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Smart Building Integration into a Smart City: Comparative Study of Real Estate Development

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Abstract: Smart buildings and smart cities are not the future perspectives anymore—the smart building integration into a smart city is an actual question for today and tomorrow. Development of smart buildings not only enhances the smart city concept but also promotes positivity to the urban development and national economy, and increases the quality of life of the whole population reacting to global challenges of sustainability. The innovative smart building and smart city technologies enable us to overcome these challenges by being employed through all real estate (RE) project development stages. The Evaluation Framework for Real Estate Development in Smart Cities created by the authors provides the possibility to assess the existing as well as to forecast future RE projects integration into a smart city during the whole life-cycle stage. The practical application of the presented evaluation framework was illustrated by the comparative case study. Based on the created smart building integration into a smart city evaluation framework for real estate development, 10 RE projects in Lithuania and over the world were assessed and rated by selected criteria relevant to different RE development stages. The evaluation results revealed that, especially at the design and construction stages, the existing intelligence of RE projects and/or cities is insufficient. Although real estate projects are technologically advanced as single entities, the integration into smart city networks is limited by interoperability capabilities of the cities or by different strategic goals settled by real estate developers.

Keywords: smart building; smart city; interoperability; real estate development

1. Introduction

According to statistics, people spend 85–90% of their time in buildings: work, study, relax, entertain, or simply live. In all cases, not only the internal but also the external environment of the buildings is important, which is directly related to the perceived and experienced quality of life. By 2050 the share of people living in cities is expected to increase by up to 68% [1]. Given the pace and direction of the development of information and communication technologies (ICT), it can be stated that the latter is and will continue to have an impact not only on our environment but also on urban infrastructure and its functioning [2]. Successful employment of ICT technologies for economic, social, environmental, and other solutions creates preconditions for today's innovations and new perspectives for smart cities [3].

In today's society, cities are the engine of the economy [4]. More economically productive cities need smarter and more efficient buildings that provide more opportunities for higher-income generation, country level, and greater competitiveness. Smart buildings build smart cities [5]. The smart buildings and smart cities are not future concepts anymore—this is a reality. The smart buildings market is projected to grow from USD 60.7 billion in 2019 up to USD 105.8 billion in 2024 [6] and the

smart home market from USD 24 billion in 2016 up to USD 53 billion in 2022 [7]. Individual countries such as China plan to invest around USD 333 billion by 2025 to transform 80% of the cities to smart ones. Since 2010, Japan has invested JPY 68 billion by rebuilding earthquake-ravaged cities into the smart cities. In 2015 the USA has reported allocating USD 160 million solely for the development of a research and development plan to address the various challenges facing cities [8].

One of the biggest challenges for the cities is related to the existing traditional buildings that consume more than 40% of the world's energy and account for 24% of greenhouse gas emissions. Buildings are the major users of water, materials, and land. Reducing the environmental impact of buildings is a priority in addressing climate change and other sustainability challenges [9]. Smart buildings are designed to preserve limited resources, contribute to the growth of perceived quality of life, and integrate individual building systems into a single whole. Studies have also shown that there is a direct relationship between buildings and employee productivity: up to an 11% increase in employee productivity can be achieved due to improved building ventilation and up to a 23% increase due to improved lighting system [2].

The development of smart buildings not only enhances the smart city concept but also promotes positivity to the urban development and national economy, increases the quality of life of the whole population reacting to global challenges: reducing CO₂ emissions, recycling, and using resources efficiently and sustainably [10]. The innovative smart building technologies enable the overcome of the above-listed challenges by being employed through whole life-cycle. i.e., all real estate (RE) project development stages.

The main aim of this study is to present the evaluation framework for smart real estate projects development in smart cities and based on the selected set of projects developed in Lithuania and over the world investigate how the capabilities of a smart city are employed during all stages of real estate project development.

The organization of the study is based on the following stages:

- Analysis of scientific literature;
- Development of evaluation framework of real estate development in a smart city;
- Selection of projects for investigation;
- Project analysis and interpretation of the results;
- Conclusions.

2. Research Framework

2.1. Theoretical Background for Smart Building Integration into a Smart City

The smart city is a multidimensional phenomenon that encompasses a wide range of interrelated sectors: transport, education, and healthcare, public security, infrastructure, logistics, ICT (Information and Communication Technologies), resource use, and many more. These sectors have an impact on the daily lives of the urban population.

It is obvious, that the concept of the smart city developed over the last few decades changes its content correspondingly to changes in technology, social structure, environment, and other factors. Undoubtedly, supportive state policies play an important role in the development of smart cities. Smart city development should include but not be limited to investment in smart buildings and infrastructure; intelligent transport and mobility; intelligent urban planning, design and construction; intelligent provision of utilities and management of related equipment systems; development and maintenance of a smart environment; the development of the smart economy, government and politics; promoting and maintaining people's intelligence; the provision of smart services [11,12].

In summarizing the concept of a smart city, firstly it is important to define the constitution of a city. Despite the complexity of the matter, the main components of the city are: governance and planning, people and their health, infrastructure, socio-economic structures, environment, and mobility. The city combines all these systems into one coherent territorial unit. In this context, intelligence should be

understood not only as having all the systems installed, but also as a more efficient operation enabling communication and collaboration with its population through technological innovation.

Several strategies are possible for the development of real estate in a smart city:

- Leading strategy—RE developer takes the initiative and raises established standards to a higher level of intelligence than the city;
- Following strategy—RE developer proceeds with the projects similar to already existing ones (possibly in other locations);
- Waiting strategy—RE developer implements projects with fragmentary features of intelligence.

In all cases, it is recommended to follow a certain coherent plan moving from one development stage to another. The theoretical model of smart building integration into a smart city (SBISC) adopted for real estate development is presented in Figure 1.

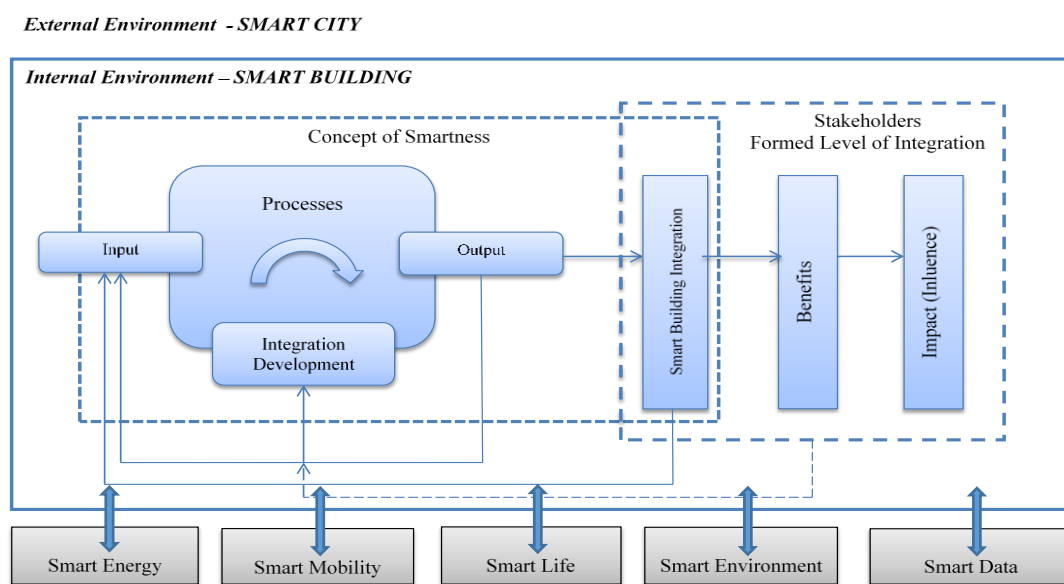


Figure 1. Theoretical model of smart building integration into a smart city (SBISC).

