → Innovative companies	Attractiveness of being innovative
B3	Government support	Attractiveness of innovation → Level of government support → Government incentives → Attractiveness of innovation	Attractiveness of being innovative
R1a	Client satisfaction driven motivation in long-term prospective	Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Construction cost to a company → Construction cost to a client → Client satisfaction → Business performance of construction companies → Attractiveness of innovation → Innovative companies	Attractiveness of being innovative
R1b	Profit driven motivation in long-term prospective	Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Construction cost to a company → Profitability → Business performance of construction companies → Attractiveness of innovation → Innovative companies	
B4	Reduction of regulatory burden	Attractiveness of innovation → Need to improve legislation → Level of administrative barriers to innovation → Attractiveness of innovation	Attractiveness of being innovative
R2	Competitive pressure to innovate	Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Quality of construction projects → Competitive advantage → Market share → Competition on traditional construction companies → Pressure to innovate → Innovative companies	Pressure to innovate
R3	Client requirements	Client demand → Pressure to innovate → Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Quality of construction projects → Client satisfaction → Client demand	Pressure to innovate
R4	Building absorptive capacity	Investment in innovation → Awareness and training → Absorptive capacity → Innovative capability → Rate of imitation → Imitators → Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Construction cost to a company → Profitability → Investment in innovation	Building innovative capability
R5a	Building R&D capability through industry involvement	Investment in innovation → R&D funding → R&D infrastructure → R&D capability → Innovative capability → UI R&D collaboration → Innovators → Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Quality of construction projects → Competitive advantage → Market share → Revenue of a company → Profitability → Investment in innovation	Building innovative capability
R5b	Building R&D capability through government involvement	GDP → Government incentives → R&D funding → R&D infrastructure → R&D capability → Innovative capability → UI R&D collaboration → Innovators → Innovative companies → Actual success rate of innovation → Gap between desired and actual success rate of innovation → Construction cost to a company → Construction cost to a client → Client satisfaction → Client demand → Revenue of a company → Construction Sector turnover → Construction contribution to GDP → GDP	Building innovative capability
B5	Overcoming industry isolation	Level of R&D activity → Level of government support → Government incentives → R&D funding → Attractiveness of research → R&D expertise → R&D capability → Level of R&D activity	R&D activity
B6a	Industry development	Gap between desired and actual import substitution policy performance → Perceived need for innovation → Need to improve legislation → Government incentives → Attractiveness of innovation → Investment in innovation → Rate of imitation → Imitators → Actual import substitution policy performance → Gap between desired and actual import substitution policy performance	Impact of import substitution policy
B6b	Import substitution	Gap between desired and actual import substitution policy performance → Perceived need for innovation → Need to improve legislation → Government incentives → R&D capability → Level of R&D activity → Industry readiness for UI R&D collaboration → UI R&D collaboration → Innovators → Actual import substitution policy performance → Gap between desired and actual import substitution policy performance	Impact of import substitution policy

Requirements for innovativeness. According to the group discussions with stakeholders and previously conducted studies (Suprun and Stewart, 2015), there are three main factors that influence or force decision-makers at construction companies to acknowledge innovation implementation as a priority process to improve the efficiency and effectiveness of the industry (Figures SM-3.2 and SM-3.3). First of all, there is a need to create an environment where innovative organisations have successful access to innovative technologies and are able to maintain high-tech business. In other words, innovations have to be attractive. Moreover, in order to be innovative, construction firms need to allocate capabilities in the entire construction innovation system in order to achieve the benefits of the high-level innovation performance. Last, and importantly, given the growing domestic and international competition in the world of construction, only companies allocating sufficient investment into the new technology and highly skilled personnel may expect to a have a stable position in the market. Additionally, a client may create demand for new alternatives (Miozzo and Dewick, 2002, Seaden and Manseau, 2001).

