Research article
DOI: https://doi.org/10.48554/SDEE.2021.1.3

VALIDATION OF FACTORS FOR ASSESSING THE DIGITAL POTENTIAL OF THE REGIONAL CONSTRUCTION COMPLEX AS A BASIS FOR SUSTAINABLE DEVELOPMENT

Ekaterina Tereshko[1]*, Irina Rudskaya[1], Mario Claudio Dejaco[2], Sofia Pastori[2]

[1] Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia, ektereshko@mail.ru, rudskaya_ia@spbstu.ru
[2] Politecnico di Milano, Milan, Italy, mario.dejaco@polimi.it, sofia.pastori@polimi.it
* Corresponding author: ektereshko@mail.ru

Abstract

It seems promising and relevant to consider digital processes of industries and complexes in the context of the digital transformation of a region, which encourages the region's sustainable development. Due to the digitalisation of the construction complex of a region we can evaluate the digital infrastructure development at the design and production stage (i.e. from the design documentation to the commissioning of facilities). The basis for the digitalisation of the construction complex is BIM technologies, which should be transferred from the micro level to the meso level (the level of a municipality or region) and later to the macro level (the level of the entire country). The study aimed to analyse and estimate groups of quantitative factors that characterise the digital potential of the construction complex. The research methods included quantitative and qualitative analysis. A comparative analysis of factors (i.e. indexes and rankings) was performed, and the groups of factors were ranked to determine whether regions are ready to digitalise the construction complex. This was done in accordance with expert assessments based on the results of a survey. The study compared the previously identified quantitative and qualitative factors with each other in order to eliminate duplication of the components of the qualitative factors, such as indices and ratings. Consequently, a necessary and sufficient sample of the factors was formed. This sample can be further used to correctly rank the degree to which Russian regions are prepared to digitalise the construction complex. To rank the factors to measure their importance and significance, the survey was conducted by groups: 1) socio-economic conditions for industry digitalisation; 2) development of science and innovation in the regions; 3) development of the construction complex in the regions; and 4) development of digital technologies in the regions. Based on the survey, the selected factors were ranked, particularly by groups. The results of this study can be used to refine the ranking of the regions' degree of readiness for the digitalisation of the construction complex as well as to determine the effectiveness of the ranking.

Keywords: digital economy, digital potential, sustainable development, regional development, construction complex, BIM technologies.

Citation: Tereshko, E., Rudskaya, I., Dejaco, M.C, Pastori, S. (2021). Validation of factors for assessing the digital potential of the regional construction complex as a basis for sustainable development. Sustainable Development and Engineering Economics 1, 3.
https://doi.org/10.48554/SDEE.2021.1.3

Научная статья
УДК 332.02
DOI: https://doi.org/10.48554/SDEE.2021.1.3

ВАЛИДАЦИЯ ФАКТОРОВ ОЦЕНКИ ЦИФРОВОГО ПОТЕНЦИАЛА РЕГИОНАЛЬНОГО СТРОИТЕЛЬНОГО КОМПЛЕКСА, КАК ОСНОВЫ УСТОЙЧИВОГО РАЗВИТИЯ

Екатерина Терешко[1]*, Ирина Рудская[1], Марио Клаудио Дейацо[2], София Пастори[2]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, ektereshko@mail.ru, rudskaya_ia@spbstu.ru
[2] Миланский технический университет, Милан, Италия, mario.dejaco@polimi.it, sofia.pastori@polimi.it
* Автор, ответственный за переписку: ektereshko@mail.ru

Аннотация

Рассмотрение цифровых процессов отраслей и комплексов через призму цифровой трансформации региона является перспективным и актуальным, что в дальнейшем способствует устойчивому развитию региона. Цифровизация строительного комплекса региона позволяет дать оценку цифрового инфраструктурного развития на проектно-производственном этапе, т.е. от проектной документации до ввода объектов в эксплуатацию. Основой цифровизации строительного комплекса являются BIM-технологии, которые должны транслироваться с микроуровня на мезоуровень – уровень муниципалитета/региона, а в дальнейшем и на макроуровень – уровень всей страны. Целью исследования является анализ и оценка групп количественных факторов, характеризующих цифровой потенциал строительного комплекса. Методами исследования являются методы количественного и качественного анализа, которые заключаются в проведении сравнительного анализа факторов – индексов и рейтингов, а также в ранжировании групп факторов характеризующих готовность регионов к цифровизации строительного комплекса в соответствии с экспертными оценками по итогу проведенного опроса респондентов. Проведенное исследование позволило сопоставить ранее выявленные количественные и качественные факторы между собой, с целью устранения дублирования составляющих качественных факторов – индексов и рейтингов. Следовательно, была сформирована необходимая и достаточная выборка факторов, которые в дальнейшем могут быть использованы для формирования скорректированного рейтинга по уровню готовности регионов России к цифровизации строительного комплекса. Для ранжирования факторов оценки цифрового потенциала строительного комплекса региона по важности и значимости был проведен опрос респондентов по группам: 1) социально-экономические условия для осуществления отраслевой цифровизации; 2) развитие науки и инноваций в регионах; 3) развитие строительного комплекса регионов; 4) развитие цифровых технологий в регионах. В соответствии с проведенным опросом респондентов отобранные факторы были ранжированы, в т.ч. по группам. В дальнейшем, данное исследование позволит сформировать уточненный рейтинг уровня готовности регионов к цифровизации строительного комплекса, а также определить границы эффективности рейтинговой оценки.

Ключевые слова: цифровая экономика, цифровой потенциал, устойчивое развитие, региональное развитие, строительный комплекс, BIM-технологии.

Цитирование: Терешко, Е., Рудская, И., Дейацо, М.К., Пастори, С. (2021). Валидация факторов оценки цифрового потенциала регионального строительного комплекса, как основы устойчивого развития. Sustainable Development and Engineering Economics 1, 3
https://doi.org/10.48554/SDEE.2021.1.3

1. Introduction

Digital transformation encourages regional development and contributes to socio-economic growth (Lygina, 2019; Chernykh et al., 2019). Measuring the digital potential of sectors and complexes is a primary objective in the formation of regional innovation systems, which build up and ensure the development of innovation potential

Measuring the digital potential of industries and complexes is a key task in stimulating the growth of regional innovation systems. These systems, together with the national innovation system and a system providing a mechanism for effective operation of the innovative economy, contribute to the development of the innovative potential of enterprises in the region (innovative infrastructure, innovation security, government regulation). In turn, this becomes a structural component of the economic development of the state, namely, the institutional foundation of the country's innovative economy (Litvinenko, 2015; Volkonitskaya and Lyapina, 2014; Rodionov et al., 2013). Regional technological planning institutions can be used to develop regional innovation systems. They are oriented on regional-specific industries, which have a relative competitive advantage due to their territorial position, as well as on the development of appropriate strategies to support these industries (Park et al., 2021). It is important to determine the potential for digital transformation of a particular territory, and thus the readiness for digitalisation must be evaluated within the sectors and complexes of the economy that define the specialisation of regions.

Digital technology is being actively introduced everywhere in sectors and complexes, for example, in the energy sector (Nguyen et al., 2021; Konovalov, 2020), the agricultural sector (Akmarov et al., 2021; Pfeiffer et al., 2021; Kovaleva, 2019), health care (Iakovleva et al., 2021), education (Akulenko et al., 2021; Ivanova et al., 2021) and construction (Tereshko et al., 2021; Muñoz-La Rivera et al., 2021; Berlak et al., 2021). One of the leading and rapidly growing sectors in the digital economy is the construction industry. It applies innovative technologies, with routine processes being digitalised and robotised, and work is optimised at various stages of the life cycle of a construction project[1]. Advanced technologies transform the process, in which working groups are organised and the work is systematised. The process, aimed at reaching strategically important goals given the sectoral specifics of the construction industry, from design documentation to the commissioning of capital development projects, should be called a construction complex (Tereshko and Rudskaya (Digital potential…), 2020). In the future, digital development of the construction complex at the regional level will bring about balanced agglomerations that can meet the challenges of modern society. Consequently, digital transformation of the construction complex can be seen as a driver of regional innovation systems, whose development is essential at the micro-, meso- and macro levels (Tereshko and Rudskaya (Digitalization of the construction…, 2020) of the digital processes evolving in the sector.