Smart building integration into a smart city requires individual knowledge, first of all from the owner/client/real estate developer perspective. Collective knowledge is considered as users' prerogative to assess the proposed real estate project value led by smart building features enabling integration into the smart city platform. The input package of individual and collective knowledge and competencies is formed in alignment with the existing environment protective culture, openness to innovation, and supportive position both of the local and central government as well as public opinion. The level of smart building integration into a smart city depends on the mindset and resources provided by real estate developer and the existing capabilities of smart city networks.

The above described input indicators generate direct output results such as urban intelligence and competitiveness, increase of environmental protection, and life quality. On a bigger scale, these results lead to more sophisticated consequences: trustful and transparent government and society, social and environmental responsibility, network development both for city infrastructure and local communities, changes in the culture of the mobility, and stimulation of economic activities. Finally, the obvious impact is made on the main sustainability areas: urban growth and economic development, prosperity of a social life, and enhanced country image, as well as environmental well-being (Figure 2).

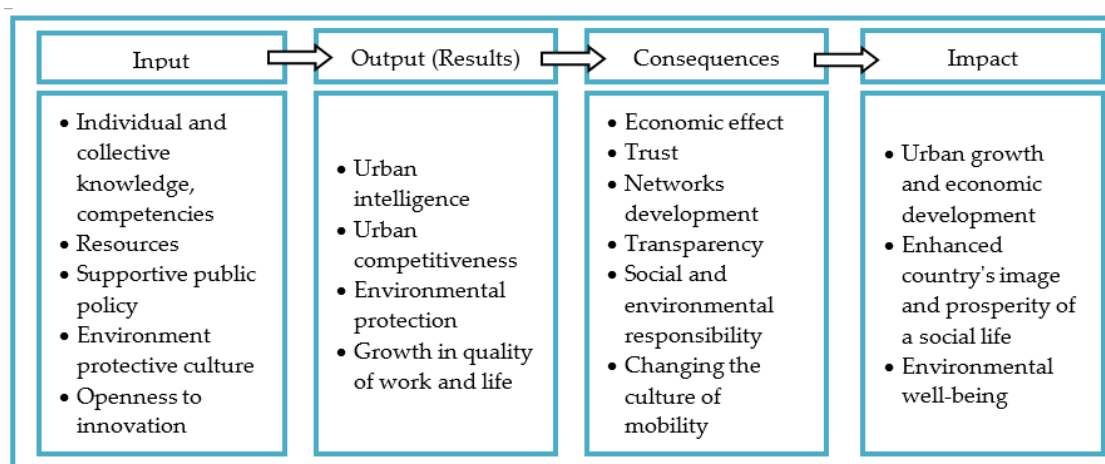


Figure 2. Input-Output-Consequences-Impact matrix of SBISC.

Smart building integration into a smart city might be evaluated by assessing the interoperability of different domains: Smart Energy, Smart Mobility, Smart Life, Smart Environment, and Smart Data (Table 1). The expanded description of the methodology for the SBISC framework development is presented in the previously published study [13].

Table 1. Description of smart building-smart city integration by smart city domains [13].

Smart City Domain	Description
Smart Energy	Response to real-time power changes when connected to the grids. Information collection, analysis, comparison and recall from previous developments; justifying decision-making and control to ensure the most effective performance.
Smart Mobility	Acquisition of real-time information from surrounding participants about their mobility and needs. Connection to the networks facilitates efficient logistics and infrastructure, considering past problems, addressing them in accordance with reasonable trends and development strategies.
Smart Life	Disaster prediction, security, health, comfort, and quality assurance, whether automatic or online, with the ability to store, analyze, compare data, and make informed decisions.
Smart Environment	Observation, analysis, and adaptation to the external environment, ability to receive information from influential actors and institutions. Online comparison and management of renewable resources, recyclable materials, waste, and justification of decisions based on past/previous reports.
Smart Data	Combination of collected data by analysis, comparison and justification. Reports and communication of combined data to different actors responsible for remote control.

The other perspective is to research the real estate development process and evaluate not only the final result, i.e., interoperability of the smart building and the smart city during the smart building operation period, but also to investigate how different features of the smart city domains can influence different real estate development stages and vice versa—what kind of smart features and how might they be deployed into the smart city platform in order to open up the real estate development process to the city community, as well as fully employ the existing in the market innovative solutions during the concept development, pre-design, design, and construction stages. The description of the RE development process in a smart city divided into stages and substages is provided in Table 2.

The methodology for real estate project development stages assessment is presented in the next section.

Table 2. Real estate development process in a smart city.

RED Stages	Substages	Description
1. Concept Development	Generation of the idea	Project idea and smart building features are based on the analysis of the real estate market. The site location alternatives for project development are selected.
	Feasibility studies	Preliminary project development costs and benefits of selected alternatives are evaluated. Initial communication with stakeholders is established by employing smart city networks.
2. Pre-Design	Goals identification	The goals and objectives of the client are determined. The needs of potential users of RE object are identified.
	Research and analysis for sustainability	Assessment of environmental impact, social and economic impact is performed. The market value of the project is further detailed and compared to the cost.
	City capabilities' assessment for smart solutions integration	Investigation if the city is ready to integrate innovative solutions, and to what extent are they compatible with the existing systems is carried out. Analysis if the companies operating or planning to operate the city are able to employ all the advantages created by the smart RE project object is being performed.
	Securing the financing	Negotiations with potential project investors, financiers or creditors, partners are initiated.
3. Design	Selection of a design company	The design company is selected, terms for design development by using Building Information Modelling (BIM) are negotiated.
	Collaboration	Common data environment (CDE) for information exchange, refinement and updating between the stakeholders during BIM-based design development process is established and maintained.
	Presentation of project design	The prepared design project is presented to stakeholders and for public hearing. Comments and suggestions are evaluated and necessary amendments are produced.
4. Construction	Selection of a Contractor	Project procurement strategy is selected. Bidding and negotiation procedures are initiated. The construction contract is signed with the selected contractors.
	Construction management	It is monitored that the works are carried out according to the approved work plan and budget by applying BIM tools. Solutions for energy efficiency, environmental protection, mobility, safety and security on the construction site are being implemented.
	Close out and commissioning	The object is checked by authorities for close out and commissioning. As-built BIM or digital twin model and operation manual of the building are produced for the users.
5. Operation	Efficient operation and maintenance	Real estate developer or the new owner of the object ensures efficient operation and maintenance of the real estate (including subletting) in order to extend the use of the building and ensure smart living and working environment for the users of RE object.
	Automatization and integration into a smart city network	Maintenance of the building and premises is performed in an automated manner. The selected Building Maintenance System (BMS) ensures interoperability with Smart city systems.
	Environmental solutions	Recycling and/or reuse of waste materials is maximized. Smart noise and mobility management solutions are implemented.