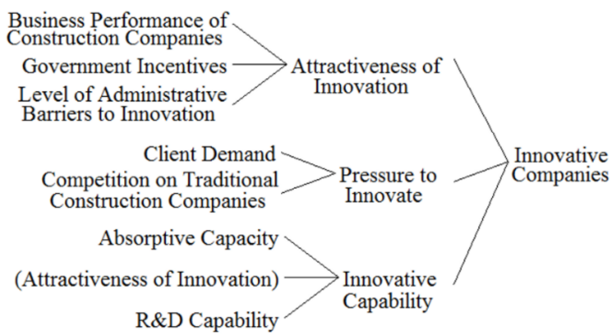

Figure SM-3.2. An influence tree for the 'Innovative companies' variable

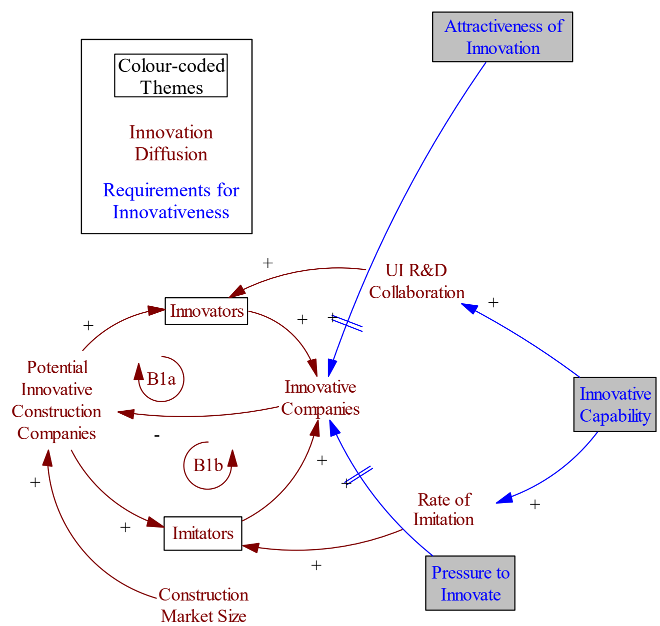

Figure SM-3.3. CLD: Layer 2

Attractiveness of being innovative. Many studies recognise innovation as a factor that directly increases a firm's performance (Dansoh et al., 2017, Lim and Peltner, 2011, Panuwatwanich et al., 2009). Use of innovative materials and technology enable companies to improve the quality of their products and services, reduce cost and time of construction works, enter new markets, and satisfy high expectations of customers. It is clear that an efficient and profitable industry drives economic growth. Nevertheless, a large number of investors and owners of construction companies have short-term business thinking, which in turn, makes them to focus only on how much profit they will obtain. In other words, in the Russian construction industry cost is still a priority. Once innovation is successfully implemented, the cost to a client increases due to high quality, subsequently leading to decline in client satisfaction, which eventually negatively influences the attractiveness of innovation (balancing loop B2a) (Figure SM-3.4). In fact, significant expenditures on innovation lead to more expensive projects at first, that in a short-term prospective makes contractors to revert to using of traditional, well-recognised methods (balancing loop B2b).

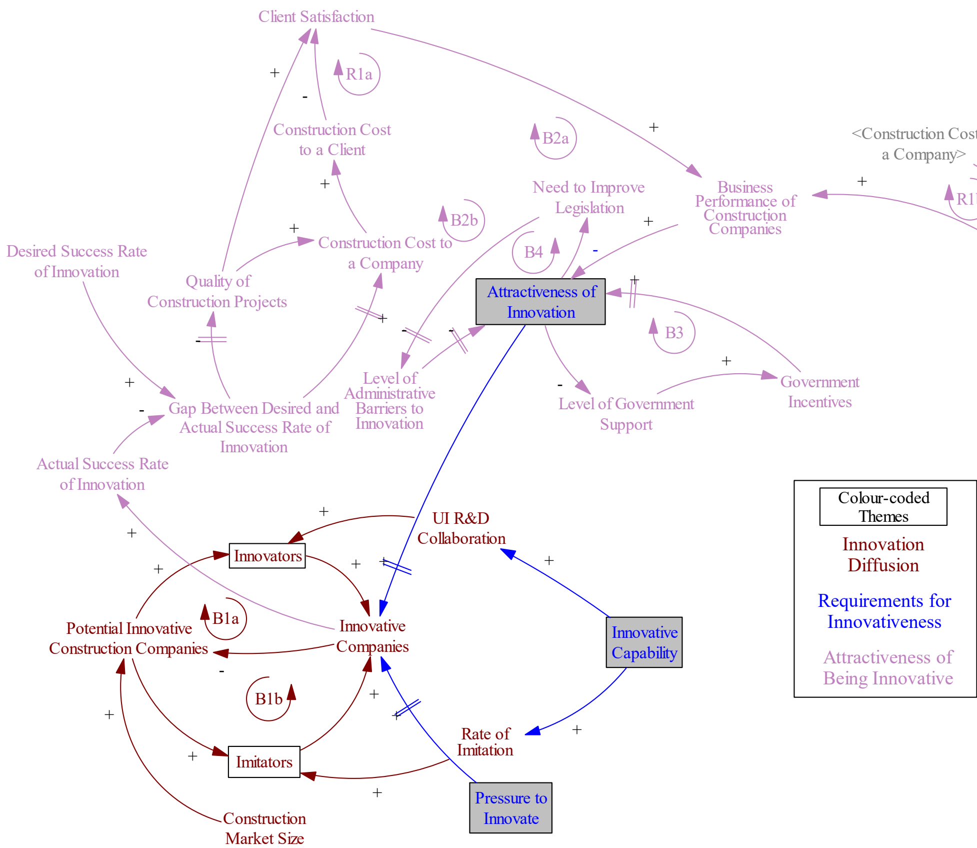

Figure SM-3.4. CLD: Layer 3

Consequently, government support is needed in order to boost innovative activity at the initial stage, cover some of industry's expenses, and maximise the profit. Appropriate incentive mechanisms would increase the economic interest of organisations and attractiveness of investments, giving the companies an opportunity to compete without forcing them to wait for short-term benefits despite the additional construction costs (balancing loop B3) (Figure SM-3.4). By receiving such support, the industry will be developing its capabilities gradually and, in a long-term prospective will increase the level of attractiveness by satisfying the customers' needs (reinforcing loop R1a) and receiving high profits (reinforcing loop R1b).