It should be noted that the indicators for the development of territories (regions) are influenced by the development of enterprises that operate in the area. Thus, construction enterprises that form the construction complex of a region play a significant role in sustainable regional development, as evidenced by the numerous studies (Stanitsas and Kirytopoulos, 2021; Ilhan and Yobas, 2019). Thus careful strategic planning and development of industrial complexes in the regions, particularly the construction complex, facilitates the formation and development of a sustainable urban environment (Vargas-Hernández, 2021; Ametepey et.al., 2020; Kozlov et.al., 2019).

[1] Talapov, V.V, 2015. BIM Technology: The Essence and Features of Building Information Modeling Implementation, DMK Press, Moscow, p. 410

Previously, the authors conducted a study entitled ‘Readiness of Regions for Digitalization of the Construction Complex’ and suggested a ranking of the regions’ readiness to digitalise the construction complex (Tereshko et al., 2021). The ranking relies on quantitative and qualitative factors. The qualitative factors include surveys, rankings and indices. Using an aggregated assessment of several parameters, the rankings and indices can give a summarised specification for a constituent entity, which is convenient for ranking and calculating the indicators of territories. However, the indicators that form a particular ranking or index can recur and lead to a distorted interpretation of the final outcome. Therefore, these qualitative factors must be revised to form the necessary and sufficient sample by group, mainly based on the quantitative data available.

The *aim* of the study is to validate the factors that constitute the ranking of the regions’ readiness to digitalise the construction complex in Russia to prevent the quantitative indicators included in the qualitative factors from being duplicated. In accordance with this aim, the following objectives must be achieved: 1) analyse the composition of controversial qualitative factors; 2) form the necessary and sufficient sample of parameters for characterising a concrete group of the formed ranking; and 3) assign weights to the formed sample of factors by group in accordance with the respondent survey.

2. Literature Review

The digital development of the construction complex relies on building information modelling (BIM) technologies. BIM implies that an information model of capital development object is built at all stages of the life cycle of a construction project (Rybin et al., 2019). BIM technologies are the basis for digital transformation of the construction industry at the micro level — the level of organisations and enterprises. Interconnected operation in a digital environment, which links the design stages (concept, detailed design, project documentation, detail engineering design documentation, executive documentation) with financial, economic and investment components helps to generate a comprehensive model at different stages of the life cycle. It is an integral part of creating an information system of municipalities and regions (Pertseva et al., 2017).

Scientists from all over the world study BIM technologies and suggest various research ideas, from improving the organisational structure to adapt it to work with BIM to structuring the algorithms to model specific processes in the design of buildings and structures. For example, Alshorafa and Ergen (2019) consider the use of BIM technologies in large-scale projects. Further, Sekisov (2019) and Lushnikov (2015) examine the effectiveness of construction production organised using BIM technologies as well as the problems and advantages of their application in construction companies. Akram et al. (2019) study bibliometric and scientific-metric databases and conclude that visualisation is the most promising function of BIM, while hazard identification is an important area where these technologies can be used to ensure construction safety.

It is challenging to research the digital transformation of the sector, the investment and construction complex and the construction complex of the region. Having analysed the studies in the SCOPUS reference and abstract database matching the search query ‘Digitalization of the construction industry’ filtered by the keyword *Digitalization*, 54 documents were identified from 2009 to 2021. Figure 1 shows the distribution of studies by year. It should be noted that the peak in publications in 2019 and their decline in 2020–2021 suggests that the process of indexing articles is often time-consuming, and therefore the sample for 2020–2021 will be gradually updated.

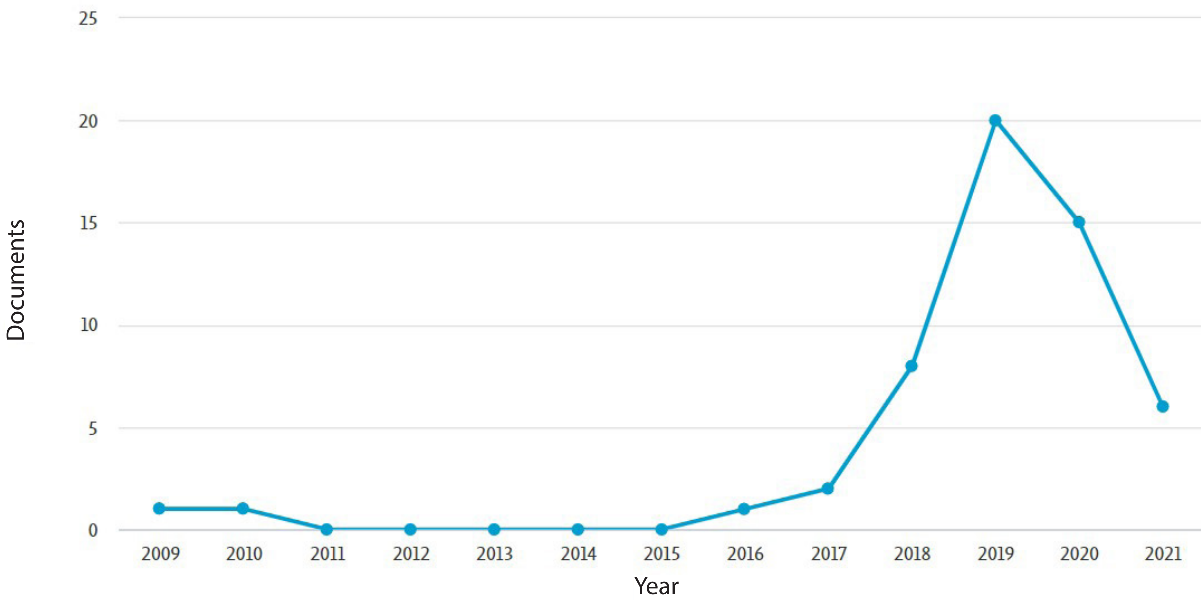

Figure 1. Researching the digitalisation of the construction industry by year in the SCOPUS database

Most of the studies on the digitalisation of the construction industry were written by authors from Germany (18 publications), Russia (8 publications), Australia (3 publications), the Czech Republic (3 publications) and the UK (3 publications). The following leading scientists in this field can be mentioned: Hosseini, Aghimien, Aigbavboa, Helmus, Jahanger, Kelm, Louis, Matejka, Zhou, Meins-Becker, Stoyanova, Oke A.E., Pestana, Stransky and Trejo. For example, Stoyanova (2020) studies advanced digitalisation practices in industrial sectors, using a selection of factors related to success potential and proposing recommendations to determine whether the digital technologies used in construction are successful.

Elghaish et al. (2020), Aghimien et al. (2019) and Golizadeh et al. (2019) show how pilotless flying vehicles and immersive technologies can be used for digitalising the construction industry and discuss the potential applications of these technologies individually or combined and integrated with each other. In their work, Aghimien et al. (2020) evaluate the aspects of the latent institutional environment that affect the digitalisation of the construction industry in South Africa. Meanwhile, Oke A. et al. (2020) analyse the challenges when the Internet of Things was introduced in the construction industry in Nigeria in order to increase awareness of and the degree to which the advantages were used by stakeholders.

Additionally, Zhou et al. (2020) describe a digital process platform that supports a wide range of users in the construction market. This platform provides more data about construction market players using an integrated cyber-physical system and contributes to the standardisation of communication infrastructure within the construction sector by combining various solutions based on information and communications technologies.

Assessing the development of the digital potential of the construction complex of the regions is advantageous, as in the initial stage it can be used to identify the regions prone to digital transformation, those that have a good technological base in their toolkit and the organisations developing together with the rapidly changing trends. No studies measuring the digital potential of the construction complex have been identified. Consequently, it is important to form the necessary and sufficient sample of factors to assess the potential of the territory or subject of the federation of a particular country, including the regions of Russia, for digitalising the construction complex.

3. Materials and Methods

The research methodology relies on qualitative and quantitative methods. Qualitative research methods involve validating the factors that characterise the regions' readiness to digitalise the construction complex, using a comparative analysis of the qualitative indicators – indices and rankings – in order to avoid duplication of the designed parameters of the sample that are used to measure the digital potential of the regional construction complex. The following ones were selected for the analysis: 1) Business Digitalization Index by constituent entities; 2) ranking of the socio-economic position of the constituent entities of the Russian Federation (RF); 3) Science and Technology Development Index; 4) innovative development ranking of the RF regions; and 5) ranking of innovative regions in Russia. These quantitative indicators assess the regions using the aggregate parameters of digital and innovative development.