2.2. Evaluation Framework for Real Estate Development in Smart Cities

The integration of smart buildings through the entire life-cycle with the components of a smart city listed in the previous chapter brings a multitude of long-term advantages for the RE industry as well as provides obvious benefits to the city community [14]. Real estate stakeholders definitely benefit

from data-driven real estate concept development while selecting project site location, employing city networks for project public presentation of the future smart building perception, and feed-back collection understanding city official's opinion, as well as future customers' needs using open source data provided by the city government during the pre-design project development stage [15]. Design and construction stages are most relevant to adopting building information modelling (BIM) and geographic information system (GIS) technologies, which enable integration with 3D City model and all digital data provided by Internet of Things (IoT) sensors and big data centers, digital services, and procedures implemented by smart city government [16–18]. The most value from the smart building integration into the smart city is accounted for in the operation stage: digital twin and building maintenance system (BMS) integration into the city networks reduces the costs of operation by optimizing resource consumption and changing the overall RE concept from the asset to the service due to shared information within smart city networks [14,19,20].

Thus, the evaluation framework of smart building integration into a smart city for real estate development can be categorized by the sets of criteria for different RE development stages that were selected based on the extensive literature review and analysis of real projects. The development of the evaluation framework was presented for consultations and discussions with academia and industry professionals during the period of 2019–2020 and revised according to the feedback received.

The assessment is based on five stages, generally accepted by the majority of the researchers and practitioners: concept development, pre-design, design, construction, and operation [21–30]. Each stage can be rated by a maximum of 10 points (pre-design and design stage scores are combined). Relevant criteria for each stage assessment and their scores are presented in Table 3 Table 4 Table 5 Table 6 Table 7. Each criterion is evaluated based on 0–1, 0–2, or 0–3 scale, rating scores are precisely described in the provided tables.

Table 3. Concept development stage evaluation criteria.

Stage	Criteria	Score	Justification
Concept Development	Uniqueness of a smart building concept	0–3	0—project is not unique in terms of smart materials, building services and smart construction processes; 1—project is unique within the smart urban context; 2—project is unique within the country context; 3—project is unique at the regional or international level.
	Impact on sustainability	0–3	0—project is not certified by Building Sustainability Assessment Schemes (BSAS); 1—project is certified by lowest BSAS ratings; 2—project is certified by average BSAS ratings; 3—project is certified by the highest BSAS ratings;
	Site location	0–2	0—project does not fit within the near-by objects; 1—project partially fits within the near-by objects; 2—project fits very well within the near-by objects;
	Government support	0–2	0—neither local nor central government is involved in project development; 1—local government supports project development; 2—both local and central government support project development.
	Total	0–10	

Table 4. Pre-design stage evaluation criteria.

Stage	Criterion	Score	Justification
Pre-Design	Pre-design studies	0–1	0—only mandatory tests are performed; 1—more detailed analysis of the environmental impact of the project is performed.
	Transparency of funding	0–2	0—project finances are known only to a limited number of stakeholders; 1—key financial information is publicly available; 2—all interested parties have access to detailed financial information on the project.
	Project concept presentation	0–2	0—formal project concept presentation as required by the law; 1—extended project concept presentation to major stakeholders; 2—virtual reality project concept is widely presented to the public.
Total		0–5	

Table 5. Design stage evaluation criteria.

Stage	Criterion	Score	Justification
Design	Design development	0–2	0—most of the data will be 2D (usually CAD) drawings and specifications; 1—3D model with a higher level of detail and the ability to easily communicate to stakeholders; 2—fully parametric 3D model, virtual reality visualizations.
	Stakeholders' cooperation	0–1	0—information exchange between stakeholders by using paper documents or their electronic copies; 1—digital information exchange by using Common Data Environment (CDE)
	Project design presentation	0–2	0—project design is presented to a closed group; 1—project design is presented to the public; however, the amount of information is limited; 2—project design is presented in public, there is an opportunity to get acquainted with project in a virtual reality-city 3D model.
Total		0–5	

Table 6. Construction stage evaluation criteria.

Stage	Criterion	Score	Justification
Construction	Construction management process	0–2	0—standard construction management process; 1—partial BIM-based and real-time construction management process; 2—fully BIM-based real-time construction management process.
	Energy efficiency solutions	0–2	0—ordinary energy supply to construction site; 1—partial use of renewable energy; 2—energy generation, renewable energy on the site, energy-efficient equipment and/or innovative solutions.
	Environmental protection solutions	0–2	0—minimum (basic requirements) solutions; 1—advanced solutions; 2—innovative solutions.
	Solutions for safety and security	0–2	0—ordinary solutions; 1—advanced solutions; 2—innovative solutions.
	Close out and commissioning digitalization	0–2	0—ordinary inspection process; 1—both on-site and remote/digital inspection; 2—fully remote/digital services.
Total		0–10	

Table 7. Operation stage evaluation criteria.

Stage	Criterion	Score	Justification
Operation	Smart Data solutions	0–2	0—physical on-site building management and administration; 1—automated building management and administration at a local service level; 2—automated and integrated into a city network building management and administration.
	Smart Energy solutions	0–2	0—smart energy solutions are not provided; 1—local service of smart energy management; 2—integrated into a city network, advanced and innovative smart energy solutions.
	Smart Mobility solutions	0–2	0—smart mobility solutions are not provided; 1—local service of smart mobility management; 2—integrated into a city network, advanced and innovative smart mobility solutions.
	Smart Environment solutions	0–2	0—smart environment solutions are not provided; 1—partially automated, locally based; 2—integrated into a city network advanced and innovative smart environment management solutions.
	Smart Life solutions	0–2	0—ordinary solutions for life and work environment quality, safety and security; 1—advanced automated smart life solutions; 2—automatically adaptive and integrated into a city network innovative smart life solution.
	Total	0–10	

In total, four criteria are considered when evaluating the project concept development stage: uniqueness of a smart building concept, impact on sustainability, selection of a project site location, and government support. The available cumulative maximum score for the concept development stage is 10 points (Table 3).

The assessment of the pre-design phase focuses on transparency and publicity. This stage is assessed in accordance to three evaluation criteria with a maximum score of five points: pre-design studies; transparency of funding and communicating project idea to all stakeholders (Table 4).

For the design stage, three assessment criteria are identified: innovative BIM technologies application for design development and stakeholder collaboration during the design process; publicity of project design results. The maximum score of the design stage assessment is five points (Table 5).

For the construction stage evaluation, five criteria are selected: construction process management; energy efficiency solutions; environmental solutions; safety and security solutions, closeout and commissioning process digitalization (Table 6).

In assessing the management of the construction process, intelligence is achieved through city-driven information management and maximum automation of processes: from planned arrivals to fact-based activation. All processes are monitored in real-time and interference rectification is ensured if any. Energy efficiency includes both technical and process management. The equipment used are as energy-efficient as possible, the required amount of electricity is generated on the construction site by using renewable recourses, and in the event of a surplus, return it to the city electricity grid. Environmental solutions cover the full range from the reduction of construction waste to its proper sorting and recycling. For example, the demolished materials of previously standing buildings are used in the construction of other facilities. Environmental solutions also include the use of environmentally and human-friendly materials. Innovative digital solutions for on-site safety and security are established. Building inspection, closeout and commissioning process might be organized

in a remote mode if the project is executed by using BIM, GIS and digital As-Built model—Digital Twin is created at the end of the construction stage.