Unlike efficient support and high business performance, administrative barriers hinder companies willingness to be a part of the innovation process (balancing loop B4) (Figure SM-3.4). For instance, uncertainty about the rules and legal frameworks as well as inflexible regulations of use of certain materials may impede the demand and image of such materials. Moreover, some government procedures such as strict state expert examination add complexities to doing work in the field, which, in turn, has a negative impact on time of construction and increasing costs (HSE, 2013, Suprun and Stewart, 2015). As mentioned above, Russia takes 115th place out of 186 for the time and ease of such procedures in obtaining building permits.

Pressure to innovate. High competition in the market and client demand force decision-makers at construction firms to consider innovation implementation to stay afloat. It is generally accepted that companies gain a competitive advantage by introducing innovative solutions and adopting new technology (Miozzo and Dewick, 2002, Stewart, 2007). By improving the quality of construction products and services along with lower costs due to the use of innovation, a contractor may significantly increase its competitive advantage in the market and even build an international reputation (reinforcing loop R2). As a result, however, entering larger markets leads to the greater competition that reinforces the pressure to invest more in cutting-edge ideas and R&D for a more competitive outlook (Figure SM-3.5).

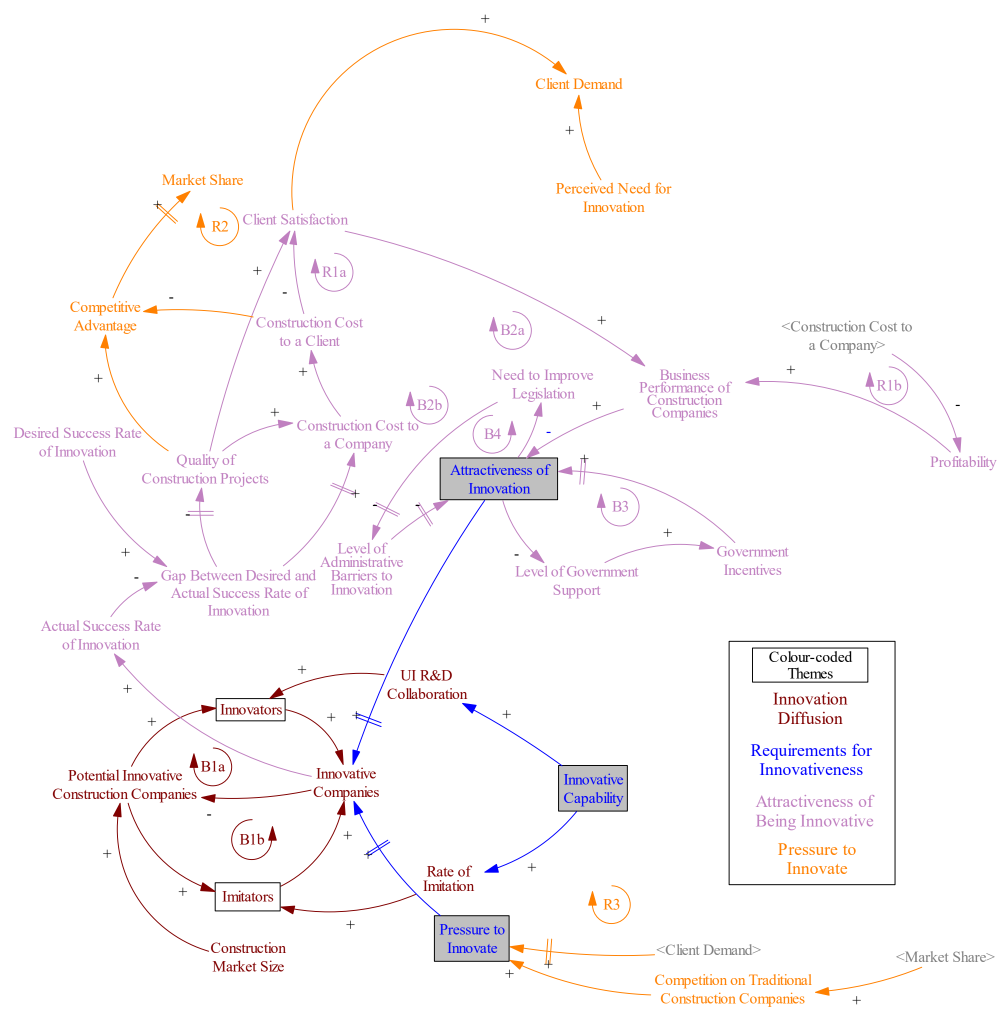

Figure SM-3.5. CLD: Layer 4

Clients, whether private customers or government, may significantly influence the industry's decision regarding innovation preferences. Satisfying the clients' needs and demands is highly conducive for innovation (reinforcing loop R3) (Figure SM-3.5). Moreover, the government may demand more active use of innovative and sustainable applications and construction methods for the industry to meet the requirements of the import substitution policy (RSCI, 2015, RSCI, 2017).