The quantitative methods involve ranking the groups of factors that characterise the regions' readiness to digitalise the construction complex, using expert assessments from the survey of respondents. The assessment algorithm includes the following stages:

Stage 1. Conducting an online survey of respondents.

Stage 2. Analysing the results of the survey by groups of the formed assessment indicators.

Stage 3. Calculating the arithmetic mean value for the groups of factors and for individual parameters. Assigning ranks to the groups of indicators and the indicators within groups or subgroups.

4. Results and Discussion

The sample of factors previously presented in the study of Tereshko et al. (2021) can be used to reflect the necessary and sufficient characteristics for measuring the digital potential of the construction complex in a particular region of Russia. The measured digital potential is the basis for sustainable development of Russian regions (Jovovic et al., 2017; Feldhoff, 2002; Roberts, 1994; Zaborovskaya et al., 2019), as it provides a foundation for defining and developing the concept of digital transformation of the construction complex in these regions. This approach is useful because it leads to demonstrative indicators achieved through ranking the regions. Further, it simplifies the evaluation of possible scenarios for the development of the socio-economic system and can be used to build a long-term strategy for digital industrial development of the region by establishing development frameworks for the sectoral economy in the RF. The factors chosen for the ranking include both quantitative and qualitative indicators (Table 1).

Let us consider the groups of factors in more detail so that the calculated parameters are not misinterpreted when the ranking is compiled. This is important because these parameters can be based on the same quantitative data that form the qualitative indicators. The major quantitative factors to be considered are in groups 1 and 2: 'Socio-economic conditions for sectoral digitalisation of the regions' and 'Development of science and innovation in the regions', respectively.

To validate the factors in the first group, let us consider factors X3 and X4. Quantitative indicator X3, 'Index of business digitalisation by constituent entities'[2], includes the following indicators: 1) The specific weight of organisations (among other organizations), using broadband Internet (%), cloud services (%), RFID technologies (%) and ERP systems (%); and 2) The specific weight

[2] Digital Economy Indicators – 2019г. Statistics Digest, pp. 216–220. https://www.hse.ru/data/2019/06/25/1490054019/ice2019.pdf

Table 1. Factors for assessing the digital potential of the construction complex in the region

Group	Indicator		Indicator type	Commentary
1. Socio-economic conditions for sectoral digitalisation of regions	X1	Human Development Index by Russian regions	Qualitative	Formed by the analytical centre under the RF government
	X2	GRP by the type of economic activity 'Construction' (%)	Quantitative	Data are posted on Rosstat website
	X3	Business Digitalization Index by constituent entities	Qualitative	Formed by the HSE and published in the periodical 'Digital Economy Indicators'
	X4	Ranking of socio-economic position of constituent entities	Qualitative	Formed by the analytical agency RIA rating
2. Science and innovation development in regions	X5	Science and Technology Development Index	Qualitative	Formed by the analytical agency RIA rating
	X6	Ranking of innovative development of Russian regions	Qualitative	Formed by the HSE
	X7	Ranking of innovative Russian regions	Qualitative	Formed by the Association of Innovative Regions of Russia (AIRR)
3. Development of construction complex in regions	X8	Commissioning residential and non-residential buildings, (m2)	Quantitative	Data are posted on Rosstat website
	X9	Investments by type of economic activity 'Construction' (excluding small business enterprises), (mil. rubles)	Quantitative	Data are posted on Rosstat website
	X10	Number of enterprises and organisations by type of economic activity 'Construction', units for the end of year according to the state registration data	Quantitative	Data are posted on Rosstat website
	X11	Distribution of the average annual number of employed by type of economic activity 'Construction', (% of the total employed)	Quantitative	Data are posted on Rosstat website
4. Development of digital technology in regions	X12	Digital Literacy Index	Qualitative	Formed by regional non-government organisation 'Internet Technology Center' (ROCIT). Based on respondent surveys
	X13	Number of building information modelling (BIM) technology users	Qualitative	Formed by Konkurator company. Based on respondent surveys.
	X14	Experience in BIM projects (from three to five years)	Qualitative	Formed by Konkurator company. Based on respondent surveys.

of organisations engaged in e-commerce, using special forms posted on the website/Extranet and EDI systems, of the total organisations (%). These indicators are important for assessing the digital equipment of organisations in Russian territories, including construction enterprises. Regarding the data available in the Rosstat databases, the relevant statistics for the regions of Russia in 2019 do not include a subsection for the selected index parameters. Consequently, the index will not be valid in the future. Thus, for factor X4 we have to introduce a group of indicators to assess the digitalisation of business in the regions of Russia. These indicators include the specific weight of organisations, using (as %) 1) broadband Internet; 2) CRM, ERP and SCM systems; 3) electronic document management systems; 4) cloud services; and 5) local computer networks.

Table 2. Indicators of the Science and Technology Development Index (X5)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
1st indicator group 'Human resources'		
X5.1.1	Number of staff members engaged in R&D per capita of working-age population	Yes
X5.1.2	Specific weight of researchers under the age of 39 of the total researchers	Yes
X5.1.3	Specific weight of highly qualified employees of the total qualified employees	Yes
X5.1.4	Share of employees by high-tech type of economic activity of the total workers employed by organisations	Yes
2nd indicator group 'Physical infrastructure'		
X5.2.1	Specific weight of machines and equipment up to 5 years of age of the total worth of the machines and equipment in R&D organisations	Yes
X5.2.2	Specific weight of organisations engaged in technology innovations	Yes
X5.2.3	Ratio of the salary of scientific workers to the cost of the minimum consumption basket	Yes
X5.2.4	Number of computers in organisations per 100 workers	Yes
X5.2.5	Internal R&D costs per capita of working-age population	Yes
X5.2.6	Specific weight of spending on technological innovations of the total of goods shipped, works executed and services rendered	Yes
X5.2.7	Innovative activity of organisations (specific weight of organisations engaged in technological, organisational and marketing innovations)	Yes
3rd indicator group 'Scale of scientific and technological activity'		
X5.3.1	Volume of shipped innovative goods, executed innovative work, rendered innovative services	Yes
X5.3.2	Volume of gross regional product from the products of high-tech and science-intensive industries	Yes
X5.3.3	Number of issued patents	Yes
4th indicator group 'Efficiency of scientific and technological activity'		
X5.4.1	Specific weight of innovative goods, work and services of the total goods shipped, works executed and services rendered	Yes
X5.4.2	Share of products of high-tech and science-intensive industries of the gross regional product	Yes
X5.4.3	Number of patents issued per capita of working age population	Yes
X5.4.4	Volume of shipped innovative goods, executed innovative work and rendered innovative services per capita	Yes
X5.4.5	Volume of gross regional product generated by products of high-tech and science-intensive industries per capita.	Yes

Factor X4 – 'Ranking of the socio-economic situation of the RF constituent entities'[3] – includes four subgroups of quantitative indicators: indicators of the scale of the economy; indicators of economic efficiency; indicators of the public sector; and indicators of the social sphere. The composition of the indicators gives quite an accurate picture of the socio-economic development of a particular Russian territory, which is one of the key aspects in measuring sectoral digitalisation. The quantitative indicators included in the subgroups are publicly available on the Rosstat website[4], where they are updated annually. The agency RIA rating constitutes the ranking annually. Therefore, this qualitative indicator can be used in the future, among other things, for convenient cumulative use of quantitative data for the socio-economic block.

Let us consider the following qualitative indicators outlining the development of science and

[3] Riarating. The ranking of socio-economic position of regions – 2018. https://riarating.ru/infografika/20180523/630091878.html

[4] Regions of Russia. Socio-economic indicators. https://rosstat.gov.ru/folder/210/document/13204

innovation in the Russian regions (X5, X6 and X7). These indicators may have repeated values that negatively affect the final ranking and present a distorted interpretation of the results. Therefore, it is necessary to scrutinise the factors that make up the group ‘Science and Innovation Development in the Region’. Accordingly, we perform a comparative analysis of the qualitative factors and examine the indicators they include in detail.

The Science and Technology Development Index (X5), formed by the agency ‘RIA rating’[5], includes four subgroups of indicators: human resources; physical infrastructure; the scale of scientific and technological activities; and the effectiveness of scientific and technological activities. The positions of the RF constituent entities in the final list were determined using the integral index, calculated by aggregating the ranking points of the regions for 19 analysed indicators, which were combined into the four subgroups listed above. Table 2 presents the analysis of the index and reflects the factors to be included in the assessment of the digital potential of the construction complex.