For the Operation stage 5 criteria are distinguished, i.e., solutions which correspond with the smart city domains: smart data applications for building management and administration, smart energy, smart mobility, smart environment, and smart life solutions both local at the building level and integrated within the city network (Table 7). The maximum evaluation score is 10 points.

The following areas are analyzed but not limited to: building operation and maintenance; rent management; waste management; energy and mobility solutions; building access solutions, level of automation of building space maintenance, compatibility with other systems, security, etc. It is necessary to assess the use of solar, wind, and other natural resources for energy production, both for building purposes and for transmission to city or country networks. Mobility solutions include but are not limited to intelligent access to the building (parking, freight delivery, etc.), sustainable integration into the existing public transport system, and solutions to reduce or eliminate congestion when needed. The possibility of parking nature-friendly vehicles and providing access roads to the building is also evaluated. Environmental solutions include light, noise, waste management, air quality, and pollution management, flora and fauna protection, building and city capability to adapt the performance to changing environmental conditions, etc. Waste management includes not only sorting but also recycling and reuse for building purposes, e.g., composting and producing energy for heating. Security solutions must cover not only the security of individuals but also the security of the building itself. To this end, there must be at least two independent energy supply sources, and in addition to conventional security cameras or a physical security response, innovative solutions should be implemented. In order to achieve the overall security of the building, it is expedient to install water, heat, and electricity leak detection systems. Security includes fire and disaster response systems. Quality of life and work environment solutions address individual and collective needs for fresh air, natural lighting, heating, or cooling. Innovative technologies include not only data collection but also automatic adaptation to the needs. All data from different building service systems need to be integrated into the building maintenance system which is connected to the smart city platform.

The summarized real estate development evaluation framework characteristics are presented in Table 8.

Table 8. Stages, criteria, and maximum evaluation scores.

Stage	Number of Criteria	Maximum Score
Concept Development	4	10
Pre-Design	3	5
Design	3	5
Construction	5	10
Operation	5	10
Total	20	40

The next section presents the comparative study results of 10 real estate project developments in smart cities.

3. Comparative Study of Real Estate Development in Smart Cities

3.1. Real Estate Projects under the Investigation

The smart building integration into a smart city through the whole RE development cycle was investigated by analyzing 10 selected RE projects which are considered nationally or internationally renowned smart buildings: 5 of them were located in Lithuania and 5 in abroad countries over the world. The most of the analyzed RE projects were built in the cities ranked as smart cities according to IESE Business School Cities in Motion Index (CIMI) index [31] and certified by

Building Research Establishment Environmental Assessment Method (BREEAM) or Leadership in Energy and Environmental Design (LEED) sustainability assessment scheme. The selected foreign projects are recognized as the flagship projects of adopted innovations in world-wide construction industry [32]; the projects from Lithuania represent the best practice examples of emerging architecture, engineering, and construction technologies implementation for the smart building on the national market. Thus, the comparative study of the selected projects enabled us to discuss the way forward for RE development companies and cities to enable the future policy and environment fostering more efficient smart building integration into a smart city during all RE development stages. The overview of RE projects that were under the investigation is presented in Table 9 and the general descriptions of the projects are provided further.

Table 9. Overview of RE projects under investigation [33–48].

Project	City, Country (CIMI Index)	Year Completed	Area, m ²	Investment Size	Building Sustainability Assessment
The Edge	Netherlands, Amsterdam (Relatively High, 3)	2015	40,000	EUR 200 million	BREEAM New Construction Outstanding, 98.36%
Burj Khalifa	Dubai, UAE (Medium, 99)	2010	309,473	USD 1.5 billion	Certification in progress: LEED v4 Existing Buildings Operations and Maintenance
The New Karolinska Solna Hospital	Stockholm, Sweden (Relatively High, 13)	2017	320,000	USD 3 billion	LEED 2009 New Construction Gold, 66 pts
Apple Park Main Building	Cupertino, California, USA (Not rated)	2017	260,000	USD 5 billion	LEED 2009 New Construction Platinum, 87 pts
Duke Energy Center	Charlotte, USA (Not rated)	2010	144,825	USD 880 million	LEED 2009 Existing Buildings Operations and Maintenance, 81
Sqveras	Kaunas, Lithuania (Not rated)	2019	6300	EUR 14 million	N/A
DC Pier	Vilnius, Lithuania (Medium, 74)	2018	11,000	EUR 32 million	BREEAM New Construction Excellent, 73.1%
Technopolis Penta	Vilnius, Lithuania	2017	13,800	EUR 18 million	LEED 2009 Core and Shell, Gold 74 pts
U219	Vilnius, Lithuania (Medium, 74)	2020	15,000	EUR 22 million	BREEAM New Construction, Very Good 58.1%
Quadrum Business Center	Vilnius, Lithuania (Medium, 74)	2017	45,000	EUR 100 million	BREEAM New Construction, Very Good /Excellent, 58.2%, 55%/75.4%, 75.3%

The Edge project in Amsterdam (the Netherlands) was recognized as one of the smartest and at the same time one of the greenest buildings in the world in 2015—for the first time in history, the BREEAM assessment rating reached 98.36%. It is important to note that solar panels installed in a building are able to produce more electricity than the building consumes [33]. The building has a sensor system that can identify the habits of each regular visitor (employee) in the building (for example, knows how strong of a coffee the employee likes, how much sugar is consumed; what is the most acceptable working room temperature, etc.). Safety is ensured not only by the installed traditional protection

systems, but also by robots, which in parallel perform the function of maintaining cleanliness. There is electricity generated in the sports facility by athletic visitors using a treadmill, bicycles, other athletic equipment, etc.

The Burj Khalifa project in Dubai (the United Arab Emirates), without numerous awards for architectural solutions, is at the same time one of the leaders of its time in the field of ecology. Most of the systems were designed at an early stage of design by collaborating architects, engineers and other professionals from more than 100 countries. A special ventilation system has been developed considering the extremely hot local climate. An advanced window cleaning system has also been installed, employing the power of wind [34].

New Karolinska Solna Hospital in Stockholm (Sweden) is one of the largest and most famous health centers in the world. The renovated and expanded building integrates both the innovations of the construction process and the most advanced ecological standards. This is the only analyzed RE project where BIM technologies were used from the very beginning. The project was developed by applying the public-private partnership model. The user-oriented environment (whether it is a patient, a visitor, or an employee) and the mobility solutions make this project unique. Technological solutions create the preconditions for halving the need for energy resources compared to hospitals of similar size. 99.7% of energy comes from renewable sources with low CO₂ emission, using combined solutions including district heating, district cooling, a separate geothermal unit, and recycled energy from ventilation air. The building has been awarded LEED Gold rating certificate [35].

Duke Energy Center was built in Charlotte (USA) in early 2010 and awarded LEED Platinum certificate. Key achievements: smart water-saving equipment, rainwater utilization system for ventilation, green roof. In the preparatory phase, all construction waste was used for the construction of the third runway at Charlotte-Douglas Airport [36].