Building innovative capability. A firm's success in implementing cutting-edge technology depends on companies' capabilities as the process of transferring ideas into the end-product or service may become extremely complicated and costly (Hampson et al., 2014, Manley, 2008). It is essential to build the innovative capabilities for any potential innovative company within the innovation system, whether it is an organization giving preference to adopting new technology and developing methods for its improvement, or companies investing in R&D (Castellacci and Natera, 2013) (Figure SM-3.6). So-called imitators need to invest in their ability to be a part of the innovation process. In other words, building of absorptive capacity needs to be supported (reinforcing loop R4). Once companies start investing in qualified personnel and training of the professionals, their innovative capability increases followed by successful innovation implementation and, as a result, higher investments to be taken on innovative processes and practices.

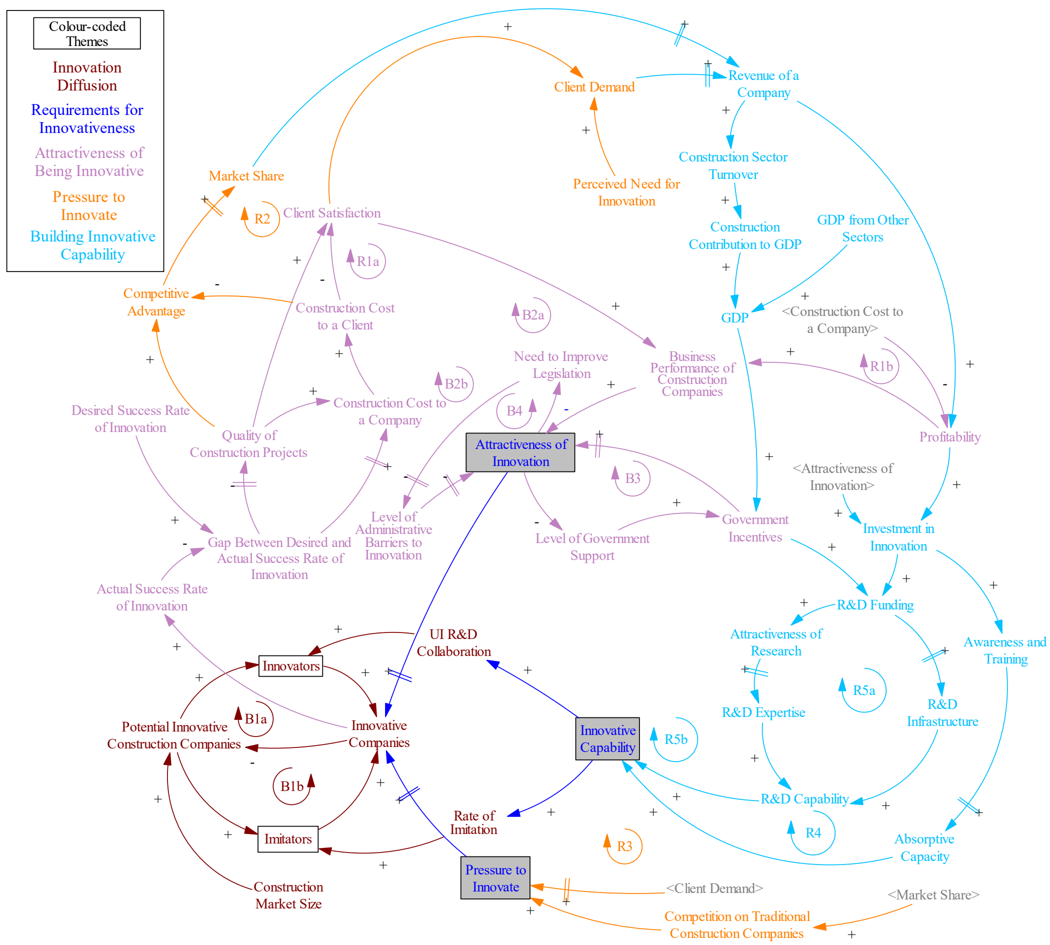

Figure SM-3.6. CLD: Layer 5

R&D activity. As previously mentioned, construction organisations do not innovate in isolation as isolation hinders the knowledge generation process (Bruneel et al., 2010, OECD, 1997, Seaden and Manseau, 2001, Suprun et al., 2016). In case of insufficient R&D capability, the government as a policy-maker can significantly influence the R&D progress and close the gap between universities and the industry by implementing encouraging incentive schemes, policies and relevant award programs. Consequently, the level of R&D activity increases due to efficient government support (balancing loop B5). As a result, industry readiness for industry-academia collaboration achieves a higher level along with gradually declining industry isolation (Figure SM-3.7).