The indicators included in this index can be freely accessed on the Rosstat database, which is the advantage of using the index in the future. The final index can vary from 1 to the maximum value of 100. The index is updated annually, and the ranking of Russian regions is based on it.

The ranking of innovative development of the Russian regions[6] (X6) is published by the Institute for Statistical Studies and Economics of Knowledge of the National Research University - Higher School of Economics (HSE), the Russian Cluster Observatory. The rating analyses the innovative development of the Russian regions and considers a number of ranking assessments. The ranking includes five groups, each of which is divided into subgroups. In total, the ranking includes 53 quantitative and qualitative indicators. The ranking is divided into the following indicator groups and subgroups: 1) socio-economic conditions for innovation; 2) scientific and technical potential; 3) innovative activity; 4) export activity; and 5) the quality of innovation policy. Table 3 provides an analysis of the index, reflecting the factors that should be included in the assessment of the digital potential of the construction complex.

Table 3. Indicators of Innovative Development Ranking of the Russian regions (X6)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
1st indicator group ‘Socio-economic conditions for innovative activity’		
1.1 Key macro-economic indicators		
X6.1.1.1	GRP per one employed in the region’s economy, thousand rubles	Yes
X6.1.1.2	Fixed assets renovation coefficient (%)	No
X6.1.1.3	Specific weight of the employed in high-tech and medium-tech (high-level) sectors of industrial manufacturing in the average number of workers in the region’s economy (%)	No
X6.1.1.4	Specific weight of the employed in science-intensive service sectors in the average number of workers in the region’s economy (%)	No
1.2 Educational potential of population		
X6.1.2.1	Specific weight of population aged 25–64 with higher education in the total population of this age group (%)	Yes
X6.1.2.2	Number of students enrolled in higher educational programmes – Bachelor’s, Master’s, specialist’s programmes, per 10,000 people, persons	Yes

[5] Riarating. The level of science and technology development in the regions of Russia – 2018. https://riarating.ru/infografika/20181017/630109152.html

[6] Ranking of innovative development of the RF constituent entities. Issue 6. https://issek.hse.ru/mirror/pubs/share/315338500

Table 3 (continued)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
X6.1.2.3	Specific weight of students specialising in mathematics, natural sciences, engineering, technology, technical sciences and fundamental medicine in the total students enrolled in higher educational programmes – Bachelor's, Master's, specialist's programmes (%)	No
X6.1.2.4	Employed population aged 25–64 involved in lifelong learning (%)	No
X6.1.2.5	Number of students enrolled in secondary vocational education programmes – programmes training medium specialists, per 10,000 people, persons	Yes
X6.1.2.6	Specific weight of students specialising in mathematics, natural sciences, engineering, technology and technical sciences in the total students enrolled in secondary vocational education programmes – programmes training medium specialists (%)	No
1.3 Digitalisation potential		
X6.1.3.1	Specific weight of organisations having access to broadband Internet with a maximum data transfer rate over 100 Mbit/sec in the total organisations (%)	Yes
X6.1.3.2	Specific weight of organisations engaged in training their personnel in digital skills in the total organisations (%)	Yes
X6.1.3.3	Specific weight of active Internet users in the total population aged 15–74 (%)	No
2nd indicator group 'Science and Technology Potential'		
2.1 Financing research and development		
X6.2.1.1	Internal R&D costs as a percentage of GRP (%)*	No
X6.2.1.2	Internal R&D costs per one researcher, thousand rub.	No
X6.2.1.3	Specific weight of organisations in the entrepreneurial sector in total internal R&D costs (%)	No
X6.2.1.4	Ratio of the average monthly salary of employees engaged in R&D to the average monthly nominal gross salary in the region (%)	No
2.2 Scientific personnel		
X6.2.2.1	Specific weight of people employed in research and development in the average annual number of people employed in the region's economy (%)	No
X6.2.2.2	Specific weight of people aged less than 39 in the number of researchers (%)	Yes
X6.2.2.3	Specific weight of people with a scientific degree in the number of researchers (%)	No
2.3 Research and development performance		
X6.2.3.1	Publications in journals indexed in the Web of Science, per 10 researchers, units	Yes
X6.2.3.2	Patent applications for inventions submitted to Rospatent by national applicants, per 1 million manpower aged 15–72, units.	Yes
X6.2.3.3	The number of advanced production technologies developed in the region, per 1 million manpower aged 15–72, units.	No
3rd indicator group 'Innovative Activity'		
3.1 Activity in the field of technological and non-technological innovations		
X6.3.1.1	Specific weight of organisations engaged in technological innovations in the total organisations (%)*	Yes
X6.3.1.2	Specific weight of organisations engaged in non-technological (marketing and/or organisational) innovations in the total organisations (%)*	No
X6.3.1.3	Specific weight of organisations that developed ready-to-use technological innovations in-house in the total organisations (%)*	No
X6.3.1.4	Specific weight of organisations engaged in joint R&D projects in the total organisations (%)*	No
3.2 Small innovative business		
X6.3.2.1	Specific weight of small enterprises engaged in technological innovations in the total small enterprises (%)*	No

Table 3 (continued)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
	3.3 Technological innovation costs	
X6.3.3.1	Specific weight of technological innovation costs in the total volume of goods shipped, work executed and services rendered by organisations (%)*	Yes
	3.4 Innovative activity performance	
X6.3.4.1	Specific weight of innovative goods, works, services in the total of goods shipped, works executed and services rendered (%)	Yes
X6.3.4.2	Specific weight of newly launched or significantly technologically modified innovative goods, works and services for the market in the total goods shipped, works executed and services rendered (%)*	No
X6.3.4.3	Specific weight of organisations that consider reduced material and energy costs as the main outcome of their innovative activities in the total organisations engaged in technological innovations (%)	No
	4th indicator group 'Export Activity'	
	4.1 Export of goods and services	
X6.4.1.1	Exports of goods per 1,000 rub. of GRP, rub.	No
X6.4.1.2	Exports of non-raw material goods per 1,000 rub. of GRP, rub	No
X6.4.1.3	Exports of services 1,000 rub. of GRP, rub	No
X6.4.1.4	Specific weight of export in the total innovative goods, work and services (%)	No
	4.2 Knowledge export	
X6.4.2.1	Number of patent applications for inventions registered abroad per 1 mil. people of manpower aged 15–72, units	No
X6.4.2.2	Technology export earnings per 1,000 rub. of GDP, rub	No
X6.4.2.3	Specific weight of international students in the total students enrolled in higher education programmes – Bachelor's, Master's and specialist's programmes, %	No
	5th indicator group 'Quality of Innovation policy'	
	5.1 Legal framework of innovation policy	
X6.5.1.1	Presence of an innovative development strategy (concept) (innovation strategy) and/or a specialised innovative development section (supporting innovations) in the regional development strategy	No
X6.5.1.2	Presence of the zones (territories) in the territorial planning scheme allocated for priority development of innovative activity	No
X6.5.1.3	Presence of a specialised legislative act that defines the basic principles, areas and measures of state support for innovative activities in the region	No
X6.5.1.4	Presence of a specialised programme or a set of state support measures for the development of innovations, innovative activities or subjects of innovative activities	No
	5.2 Organisational support for innovation policy	
X6.5.2.1	Presence of specialised (advisory) bodies coordinating innovation policy (supporting innovative activity) under a senior official or the supreme executive body of state power of the RF constituent entity	No
X6.5.2.2	Presence of specialised regional institutions developing the base of regional legal acts (funds, agencies, development corporations, etc.) with the functionality to support the subjects of innovative activity and/or to implement innovative projects	No
	5.3 Budgetary science and innovation expenditure	
X6.5.3.1	Specific weight of allocations for civil science from the consolidated budget of the RF constituent entity in the expenditures of the consolidated budget of the RF constituent entity (%)	No
X6.5.3.2	Specific weight of federal budget funds in total expenditures on technological innovations (%)	No

Table 3 (end)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
X6.5.3.3	Specific weight of funds from the budget of the RF constituent entity and local budgets in the total technological innovation expenditure (%)	No
5.4 Participating in federal science, technology and innovation policy		
X6.5.4.1	The number of research, scientific-technical and innovative projects supported by federal government bodies and development institutions, per 1 million people of manpower aged 15–72, units	No
X6.5.4.2	The number of federal development institutions supporting research, scientific-technical and innovative projects implemented in the RF constituent entity, units	No
X6.5.4.3	Funding from federal authorities and development institutions attracted for research, scientific-technical and innovative projects in the RF constituent entity, per 1 million rubles of GRP, rub.	No

The ranking reflects the whole picture of innovative development in the Russian regions. However, it includes some qualitative indicators that are hard to collect if no relevant ranking has been published yet.