The Apple Park Main buildings in Cupertino, California State, USA, is one of the most energy-efficient projects in the world, apart from its distinctive shape [37]. In April of 2018 in a press release, Apple announced that it uses only renewable energy sources [38]. Solar panels built on the roof of an Apple campus can generate 17 megawatts of power, which covers 75% of the power demand during peak hours, making it one of the largest solar roofs in the world. The other 4 megawatts are generated locally using Bloom Energy Server fuel cells powered by biofuels or natural gas [39]. Air flows freely between the inside and outside of the building, ensuring natural ventilation and eliminating the need for HVAC systems for nine months of the year [37].

The next five RE projects were developed in Lithuania, one in Kaunas, the second-largest city and the other four in Vilnius, the capital city of Lithuania. The projects are known not only in Lithuania. The titles of these projects are listed within the contracts of the biggest international RE transactions within the area of three Baltic States. According to the innovative solutions, all these projects might be assigned to the category of smart and sustainable buildings.

In the center of Kaunas, next to the pedestrian bridge to the Nemunas river island, the A+ energy efficiency class business center SQVERAS stands out with advanced technologies and engineering systems: combined solar control system, geothermal heating, windows with the function “fresh air”, microclimate control system, etc. [40].

DC Pier project has been awarded BREEM New Construction Excellent rating certificate. When evaluating the DC PIER building, the highest scores were credited for the use of responsibly produced and ecological materials, sorting of construction waste, 40% lower energy demand as well as the use of renewable energy sources. Designed double facade and external blinds are controlled automatically. The white color of the façade and the bright roof help to save energy for cooling. Acoustic and natural light comfort was also assessed, a modern air ventilation and humidification system was installed [41]. The building complies with A class energy efficiency requirements. It integrates modern engineering systems. A smart building management system has also been installed. A total of 10% of the energy needed for the building is produced by solar cells placed on the

roof. It is stated that this building requires 40% less energy, 52% less water consumption, and 32% less CO₂ is emitted into the environment [42].

Technopolis building complex started its operations in Lithuania in 2013. The office campus consists of 8 office buildings—ALFA, BETA (2 buildings), GAMA, DELTA (2 buildings), PENTA, and NOVA. Only the PENTA building is certified with the LEED Gold sustainable construction certificate, the quality of the building is ensured by A-class energy efficiency standards [43]. The building is equipped with modern engineering systems—automatically regulated indoor lighting, window blinds, room temperature, and humidity control. A speakerphone system is installed everywhere to ensure the safety of employees. A sense of modernity is provided by the touch screens reservation system hanging on each door of the halls, fingerprint readers are used instead of ID cards or other locks throughout the building [44].

The interior of U219 project is supplied with a large amount of high-quality fresh air that meets the strictest requirements of European building regulations. Each workplace is equipped with natural lighting and a view through the window, as well as artificial lighting in line with world-best practice. Special attention is paid to noise level and acoustics—modern façade technological solutions ensure good sound resistance and prevent noise transmission from the outdoor environment into the work environment. Particular attention is paid not only to the building's staff but also to visitors: the building's access roads, paths, lounges, and heavy traffic routes are designed to ensure very strict and hard-to-reach BREEAM "Safe Access" requirements. Environmentally friendly building materials with responsible origin and environmental certificates have been selected for the construction and decoration of the building [45].

Quadrum Business Center, representing an ensemble of administrative buildings, a business city in the city, has been designed according to the latest architectural trends. The building has been awarded BREEAM Very Good rating certificate. The building is equipped with geothermal heating, intelligent ventilation and lighting systems, special facade insulation properties, rainwater-saving roofs, and other advanced energy-saving technologies. Quadrum became the first newly built business center in the Baltics to receive BREEAM certificate. The builders of the complex have implemented innovative indoor ventilation solutions that ensure the supply of fresh air in the premises, automatically regulated ventilation capacity considering the occupancy and the number of people, which is recorded by smart sensors. The automatic overlaps installed on the façades of the building react to the sun and help to save energy: in summertime to cool the premises, in wintertime to heat them. LED lighting is adjusted according to the general lighting level, and projectors are powered by solar energy to illuminate terraces [46,47].

The above described smart RE projects integration into a smart city evaluation results and the discussion for each smart real estate project development stage are presented in the following section of the study.

3.2. Results and Discussions

Based on the created smart building integration into a smart city evaluation framework for real estate development all 10 RE projects were assessed and rated by identified criteria relevant to different real estate development stages. The comparative case projects were evaluated according to the established criteria and their scoring is based on the objective wide-range real estate development information for the selected projects retrieved from the listed information resources. Since the scoring of the criteria is described quite precisely within the framework, there is no need for subjective assessments to be involved. The authors consider that applicability of this tool for the future projects evaluation based on the objective information would be counted as an advantage by researchers and professionals working within the RE and construction industry as experts of the field.

The summarized results of the analyzed RE projects are presented in Table 10 and Figure 3.

Table 10. Summary of evaluation results.

RE Project/Stage	Concept	Pre-Design	Design	Construction	Operation	Total	Ranking
The Edge	10	4	4	8	9	35	2–3
Burj Khalifa	9	4	4	7	8	32	5
Karolinska Hospital	9	5	5	10	10	39	1
Apple park	10	4	4	8	9	35	2–3
Duke Energy Center	9	4	4	7	9	33	4
SQVERAS	7	3	3	5	8	26	7–10
DC Pier	8	3	3	5	8	27	6
Penta	7	3	3	5	8	26	7–10
U219	7	3	3	5	8	26	7–10
Quadrum	7	3	3	5	8	26	7–10



Figure 3. Cont.



Figure 3. Results of the analyzed RE projects. For the comparative analysis purposes Pre-Design and Design stage scores were combined into a single rating of 0–10 points scale.

The discussion part provides the interpretation of the results in the context of smart real estate projects development in smart cities in Lithuania and over the world. The evaluation of the concept development stage is discussed first and the scores are presented in Figure 4.

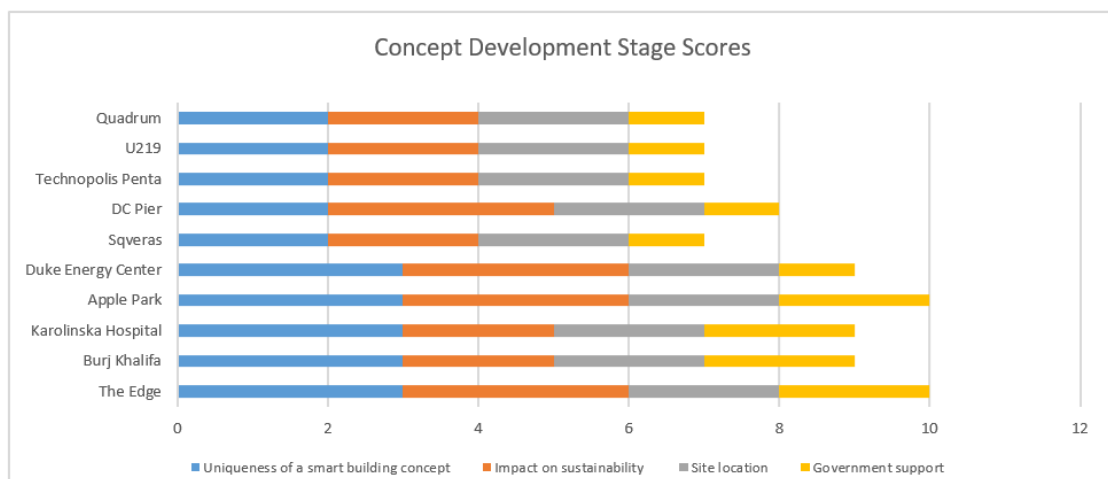


Figure 4. Concept development stage scores.