Impact of import substitution policy. As mentioned above, the Russian government takes measures aimed at stimulating the demand for domestic production and development along with innovated goods and services (RSCI, 2015, RSCI, 2017, TASS, 2014). Hence, a need for innovation occurs, leading to changes in the legislation and implementation of more efficient incentive schemes. As a result, some regulatory and financial frameworks encourage companies to invest more and bring new ideas into construction projects successfully. The industry is developing gradually due to increasing numbers of companies adopting innovations from others (balancing loop B6a) (Figure SM-3.8). However, it may not lead to a country's development as a result of R&D improvement. Hence, additional government intervention and support is needed (balancing loop B6b). At the same time, when there are more innovators than imitators, the government starts giving more responsibilities to the industry itself. Due to various motivating factors the industry continues to be innovative with less government contribution.

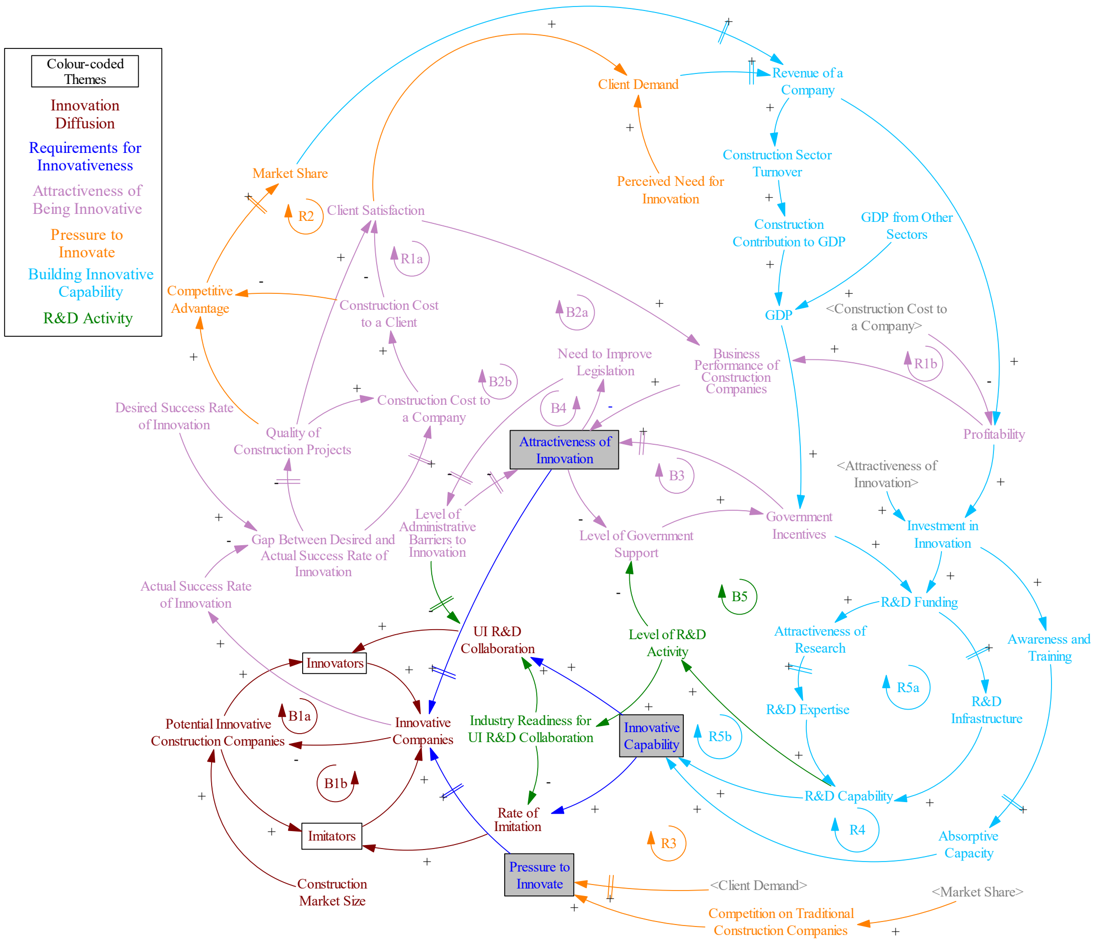

Figure SM-3.7. CLD: Layer 6

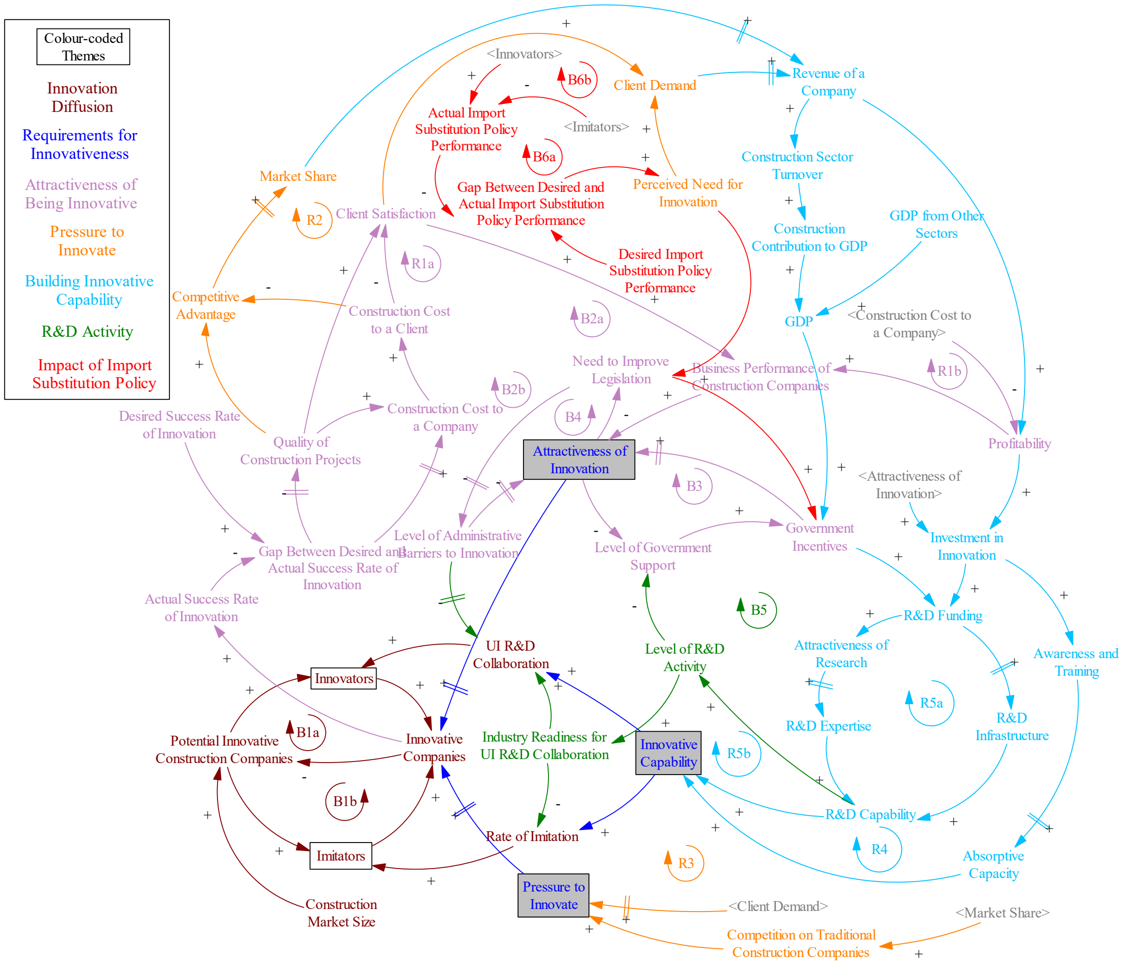

Figure SM-3.8. CLD: Layer 7

SM-4. Summary of variables within the stock and flow diagram of innovation diffusion in the construction industry

Table SM-4.1. Qualitative scale for the variables impacting attractiveness of being innovative