The ranking of the innovative regions of Russia[7] (X7) was formed by the Association of Innovative Regions of Russia (AIRR) and includes four groups of indicators: research and development; innovative activity; socio-economic conditions for innovation; and innovative activity of the region. The ranking includes 29 indicators. Let us have a careful look at the ranking groups in Table 4 and focus on the factors that should be accepted to assess the digital potential of the construction complex.

Similar to indicator X6, the ranking of the innovative regions of Russia fully reflects the digital development picture. It is generated on a regular basis and includes the most relevant information on the changes occurring in the innovation sphere of the economies of the RF constituent entities. A feature of the ranking is the presence of quality indicators, in the future, when the annual characteristics of the ranking are updated, it may have a negative effect due to the lack of data. Factor X7 is similar in content to factor X6. Therefore, using these two parameters in the sample is redundant.

In the comparative analysis of the qualitative indicators presented in the sample of the second group of factors, which characterise the level of readiness of the Russian regions to digitalise the construction complex, a number of repetitive ones factors can be highlighted: X5.1.2=X6.2.2.2; X5.2.2=X6.3.1.1=X7.2.1; X6.3.2.1=X7.2.3; X5.2.6=X6.3.3.1=X7.2.9; X5.4.1=X6.3.4.1=X7.2.4; X5.4.2=X7.3.4; X5.4.3=X6.2.3.2=X7.1.5; X7.1.1=X6.1.2.2; X7.1.3=X6.1.2.1; X7.1.6=X6.2.3.1; X7.1.8=X6.2.1.1; X7.1.9=X6.2.1.3; X7.2.5=X6.3.4.2; X7.2.7=X6.4.2.2; X7.2.8=X6.2.3.3; X7.3.1=X6.1.1.2; X7.3.2=X6.1.1.1; X7.3.3=X6.1.1.3; X7.4.1=X6.5.4.3; and X7.4.2=X6.5.4.1. As you can see, the indicators in the three groups have intersections by the same parameters. Consequently, the previously selected quantitative factors X5, X6, and X7 cannot be used in the aggregate. In addition, the factor 'Ranking of innovative development of the RF regions' contains indicator X6.1.3.1, which is identical to the indicator from the first group of factors – 'Specific weight of organisations using broadband Internet (%)'. The group of factors 'Development of digital technology in regions' has to be supplemented with the quantitative indicator 'Specific weight of organisations using design software (%)', which reflects the information support of construction complex enterprises with software products necessary for carrying out design processes in accordance with BIM technologies.

[7] Ranking of innovative regions of Russia: version 2017. http://i-regions.org/images/files/airr17.pdf

Table 4. Indicators of the Ranking of Innovative Russian Regions (X7)

Indicator designation	Indicator	Factor is considered in evaluation (yes/no)
1st indicator group 'Research and Development'		
X7.1.1	Number of students studying in higher professional education institutions per total population	Yes
X7.1.2	Number of researchers per total population	No
X7.1.3	Specific weight of working age employees with higher education in total working age population (%)	Yes
X7.1.4	Number of international PCT applications filed per total economically active population	No
X7.1.5	Number of patent applications for inventions submitted to Rospatent by national applicants per total economically active population	Yes
X7.1.6	Number of papers published in journals indexed in the Web of Science per total researchers	Yes
X7.1.7	Number of papers published in peer-reviewed journals indexed in the RSCI per total researchers	No
X7.1.8	Internal R&D expenditures as percentage of GRP (%)	No
X7.1.9	Specific weight of funds of organisations in the entrepreneurial sector in total internal R&D expenditures (%)	No
2nd indicator group 'Innovative Activity'		
X7.2.1	Specific weight of organisations engaged in technological innovations in the total organisations (%)	Yes
X7.2.2	Specific weight of organisations engaged in non-technological innovations in the total organisations (%)	No
X7.2.3	Specific weight of small enterprises engaged in technological innovations in the total small enterprises (%)	No
X7.2.4	Specific weight of innovative goods, work, services in the total of good shipped, work executed and services rendered	Yes
X7.2.5	Specific weight of newly launched or significantly technologically modified innovative goods, work and services for the market in the total goods shipped, work executed and services rendered (%)	No
X7.2.6	Number of inventions used per total population	No
X7.2.7	Technology export earnings in relation to GRP	No
X7.2.8	Number of created advanced production technologies per total economically active population members	No
X7.2.9	Intensity of expenditure on technology innovations (%)	Yes
3rd indicator group 'Socio-Economic Conditions for Innovative Activity'		
X7.3.1	Fixed assets renovation coefficient (%)	No
X7.3.2	GRP per one person employed in the region's economy (excluding extractive industries)	Yes
X7.3.3	Specific weight of the employed in high-tech and medium-intensive (high-level) types of activity per total employed in the region's economy (%)	No
X7.3.4	Share of products of high-tech and science-intensive industries of GRP (%)	Yes
X7.3.5	Specific weight of organisations using Internet with a data transfer rate 2 Mbit/sec as a minimum in the total organisations investigated* (%)	No
4th indicator group 'Innovative Activity of the Region'		
X7.4.1	Attracting investments from federal sources into the innovative sphere of the region's economy in relation to GRP	No
X7.4.2	Support of innovative projects by federal development institutes	No
X7.4.3	Innovative activity of regional government bodies (score indicator)	No
X7.4.4	Winning competitions held by federal executive government bodies and federal development institutions (score indicator)	No
X7.4.5	Involving companies in interaction within clusters and technology parks	No
X7.4.6	Publicly held innovative events (score indicator)	No

Let us form the necessary and sufficient sample of factors for the subgroups in order to assess the level of readiness of the Russian regions to digitalise the construction complex. The key requirement for the factors is their availability and annual update (Table 5). The factors for the group 'Development of Science and Innovation in the Regions' are revised based on a detailed analysis of the indicators included in the index and rankings. Thus, we can form the necessary sample of available quantitative indicators, which are divided into subgroups within the group. We keep the index of scientific and technological development, as it is updated annually, is minimally sufficient for measuring the potential of the constituent entities and the data it contains are freely accessed from the Rosstat state statistics base. It is worth

Table 5. Adjusted sample of factors for assessing the digital potential of the construction complex of the region

Group	Indicator	
1. Socio-economic conditions for sectoral digitalisation of the regions	X1	Human Development Index by RF region
	X2	GRP by type of economic activity 'Construction' (%)
	X3	Indicator subgroup 'Business Digitalisation' includes: X3.1 Specific weight of organisations using broadband Internet (%); X3.2 Specific weight of organisations using CRM, ERP, SCM – systems (%); X3.3 Specific weight of organisations using electronic document management systems (%); X3.4 Specific weight of organisations using cloud services (%); X3.5 Specific weight of organisations using local area networks (%)
	X4	Ranking of the socio-economic position of the RF constituent entities
	X5	Indicator subgroup 'Educational Potential of Population' includes: X5.1 Specific weight of employed population by level of education (higher) (%); X5.2 Specific weight of employed population by level of education (secondary vocational) (%); X5.3 Number of students enrolled in higher educational programmes – Bachelor's, Master's, specialist's programmes, per 10,000 people, persons; X5.4 Number of students enrolled in secondary vocational education programmes – programmes training medium specialists, per 10,000 people, persons; X5.5 Specific weight of organisations engaged in training their personnel in digital skills (%)
2. Development of science and innovation in regions	X6	Science and Technology Development Index
	X7	Number of papers published in journals indexed in the Web of Science per total researchers, units
3. Development of the construction complex of regions	X8	Commissioning residential and non-residential buildings, m^2
	X9	Investments by type of economic activity 'Construction' (excluding small business enterprises), million rubles
	X10	Number of enterprises and organisations by type of economic activity 'Construction', units at the end of year according to the state registration data
	X11	Distribution of the average annual number of employed people by type of economic activity 'Construction' (%) of the total employed
4. Development of digital technology in regions	X12	Digital Literacy Index
	X13	Number of Building Information Modelling (BIM) technology users
	X14	Experience in BIM projects (from three to five years)
	X15	Specific weight of organisations using design software (%)

introducing the assessment of publication activity in the Web of Science as an additional parameter. The educational potential of the population, previously included in the ranking of innovative development of the RF regions, is also revised. Given the implications of the factors characterising the educational potential, the sample of quantitative indicators within the subgroup 'Educational potential of the population' is assigned to the first group of factors.