It is important to notice that external communication reveals a fundamental difference between Lithuanian and foreign valued projects. If the idea of the project is presented publicly, clearly, and unambiguously declaring the goals pursued, this makes it easier to gain the support of both the government and the public for the projects being developed.

Most of the projects fully meet all the set criteria. Exceptions: Karolinska Hospital, due to the specifics of its activities and due to the buildings still being renovated, cannot achieve full coherence/sustainability in the assessment; LEED sustainability assessment of Burj Khalifa project is still in progress; Duke Energy Center has received only local government support. Several moments stand out in assessing Lithuanian projects in the concept development stage. First of all, partial solutions for sustainability are most often used. Secondly, support from local authorities prevails. Third, there is a lack of a holistic approach to the uniqueness of a smart building concept. In all cases, the highest ratings are for the site location selection.

The second point of a discussion is the evaluation results of the pre-design stage (Figure 5).

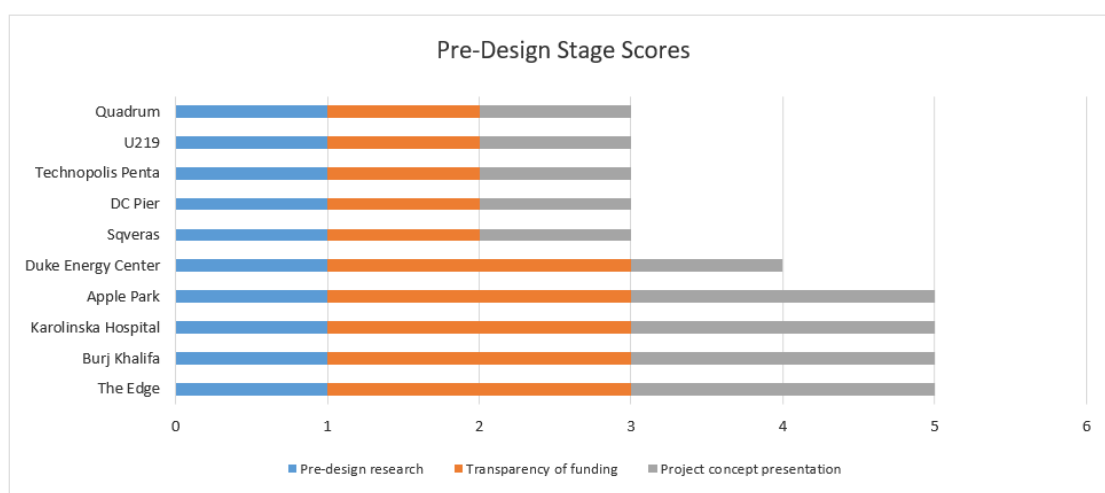


Figure 5. Pre-design stage scores.

As can be seen from Figure 5, the majority of the foreign projects demonstrated the highest evaluation results in pre-design studies and the transparency of funding. For example, the construction of new buildings might cross the existing pathways of wild animals, birds or insects. The designers of The Edge—a smart building in Amsterdam—researched the path of bees and other beneficial insects and their need for urban vegetation and installed appropriate spaces. Duke Energy Center’s initial pre-design ideas on sustainability and smartness were upgraded during the detailed design and construction phase.

Analyzing the case of Lithuanian buildings, it was noticed that real estate development companies in Lithuania (regardless of foreign capital) tend to meet the requirements for preparing pre-design studies. The second feature—the presentation of the idea to stakeholders—shows that almost all presentations of the pre-design idea is limited to a public hearing which is mandatory according to the law. However, there are no minimum requirements for citizens’ participation in public hearings, thus, this is a quite formal procedure, apparently representing the possibility to avoid any resistance. The third feature is that less information (compared to foreign companies) is presented about the financial side of the project, i.e., limited or no information is available on project funding.

The evaluation of the design phase is presented in Figure 6.

It is notable that the stakeholders’ cooperation category achieved a maximum rating for all projects. Only Karolinska Hospital’s design development fully integrated BIM technologies, despite the fact that the project was implemented on the basis of a public-private partnership.

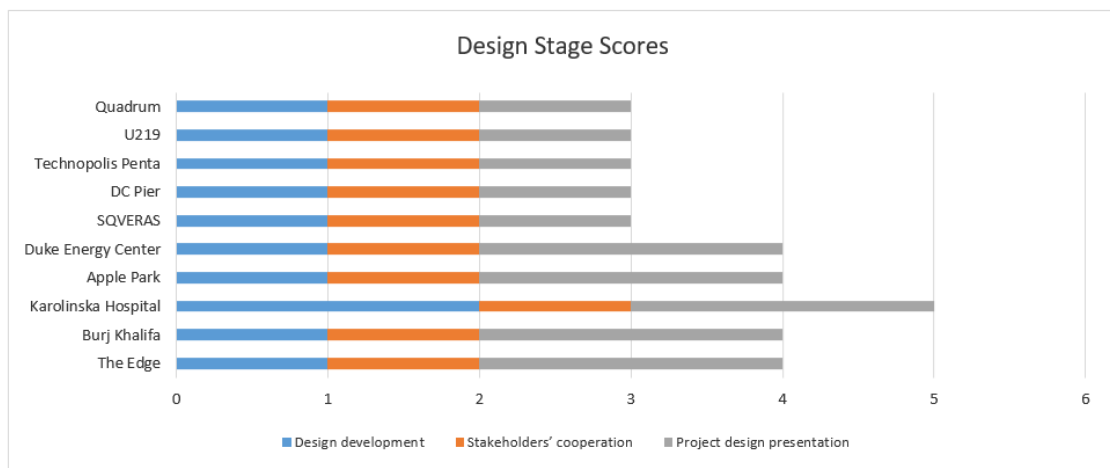


Figure 6. Design stage scores.

In the case of Lithuania, the same tendencies prevail, but the presentation of project design results is used less often, the preparation of the design project has not yet reached full BIM application, and design projects are not publicly available in digital space.

Assessing the construction stage, it was observed that of all the examined foreign buildings, only Karolinska Hospital meets the highest available score due to BIM integration into the construction management and closeout and commissioning processes. It is notable to consider the specifics of the object and the fact that this is a renovation and development project (Figure 7).