Variable	Scale (%)	Characterisation	Description
Administrative barriers	< 20	Acceptable	• improved regulatory and technical legislation in research, architectural and construction design, construction and standardisation; • improved regulatory and technical documents harmonised with the international standards ensuring innovation implementation;
	20 – 39	Medium	• simplified and accelerated certification procedure in accordance with international quality standards; • simplified procedures for interaction with the federal and local public authorities;
	40 – 59	High	• imperfection of technical regulation;
	60 – 79	Excessive	• lack of developed and implemented standards that encourage industrialists to minimise usage of obsolete technologies and equipment; • incompatibility of construction norms, codes and rules with international standards;
	80 – 100	Insurmountable	• outdated standards and other regulatory documents.
Government support	< 20	Insufficient	• lack of or very weak systemic public support and inadequate incentive measures to stimulate the construction sector and related industries (e.g. design, transportation, engineering, protection of natural resources, science, education).
	20 – 39	Poor	• insufficient instruments of government support for innovative activities, i.e. limited flexibility and underdevelopment of mechanisms for allocating risks between the state and construction companies; weak focus on stimulating links between various actors in innovation processes, including research and production partnerships.
	40 – 59	Adequate	• development of various mechanisms to support technological modernisation of the industry, while there are still only individual improvements, fragmentation and instability of the overall progress in this area remain; • stimulation of demand for innovative products; • state control of enterprises that do not meet the requirements of energy and resource consumption along with the environmental safety.
	60 – 79	Sufficient	• improved grant schemes for medium and large enterprises in the construction industry that implement innovative solutions; • strengthening support for fundamental and applied research in universities and research centres followed by integrated scientific and educational activities; strengthening the export role of the Russian science.
	80 – 100	High	• direct budget funding; • subsidising of an interest rate on loans for enterprises that produce and purchase innovative equipment.
Industry business performance	< 20	Poor	• weak business performance in terms of low quality, high costs, very narrow profit margins and unsatisfied clients.
	20 – 39	Unsatisfactory	• low quality-price ratio of the investments.
	40 – 59	Satisfactory	• a company's revenue is higher than the investment required for development and implementation of innovation.
	60 – 79	Good	• increased productivity and profitability as a result of application of innovative practices; • completed projects meet specifications and clients' expectations.
	80 – 100	Excellent	• desired performance in terms of superior quality and high client satisfaction; • strong financial performance and profitability; • arising opportunities to enter new markets.

Table SM-4.2. Summary of variables within the stock and flow diagram of innovation diffusion in the construction industry

Variable	Unit	Description	Equation and/or assumption	Source
Potential innovative companies	Firm	Number of medium and large-sized construction firms that have not introduced / implemented technological innovation yet	INTEG (Change in potential innovative companies – Innovativeness attraction rate, initial potential innovative companies stock) Initial potential innovative companies = Proportion of large and medium-sized construction firms * Construction market size – Actual innovative companies	Stakeholder workshops; RSCI (2015), RSCI (2017)
Construction companies willing to innovate	Firm	Construction firms making decision in favour of introducing / implementing technological innovation depending on change in attractiveness of being innovative based on business performance of construction firms, level of government support and level of administrative barriers	INTEG (Innovativeness attraction rate – Imitation rate – Innovation rate, initial construction companies willing to innovate stock) Initial construction companies willing to innovate = Potential innovative companies * 0.18 0.18 is the initial attractiveness of innovation	Stakeholder workshops
Innovators	Firm	Number of construction firms introducing / implementing technological innovation as a result of collaborative R&D	INTEG (Innovation rate, initial innovators stock) Initial innovators = 1177	Stakeholder workshops; RSCI (2015), RSCI (2017) Authors' calculation based on FSSS (2018) and Gorodnikova et al. (2017)
Imitators	Firm	Number of construction firms introducing / implementing technological innovation by adopting from others	INTEG (Imitation rate, initial imitators stock) Initial imitators = 3530	Stakeholder workshops; RSCI (2015), RSCI (2017) Authors' calculation based on FSSS (2018) and Gorodnikova et al. (2017)
Actual innovative companies	Firm	Number of innovative construction firms	Imitators + Innovators	Stakeholder workshops
Construction market size	Firm	Total amount of construction companies	INTEG (Change in construction market size, initial construction market size stock) Construction market size = 235351	Stakeholder workshops FSSS (2018)
Innovativeness attraction rate	Firms/Year	Construction firms making decision in favour of introducing / implementing technological innovation annually	Potential innovative companies * Attractiveness of being innovative / Time for industry to adjust to attractiveness factors	Stakeholder workshops
Innovation rate	Firms/Year	Construction firms introducing / implementing technological innovation through R&D annually	New innovative companies from R&D collaboration	Stakeholder workshops; RSCI (2015), RSCI (2017)
Imitation rate	Firms/Year	Construction firms introducing / implementing technological innovation through adoption from others annually	New innovative companies from imitation	Stakeholder workshops; RSCI (2015), RSCI (2017)
Change in construction market size	Firms/Year	Construction companies entering or exiting the market annually	Construction market size * Market growth rate / Time to grow	Stakeholder workshops, FSSS (2018) and Gorodnikova et al. (2017)
Change in potential innovative companies	Firms/Year	Construction companies becoming medium and large-sized annually	Construction market size * Market growth rate * Proportion of large and medium-sized construction firms / Time to adjust to changes in the market	
New innovative companies from R&D collaboration	Firms/Year	Construction firms introducing / implementing technological innovation through R&D annually according to the effectiveness of the industry and academia collaborative effort with the pool of potential innovative companies	Construction companies willing to innovate * Effectiveness of industry and academia collaboration	Stakeholder workshops; RSCI (2015), RSCI (2017)