In order to rank the selected factors and then correctly assess the level of readiness of the regions to digitalise the building complex, the authors conducted a surveywith 49 specialists . The interviewees are experts in the field of construction and are engaged in management, pedagogical or administrative activities. In terms of their geographical distribution, all the respondents belong to St. Petersburg, Leningrad Region, Moscow and Moscow Region. The survey was conducted for the following groups: 1) Socio-economic conditions for sectoral digitalisation; 2) Development of science and innovation in the regions; 3) Development of the construction complex of the regions; and 4) Development of digital technology in the regions. Within each block, the respondents assessed the characteristics that affect the development of a particular block in the context of the construction complex digitalisation. Blocks were assessed using a ten-point scale, where 1 indicates a low level of significance, and 10 indicates a high level of significance. The groups of factors, subgroups and/or factors included in the groups were ranked based on the total distribution of assessments in accordance with the arithmetic mean parameter. The arithmetic mean value for the groups was adopted as a calculation method. For example, to perform calculations for the first group consisting of factors X1–X5, expert assessments on a 10-point scale were considered. Then, the arithmetic mean value was considered for each factor (X1 is 7.367; X2 is 6.041; X3 is 7.694; X4 is 7.735; X5 is 9.000), and in accordance with it the weight was determined using some parameter within the group (X1 is 0.195; X2 is 0.160; X3 is 0.203; X4 is 0.204; X5 is 0.238). The parameters for each group of factors were calculated in a similar way. Then, the weight was calculated for each group in accordance with the arithmetic mean of the factors in this group. For example, for group 1 the total arithmetic mean is 7.567, for group 2 it is 7.827, for group 3 it is 6.827 and for group 4 it is 8.106.

Table 6 contains the weights calculated by group and by indicator. In addition, a significance rank was assigned to each factor, where 1 indicates the greatest significance. The rank was determined both between the groups of factors and within the indicators/subgroups of indicators.

Table 6. Ranking the factors for assessing the digital potential of the construction complex in the region according to the survey

Group	Weight	Rank	Subgroup/Indicator	Weight	Rank in the group
1. Socio-economic conditions for sectoral digitalisation of regions	0.250	3	X1	0.195	4
			X2	0.160	5
			X3	0.203	3
			X4	0.204	2
			X5	0.238	1
2. Development of science and innovation in regions	0.258	2	X6	0.732	1
			X7	0.268	2
3. Development of the construction complex of regions	0.225	4	X8	0.244	2
			X9	0.288	1
			X10	0.241	3
			X11	0.226	4
4. Development of digital technology in regions	0.267	1	X12	0.262	1
			X13	0.256	2
			X14	0.242	3
			X15	0.240	4

In future research, a correlation and regression analysis of the indicator sample has to be carried out to determine how the indicators affect the development of the region. We also plan to study the efficient frontiers of the formed ranking indicator using the DEA shell analysis method to develop more accurate ranking indicators in the future. The ranking itself will further be used to form a mechanism for strategic development of the digital potential of the construction complex in Russian regions in conjunction with the regional innovation system.

5. Conclusion

This study validates the factors that were previously identified as important for assessing the readiness of regions to digitalise the construction complex in order to avoid: 1) duplicating the indicators within qualitative factors – rankings and indices; and 2) using data inaccessible through Rosstat (i.e. those that are no longer collected or published in the open government statistical database). In addition, a necessary and sufficient sample of factors was constructed. An updated ranking for measuring the digital potential of the construction complex of Russian regions using the fuzzy sets method could be considered in the future. Additionally, the identified group ranks of factors and indicators included in these groups will be used to form the ranking, and the calculated parameters will be adjusted considering the weighted average values and priority ranks. Therefore, the study is unique for Russian territories and contributes significantly to the methodological assessment of the digital development of the construction complex of these territories. Research of this kind is rudimental so far. The study suggests the data that could be used for assessing the readiness of regions to digitalise the construction complex. Moreover, these data can be used to track the development at different levels of management.

It should be noted that the research results are of international interest. The proposed selection of factors for measuring the digital potential of the construction complex of a territory can be translated from the micro to the macro level to make comparisons between various countries. Consequently, in the near future an international ranking based on the formed sample of factors could be compiled to measure the degree to which countries are ready to digitalise their construction complexes.

References

Aghimien, D., Aigbavboa, C., Oke, A., Aghimien, L., 2020. Latent institutional environment factors influencing construction digitalization in South Africa. IJCE&R 1–17. https://doi.org/10.1080/15578771.2020.1838973

Aghimien, D.O., Aigbavboa, C.O., Oke, A.E., Thwala, W.D., 2019. Mapping out research focus for robotics and automation research in construction-related studies: a bibliometric approach. JED&T18(5), 1063–1079. https://doi.org/10.1108/JEDT-09-2019-0237

Akmarov, P.B., Knyazeva, O.P., Tretyakova, E.S., 2021. Assessing the potential of the digital economy in agriculture. IOP Conference Series: Earth and Environmental Science 666(4), 042036. https://doi.org/10.1088/1755-1315/666/4/042036

Akram, R., Thaheem, M.J., Nasir, A.R., Ali, T.H., Khan, S., 2019. Exploring the role of building information modeling in construction safety through science mapping. Safety Science 120, 456–470. https://doi.org/10.1016/j.ssci.2019.07.036

Akulenko, N.B., Ignatova, L.N., Kucherenko, A.I., 2021. Digitalization of education as a prerequisite for the implementation of industry 4.0 technologies in the activities of enterprises. IOP Conference Series: Earth and Environmental Science 666(6), 062067. https://doi.org/10.1088/1755-1315/666/6/062067

Alshorafa, R., Ergen, E., 2019. Determining the level of development for BIM implementation in large-scale projects: a multi-case study. EC&AM 28(1), 397–423. https://doi.org/10.1108/ECAM-08-2018-0352