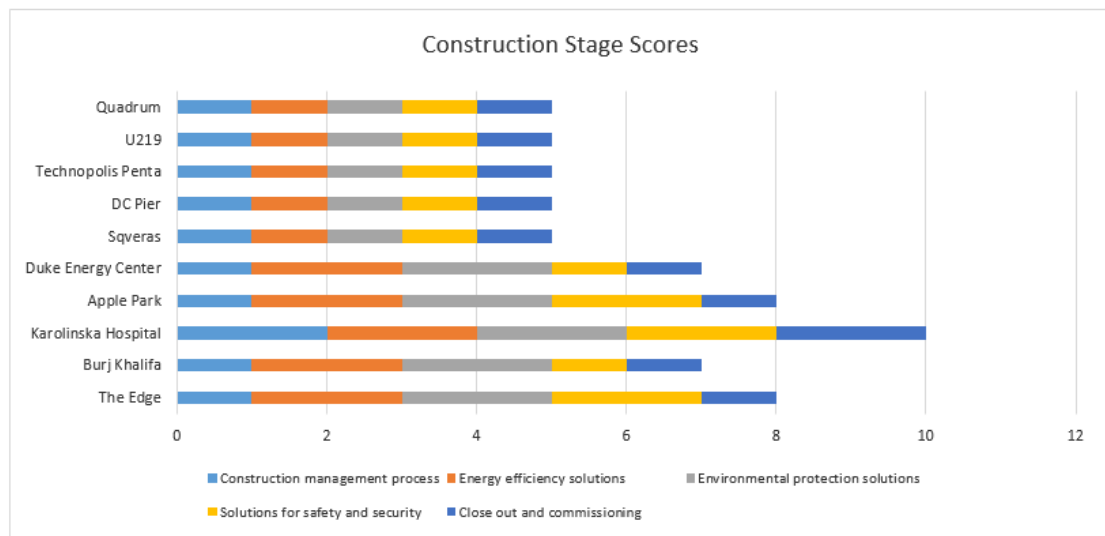


Figure 7. Construction stage scores.

When evaluating buildings in Lithuania, some differences are obvious. Energy efficiency solutions, environmental, safety and security solutions, closeout and commissioning solutions were implemented to compile only to the advanced level on the construction sites of the newest buildings in Lithuania. For the management of the construction process, the projects also lag behind the most innovative solutions in this area and as in the other areas, some advanced solutions were implemented. In the case of Lithuania, the selection of contractors at the construction stage is a closed process. Meanwhile, for example, Apple Corporation made all stages, including the change of contractors or subcontractors, public, although it did not detail the reasons for the decisions.

While evaluating the operational stage, it can be noticed that special attention to ensuring smart energy, environmental management, and smart life solutions already was taken already at the idea development stage for most of the projects under the investigation (Figure 8).

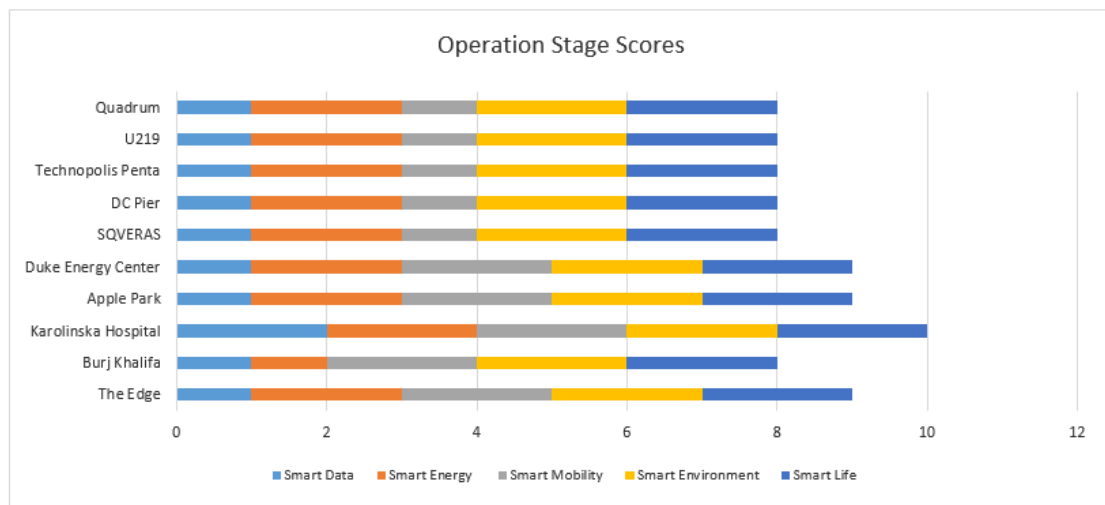


Figure 8. Operation stage scores.

Karolinska Hospital again was awarded the maximum score for the above-listed criteria and for smart data management due to BIM integration into the entire life-cycle of the project.

Projects built in Lithuania still lack complex vision in the field of mobility. On the one hand, the fragmented solutions such as building access flow management, automation of parking systems, etc. can be observed, but there is still insufficient investment in the overall integration of urban traffic with the public and other modes of transport. In the field of smart administration, open to the public renting and reservation services are taking the first steps.

The overall RE estate projects evaluation results are summarized in Figure 9.

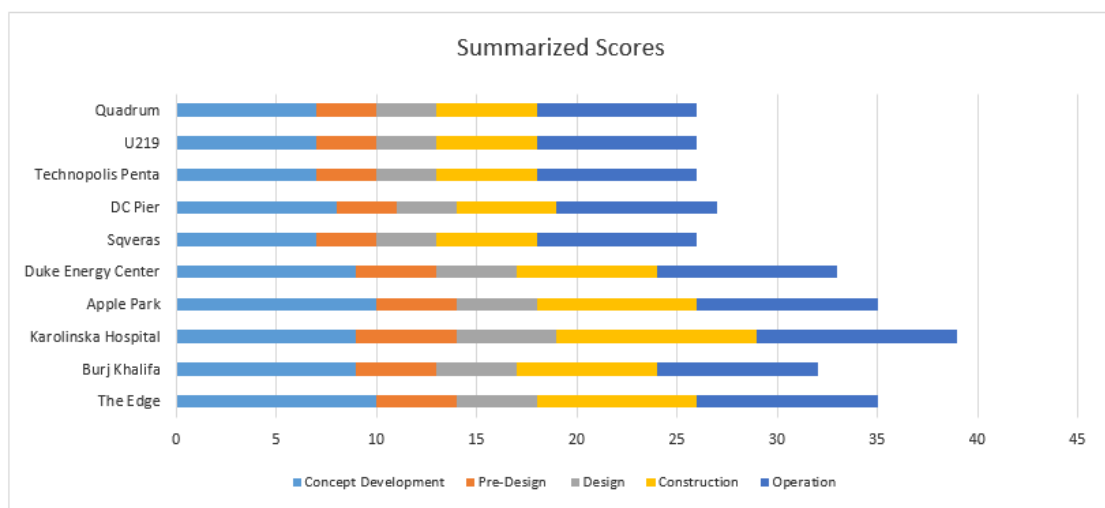


Figure 9. Summarized scores.

It can be noticed that the leading projects are distinguished by a clear and unique vision of the idea and excellent realization of it. From the presented data it is obvious that there is no one right way to achieve the highest ratings. This is due to the uniqueness of the projects as well as different capabilities of smart cities digital platforms and networks the smart buildings might be integrated into.

Meanwhile, real estate project development stages of Lithuanian projects achieved lower average ratings (Figure 10). It can be assumed that both Lithuanian cities and real estate developers are not yet inclined to take the lead and go beyond the established performance standards in terms of smart building and smart city interoperability. Innovation progress of Lithuania in comparison to the world-wide renowned real estate project development and integration into the smart city systems practices is still evolving gradually.