Variable	Unit	Description	Equation and/or assumption	Source
New innovative companies from imitation	Firms/Year	Construction firms introducing / implementing technological innovation annually by adopting innovations from others. The number of firms is driven by the rate of contacts among potential adopters and active innovative companies. The adoption from competitors is small if the number of active innovative companies relative to the total number of construction companies is small.	Fraction of imitation * Actual innovative companies * Construction companies willing to innovate / (Construction market size * Proportion of large and medium-sized construction firms)	Stakeholder workshops; RSCI (2015), RSCI (2017)
Effectiveness of industry and academia collaboration	1/Year	Research results leading to innovation implementation according to the effectiveness of industry collaboration with academia	0.011	Authors' calculation based on stakeholder workshops, FSSS (2018) and Gorodnikova et al. (2017)
Fraction of imitation	1/Year	Rate at what potential innovative construction companies adopt innovative solutions from innovative competitors due to companies access to innovation-related information	0.22	Authors' calculation based on stakeholder workshops, FSSS (2018) and Gorodnikova et al. (2017)
Market growth rate	Dimensionless	Proportion of construction companies entering or exiting the market	0.02	Authors' calculation based on FSSS (2018) and Gorodnikova et al. (2017)
Level of innovation	Dimensionless	Proportion of innovative construction companies in the total market size	Actual innovative companies / Construction market size * 100	Stakeholder workshops; Structural analysis with MICMAC; RSCI (2015), RSCI (2017)
Proportion of large and medium-sized construction firms	Dimensionless	Proportion of construction companies potentially capable of introducing / implementing technological innovation	0.152	FSSS (2018)
Attractiveness of being innovative	Dimensionless	Index based on three factors that influence industry's decision to consider higher investments in innovation: business performance of construction companies, level of government support and level of administrative barriers	Effect of Government Support on Attractiveness of Innovation * 0.33 +(Effect of Industry Business Performance on Attractiveness of Innovation * 0.26 + Effect of Administrative Barriers on Attractiveness of Innovation * 0.41	Stakeholder workshops; Structural analysis with MICMAC
Effect of industry business performance on attractiveness of innovation	Dimensionless	Level of attractiveness of innovation as a function of the industry's business performance	Effect of industry business performance on attractiveness of innovation lookup (Business performance of construction companies)	Stakeholder workshops
Effect of government support on attractiveness of innovation	Dimensionless	Level of attractiveness of innovation as a function of the level of government support	Effect of government support on attractiveness of innovation lookup (Level of government support)	Stakeholder workshops
Effect of administrative barriers on attractiveness of innovation	Dimensionless	Level of attractiveness of innovation as a function of the level of administrative barriers to innovation	Effect of administrative barriers on attractiveness of innovation lookup (Level of administrative barriers to innovation)	Stakeholder workshops
Business performance of construction companies	Dimensionless	A function of a company's profitability and client satisfaction as ones of the most essential industry motivation points.	0.4	Stakeholder workshops
Level of government support	Dimensionless	State of public support and public policies (e.g., federal targeted programmes, direct financial investments)	0.4	Stakeholder workshops; RSCI (2015), RSCI (2017)
Level of administrative barriers to innovation	Dimensionless	Barriers related to the conservative building codes and standards; government contracts with inflexible fixed budgets, and so forth.	0.7	Stakeholder workshops; RSCI (2015), RSCI (2017)
Effect of administrative barriers on attractiveness of innovation lookup	Dimensionless	Lookup function showing relationship between level of administrative barriers to innovation and attractiveness of innovation (exponential decay behaviour)	Lookup function	Stakeholder workshops

Variable	Unit	Description	Equation and/or assumption	Source
Effect of government support on attractiveness of innovation lookup	Dimensionless	Lookup function showing relationship between level of government support and attractiveness of innovation (goal seeking behaviour)	Lookup function	Stakeholder workshops
Effect of industry business performance on attractiveness of innovation lookup	Dimensionless	Lookup function showing relationship between industry's business performance and attractiveness of innovation (s-shaped growth behaviour)	Lookup function	Stakeholder workshops
Time to grow	Year	Time for construction companies to set up business and start functioning	1	Stakeholder workshops; RSCI (2015), RSCI (2017)
Time to adjust to changes in the market	Year	Time needed for companies new to the market to become medium and large-sized	4	Stakeholder workshops; RSCI (2015), RSCI (2017)
Time for industry to adjust to attractiveness factors	Year	Time needed for the industry to make a decision in favour of innovation pathway due to improving business performance, reducing administrative and regulatory burden as well as a result of active government involvement in the innovation process	2	Stakeholder workshops; RSCI (2015), (RSCI (2017))

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