Ametepey, S.O., Ansah, S., Gyadu-Asiedu, W., 2020. Strategies for sustainable environmental management of construction activities in Ghana. JBC&PR 8(3), 180–192. https://doi.org/10.4236/jbcpr.2020.83011
Berlak, J., Hafner, S., Kuppelwieser, V.G., 2021. Digitalization's impacts on productivity: a model-based approach and evaluation in Germany's building construction industry. PP&C 32(4), 335–345. https://doi.org/10.1080/09537287.2020.1740815
Chernykh, V.V., Suvorova, A.P., Bazhenov, R.I., 2019. Digital transformation of economic systems-a factor of strategic development of territories. Bulletin of the NNSEEU 12(103). (In Russ.)
Elghaish, F., Matarneh, S., Talebi, S., Kagioglou, M., Hosseini, M.R., Abrishami, S., 2020. Toward digitalization in the construction industry with immersive and drones technologies: a critical literature review. S&SBE. https://doi.org/10.1108/SASBE-06-2020-0077
Feldhoff, T., 2002. Japan's construction lobby activities – systemic stability and sustainable regional development. Asien 84, 34–42.
Golizadeh, H., Hosseini, M.R., Martek, I., Edwards, D., Gheisari, M., Banihashemi, S., Zhang, J., 2019. Scientometric analysis of research on "remotely piloted aircraft": a research agenda for the construction industry. EC&AM 27(3), 634–657. https://doi.org/10.1108/ECAM-02-2019-0103
Iakovleva, T., Oftedal, E., Bessant, J., 2021. Changing role of users – innovating responsibly in digital health. Sustainability (Switzerland) 13(4), 1–17. https://doi.org/10.3390/su13041616
Ilhan, B., Yobas, B., 2019. Measuring construction for social, economic and environmental assessment. EC&AM 26(5), 746–765. https://doi.org/10.1108/ECAM-03-2018-0112
Ivanova, A.O., Ignatieva, T.A., Pilyavsky, V.P., 2021. Trends, opportunities and perspectives of digital education development in the global economy. IOP Conference Series: Earth and Environmental Science 666(3), 032033. https://doi.org/10.1088/1755-1315/666/3/032033
Jovovic, R., Draskovic, M., Delibasic, M., Jovovic, M., 2017. The concept of sustainable regional development – institutional aspects, policies and prospects. JIS 10(1), 255–266. https://doi.org/10.14254/2071-8330.2017/10-1/18
Konovalov, Yu.V., 2020. Digitalization of the electric consumption system of oil and gas production enterprises. JF: Conference Series 1680(1), 012025. https://doi.org/10.1088/1742-6596/1680/1/012025
Kovaleva, I.V., 2019. Digitalization of agriculture as a strategic element of industry management. Economics and Business: Theory and Practice 3(1). (In Russ.)
Kozlov, A., Gutman, S., Tereshko, E. Analysis of the Industry and Entrepreneurship component of the Murmansk region construction complex strategic chart. E3S Web of Conferences, 2019. 91, 05011. https://doi.org/10.1051/e3sconf/20199105011
Litvinenko, I.L., 2015. Regional innovation system: features of the management system. Eurasian Scientific Association 2(4), 135–140. (In Russ.)
Lushnikov, A.S., 2015. Problems and advantages of implementing BIM technologies in construction companies. Bulletin of Civil Engineers 6, 252–256. (In Russ.)
Lygina, N.I., 2019. Digital transformation of socio-economic activity of the region. E&CWB: F&AR 9, 21–25. (In Russ.)
Muñoz-La Rivera, F., Mora-Serrano, J., Valero, I., Oñate, E., 2010. Methodological-technological framework for construction 4.0. ACME 28(2), 689–711. https://doi.org/10.1007/s11831-020-09455-9
Nguyen, T., Gosine, R.G., Warrian, P., 2021. Digitalization of the oil and gas industry: Practical lessons learned from digital responses during the first stage of the COVID-19 outbreak. Advances in Intelligent Systems and Computing 1290(2021), 313–325. https://doi.org/10.1007/978-3-030-63092-8_21
Oke, A.E., Arowoiya, V.A., Akomolafe, O.T., 2010. An empirical study on challenges to the adoption of the Internet of Things in the Nigerian construction industry. AJSTI&D. https://doi.org/10.1080/20421338.2020.1819117
Park, H., Anderson, T.R., Seo, W., 2021. Regional innovation capability from a technology-oriented perspective: An analysis at industry level. Computers in Industry 129(2021), 103441. https://doi.org/10.1016/j.compind.2021.103441
Pertseva, A.E., et al., 2017. Features of the implementation of BIM technology in domestic organizations. BES 9 (6(43)). (In Russ.)
Pfeiffer, J., Gabriel, A., Gandorfer, M., 2021. Understanding the public attitudinal acceptance of digital farming technologies: A nationwide survey in Germany. A&HV 38(1), 107–128. https://doi.org/10.1007/s10460-020-10145-2
Roberts, P., 1994. Sustainable regional planning. JRSA Journal of the Regional Studies Association 28(8), 781–787. https://doi.org/10.1080/00343409412331348666
Rodionov, D.G., Rudskaya, I.A., Gorovoy, A.A., 2013. On the methodology of regional innovation systems management. Bulletin of the Leningrad State University named after A. A. Pushkin. 6(4), 64–76. (In Russ.)
Rybin, E.N., et al., 2019. BIM-technologies. Izvestiya vuzov. Investment. Construction. Realty 9 (1(28)). (In Russ.)
Sekisov, A.N., 2019. Improving the construction production organization efficiency based on the BIM-technologies use. IOP Conference Series: Materials Science and Engineering 698(6), 066005. https://doi.org/10.1088/1757-899X/698/6/066005

Stanitsas, M., Kirytopoulos, K., 2021. Investigating the significance of sustainability indicators for promoting sustainable construction project management. IJCM 1–26. https://doi.org/10.1080/15623599.2021.1887718

Stoyanova, M., 2020. Good practices and recommendations for success in construction digitalization. TEM Journal 9(1), 42–47. https://doi.org/10.18421/TEM91-07

Tereshko, E., Romanovich, M., Rudskaya, I., 2021. Readiness of regions for digitalization of the construction complex. JOITMC 7(1), 1–17. https://doi.org/10.3390/joitmc7010002

Tereshko, E., Rudskaya, I., 2020. Digitalization of the construction complex of the region as a factor of development RIS. 2020 IOP Conf. Ser.: Mater. Sci. Eng. 940, 012022. https://doi.org/10.1088/1757-899X/940/1/012022

Tereshko, E.K., Rudskaya, I.A., 2020. Digital potential of the construction complex: concept, essence and problems of development. Scientific and Technical Bulletin of SPbSPU. Economic Sciences 13(3), 27–40. https://doi.org/10.18721/JE.13302 (In Russ.)

Vargas-Hernández, J.G., 2021. Strategic organizational sustainability. CE&S 1–19. https://doi.org/10.1007/s43615-020-00003-y

Volkonitskaya, K.G., Lyapina, S.Yu., 2014. Development of regional innovation systems. Bulletin of Eurasian Science 5(24). (In Russ.)

Zaborovskaya O., Kudryavtseva T., Zhogova E., 2019. Examination of mechanisms of regional sustainable development strategy as exemplified by the Leningrad region. IJE&AT 9(1), 5065–5076. https://doi.org/10.35940/ijeat.A2142.109119

Zhou, H.A., Gannouni, A., Otte, T., Odenthal, J., Abdelrazeq, A., Hees, F., 2020. Towards a digital process platform for future construction sites. 2020 ITU kaleidoscope: Industry-Driven Digital Transformation, ITU K 2020,9303198. https://doi.org/10.23919/ITUK50268.2020.9303198

Список источников

Aghimien, D., Aigbavboa, C., Oke, A., Aghimien, L., 2020. Latent institutional environment factors influencing construction digitalization in South Africa. IJCE&R 1–17. https://doi.org/10.1080/15578771.2020.1838973

Aghimien, D.O., Aigbavboa, C.O., Oke, A.E., Thwala, W.D., 2019. Mapping out research focus for robotics and automation research in construction-related studies: a bibliometric approach. JED&T18(5), 1063–1079. https://doi.org/10.1108/JEDT-09-2019-0237

Akmarov, P.B., Knyazeva, O.P., Tretyakova, E.S., 2021. Assessing the potential of the digital economy in agriculture. IOP Conference Series: Earth and Environmental Science 666(4), 042036. https://doi.org/10.1088/1755-1315/666/4/042036

Akram, R., Thaheem, M.J., Nasir, A.R., Ali, T.H., Khan, S., 2019. Exploring the role of building information modeling in construction safety through science mapping. Safety Science 120, 456–470. https://doi.org/10.1016/j.ssci.2019.07.036

Akulenko, N.B., Ignatova, L.N., Kucherenko, A.I., 2021. Digitalization of education as a prerequisite for the implementation of industry 4.0 technologies in the activities of enterprises. IOP Conference Series: Earth and Environmental Science 666(6), 062067. https://doi.org/10.1088/1755-1315/666/6/062067

Alshorafa, R., Ergen, E., 2019. Determining the level of development for BIM implementation in large-scale projects: a multi-case study. EC&AM 28(1), 397–423. https://doi.org/10.1108/ECAM-08-2018-0352

Ametepey, S.O., Ansah, S., Gyadu-Asiedu, W., 2020. Strategies for sustainable environmental management of construction activities in Ghana. JBC&PR 8(3), 180–192. https://doi.org/10.4236/jbcpr.2020.83011

Berlak, J., Hafner, S., Kuppelwieser, V.G., 2021. Digitalization's impacts on productivity: a model-based approach and evaluation in Germany's building construction industry. PP&C 32(4), 335–345. https://doi.org/10.1080/09537287.2020.1740815

Elghaish, F., Matarneh, S., Talebi, S., Kagioglou, M., Hosseini, M.R., Abrishami, S., 2020. Toward digitalization in the construction industry with immersive and drones technologies: a critical literature review. S&SBE. https://doi.org/10.1108/SASBE-06-2020-0077

Feldhoff, T., 2002. Japan's construction lobby activities – systemic stability and sustainable regional development. Asien 84, 34–42.

Golizadeh, H., Hosseini, M.R., Martek, I., Edwards, D., Gheisari, M., Banihashemi, S., Zhang, J., 2019. Scientometric analysis of research on "remotely piloted aircraft": a research agenda for the construction industry. EC&AM 27(3), 634–657. https://doi.org/10.1108/ECAM-02-2019-0103

Iakovleva, T., Oftedal, E., Bessant, J., 2021. Changing role of users – innovating responsibly in digital health. Sustainability (Switzerland) 13(4), 1–17. https://doi.org/10.3390/su13041616

Ilhan, B., Yobas, B., 2019. Measuring construction for social, economic and environmental assessment. EC&AM 26(5), 746–765. https://doi.org/10.1108/ECAM-03-2018-0112

Ivanova, A.O., Ignatieva, T.A., Pilyavsky, V.P., 2021. Trends, opportunities and perspectives of digital education development in the global economy. IOP Conference Series: Earth and Environmental Science 666(3), 032033. https://doi.org/10.1088/1755-1315/666/3/032033

Jovovic, R., Draskovic, M., Delibasic, M., Jovovic, M., 2017. The concept of sustainable regional development – institutional aspects, policies and prospects. JIS 10(1), 255–266. https://doi.org/10.14254/2071-8330.2017/10-1/18

Konovalov, Yu.V., 2020. Digitalization of the electric consumption system of oil and gas production enterprises. JF: Conference Series 1680(1), 012025. https://doi.org/10.1088/1742-6596/1680/1/012025

Kozlov, A., Gutman, S., Tereshko, E. Analysis of the Industry and Entrepreneurship component of the Murmansk region construction complex strategic chart. E3S Web of Conferences, 2019. 91, 05011. https://doi.org/10.1051/e3sconf/20199105011

Muñoz-La Rivera, F., Mora-Serrano, J., Valero, I., Oñate, E., 2010. Methodological-technological framework for construction 4.0. ACME 28(2), 689–711. https://doi.org/10.1007/s11831-020-09455-9

Nguyen, T., Gosine, R.G., Warrian, P., 2021. Digitalization of the oil and gas industry: Practical lessons learned from digital responses during the first stage of the COVID-19 outbreak. Advances in Intelligent Systems and Computing 1290(2021), 313–325. https://doi.org/10.1007/978-3-030-63092-8_21

Oke, A.E., Arowoiya, V.A., Akomolafe, O.T., 2010. An empirical study on challenges to the adoption of the Internet of Things in the Nigerian construction industry. AJSTI&D. https://doi.org/10.1080/20421338.2020.1819117

Park, H., Anderson, T.R., Seo, W., 2021. Regional innovation capability from a technology-oriented perspective: An analysis at industry level. Computers in Industry 129(2021), 103441. https://doi.org/10.1016/j.compind.2021.103441

Pfeiffer, J., Gabriel, A., Gandorfer, M., 2021. Understanding the public attitudinal acceptance of digital farming technologies: A nationwide survey in Germany. A&HV 38(1), 107–128. https://doi.org/10.1007/s10460-020-10145-2

Roberts, P., 1994. Sustainable regional planning. JRSA Journal of the Regional Studies Association 28(8), 781–787. https://doi.org/10.1080/00343409412331348666

Sekisov, A.N., 2019. Improving the construction production organization efficiency based on the BIM-technologies use. IOP Conference Series: Materials Science and Engineering 698(6), 066005. https://doi.org/10.1088/1757-899X/698/6/066005

Stanitsas, M., Kirytopoulos, K., 2021. Investigating the significance of sustainability indicators for promoting sustainable construction project management. IJCM 1–26. https://doi.org/10.1080/15623599.2021.1887718

Stoyanova, M., 2020. Good practices and recommendations for success in construction digitalization. TEM Journal 9(1), 42–47. https://doi.org/10.18421/TEM91-07

Tereshko, E., Romanovich, M., Rudskaya, I., 2021. Readiness of regions for digitalization of the construction complex. JOITMC 7(1), 1–17. https://doi.org/10.3390/joitmc7010002

Tereshko, E., Rudskaya, I., 2020. Digitalization of the construction complex of the region as a factor of development RIS. 2020 IOP Conf. Ser.: Mater. Sci. Eng. 940, 012022. https://doi.org/10.1088/1757-899X/940/1/012022

Vargas-Hernández, J.G., 2021. Strategic organizational sustainability. CE&S 1–19. https://doi.org/10.1007/s43615-020-00003-y

Zaborovskaya O., Kudryavtseva T., Zhogova E., 2019. Examination of mechanisms of regional sustainable development strategy as exemplified by the Leningrad region. IJE&AT 9(1), 5065–5076. https://doi.org/10.35940/ijeat.A2142.109119

Zhou, H.A., Gannouni, A., Otte, T., Odenthal, J., Abdelrazeq, A., Hees, F., 2020. Towards a digital process platform for future construction sites. 2020 ITU kaleidoscope: Industry-Driven Digital Transformation, ITU K 2020,9303198. https://doi.org/10.23919/ITUK50268.2020.9303198

Волконицкая К.Г., Ляпина С.Ю., 2014. Развитие региональных инновационных систем. Вестник Евразийской науки 5(24).

Ковалева И.В., 2019. Цифровизация сельского хозяйства как стратегический элемент управления отраслью. Экономика и бизнес: Теория и практика 3(1).

Литвиненко И.Л., 2015. Региональная инновационная система: особенности системы управления. Евразийская научная ассоциация 2(4), 135-140.

Лушников А.С., 2015. Проблемы и преимущества внедрения BIM-технологий в строительных компаниях. Вестник инженеров-строителей 6, 252-256.

Лыгина, Н.И., 2019. Цифровая трансформация социально-экономической деятельности региона. Образование и наука без границ: фундаментальные и прикладные исследования, 9, 21-25.

Перцева А. Е. и др., 2017. Особенности внедрения BIM-технологии в отечественных организациях. Вестник евразийской науки 9, 6(43).

Родионов Д.Г., Рудская И.А., Горовой А.А., 2013. О методологии управления региональными инновационными системами. Вестник Ленинградского государственного университета имени А.А. Пушкина. 6(4), 64–76.

Рыбин Е.Н. и др., 2019. BIM-технологии. Известия вузов. Инвестиции. Строительство. Недвижимость 9 (1(28)).

Терешко Е.К., Рудская И.А., 2020. Цифровой потенциал строительного комплекса: концепция, сущность и проблемы развития. Научно-технический вестник СПбГПУ. Экономические науки 13(3), 27-40. https://doi.org/10.18721/JE.13302

Черных В.В., Суворова А.П., Баженов Р.И., 2019. Цифровая трансформация экономических систем – фактор стратегического развития территорий. Вестник Нижегородского государственного инженерно-экономического университета, 12(103).

The article was submitted 30.04.2021, approved after reviewing 15.06.2021, accepted for publication 23.06.2021.

Статья поступила в редакцию 30.04.2021, одобрена после рецензирования 15.06.2021, принята к публикации 23.06.2021.

About the authors:

1. Ekaterina Tereshko, Postgraduate student, Higher School of Engineering and Economics, Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg, Russia,
https://orcid.org/0000-0001-7117-7549, ektereshko@mail.ru, ektereshko@mail.ru

2. Irina Rudskaya, Doctor of Economics, Professor, Higher School of Engineering and Economics, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia,
https://orcid.org/0000-0002-9953-6619, rudskaya_ia@spbstu.ru

3. Mario Claudio Dejaco, Associate Professor, Department of Architecture, Built environment and Construction engineering, Politecnico di Milano, Milano, Italy,
https://orcid.org/0000-0001-6804-4032, mario.dejaco@polimi.it

4. Sofia Pastori, PhD Candidate, Department of Architecture, Built environment and Construction engineering, Politecnico di Milano, Milano, Italy,
https://orcid.org/0000-0002-1755-0602, sofia.pastori@polimi.it

Информация об авторах:

1. Екатерина Терешко, аспирант, Высшая инженерно-экономическая школа, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия,
https://orcid.org/0000-0001-7117-7549, ektereshko@mail.ru, ektereshko@mail.ru

2. Ирина Рудская, доктор экономических наук, профессор, Высшая инженерно-экономическая школа, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия,
https://orcid.org/0000-0002-9953-6619, rudskaya_ia@spbstu.ru

3. Марио Клаудио Дейацо, доцент кафедры архитектуры, строительной среды и строительной инженерии, Миланский политехнический университет, Милан, Италия,
https://orcid.org/0000-0001-6804-4032, mario.dejaco@polimi.it

4. София Пастори, кандидат технических наук, кафедра архитектуры, строительной среды и строительной инженерии, Миланский политехнический университет, Милан, Италия,
https://orcid.org/0000-0002-1755-0602, sofia.pastori@polimi.it