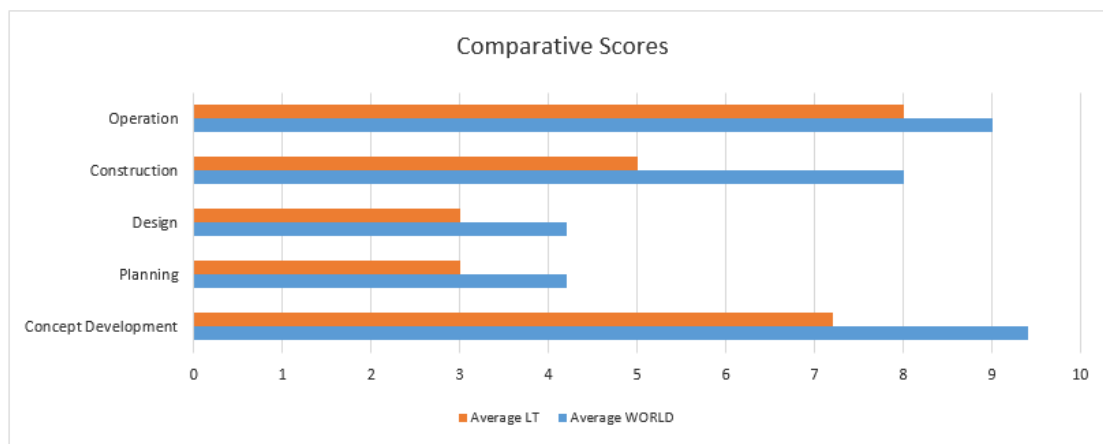


Figure 10. Comparative scores.

While further discussing the results of this comparative study in the light of the previous research conducted by the authors and other researches, it is necessary to underline that the concepts all of the selected for analysis smart buildings were very precisely developed in terms of uniqueness, impact on sustainability, and selection of a project site location. Since the concept development very closely refers to the future building operation stage characteristics as well as interoperability between the smart building and the city, the concepts of all of the projects under the investigation included majority of the smart building features enlisted by Dakheel et al. [9]. The development of these projects only in some cases were supported by government authorities, however the concept and pre-design stage results were widely presented for public hearing and the feedback was collected from the communities. Smart city networks as part of smart environment and smart data domains within the smart city enabled efficient participatory planning by inviting the local citizens to join the process using the most innovative communication channels and technologies. Thus, due to open data and communication networks within smart cities there might be less possibility of nontransparent nor undeclared collaboration of local governments, international technology companies, and real estate developers for seeking self-serving business interests, whilst that kind of a problem was identified and some specific smart real estate development cases were critiqued by Rebentisch et al. [48].

The overall design stage results of the selected RE projects reflect quite intensive and extensive application of innovative BIM technologies for design development and stakeholder collaboration during the design process as it is emphasized by Panteli et al. [16]. For the present time publicity of the future project design stage results in a virtual reality of 3D city model/map is the most advanced informative resource for the city inhabitants, guests, RE investment funds, and perspective tenants [17]. The most desirable attribute of a smart city in terms of BIM and GIS technologies would be a future digital twin model of a city integrating all digital twins of the buildings as well as infrastructure. Dynamic digital twin model would empower not only the digital communication but also the modelling and forecasting the future performance of the city and the smart buildings within the smart data, smart transportation, and smart energy domains [20].

Construction stages of real estate project development in terms of analyzed energy efficiency solutions, environmental solutions, safety, and security solutions were related to smart energy, smart mobility, and smart environment domains of the smart city [13]. However, the smart construction

concept is still mostly limited by smart technologies elaboration within the construction site and collaboration within the project internal environment but not so intense integration with the city systems [18]. Construction process management as an internal and closeout and commissioning as a process involving external public authorities are expected to reflect digitalization tendencies such as virtual site and building inspection, virtual elements identification, quantity take off, and quality control by applying IoT, BIM, and GIS technology tools and communication technologies for digital contract and document administration as they correspond to smart life and smart data domains of smart city [18]. Thus, the policy of collaboration and extended interoperability between smart construction sites and smart city ecosystems is recommended to be established and further advanced within the smart cities development strategies [8].

Operation stage of the smart buildings comparative study demonstrated the best results and proved the existing tendency that in terms of integration and interoperability with the smart city, the priority is assigned to the final RE development achievements together with initial concept development results, but not to the intermediate processes, i.e., design and construction stages. This approach is quite reasonable from the RE developers and other stakeholders' point of view—to provide and open up more information for the public and foster interoperability with the city systems at the above-mentioned stages and to retain confidentiality of business processes during the intermediate real estate project delivery process. However, exploitation of the technological potential of a smart city platform during all RE development process enables to deploy new business models, when the customer participation stands as complementary variable in order to gain the competitive advantage [11].

Variety of operational stage solutions corresponding to the smart city domains such as smart data applications for building management and administration, smart energy, smart mobility, smart environment, and smart life solutions were widely applied within the selected projects both at the building level as well as integrated within the city network [13]. However, as it was already mentioned the state-of-the-art future tendency of operational stage belongs to the development of predictive and prescriptive digital twin models simulating future scenarios and enabling to make more informed decisions based on the data captured by IoT from the physical environment as well as information transmitted from smart city networks and data centers [20].

4. Conclusions

Real estate development as a result and as a process of smart buildings creation becomes significantly important part of a smart city expansion. The Evaluation Framework for Real Estate Development in Smart Cities created by the authors provides the possibility to assess the existing as well as to forecast the future RE projects integration into a smart city during the whole life-cycle stages based on the objective information. The practical application of the presented evaluation framework was illustrated by the comparative case study.

The performed assessment of foreign and Lithuanian real estate projects revealed, that in some cases, the existing intelligence of cities is insufficient. Although the real estate projects are technologically advanced as single entities, they lack integration into smart city networks because of the limited interoperability capabilities of the cities.

The EDGE, Apple Park, and other worldwide real estate projects were already being developed at the concept development stage as unique structures that complement and expand the areas of city intelligence, sustainability, and interoperability. Lithuanian buildings were designed with a clear architectural idea and the aim to satisfy the specific sustainability goals. There is still a lack of holistic building and city integration vision.

The pre-design phase should focus on the stakeholder communication, comprehensive assessment of the areas of environmental impact, energy efficiency, mobility, quality of work, and quality of life; urban capacity (in the context of intelligence); transparency of funding. It must be stated that Lithuanian real estate developers have room to enhance these areas. Despite cooperation with international companies, there is a lack of openness in project development. In most cases, only mandatory and less

frequent additional environmental assessment studies are performed. The financial side of the project development is provided only at the end of the project. Dominant mobility solutions are more focused on adaptation rather than complimentary to urban needs.

As in the pre-design stage, the mantle of “commercial secret” is valid for the objects developed in Lithuania at the design stage. The technologies and software solutions available on the market create the preconditions for increasing the openness of the project to all stakeholders. Social media creates favorable conditions for the dissemination of design results and openness to discussions.

Lithuanian real estate developers are cautious about innovations and implement them selectively in design, construction and operation stages. The aim is to ensure BREEM or LEED standards, but the solutions chosen are selective, often only above average, without trying to set new limits for other development projects (e.g., only 10–30% of energy is generated from renewable energy sources; waste management is in line but does not exceed the standards, etc.). This is one of the main reasons for the lower ratings compared to foreign real estate projects.

Assessing the case of Lithuanian real estate projects, it was noticed that advanced technologies are used in the construction stage to manage the construction process, but they still lag behind the innovative practices of foreign countries. In objects developed in Lithuania, building management is only partially proficient. In areas that could be automated, people are still physically employed in such areas as rental and maintenance management, etc.

Assessment of smart RE project development and integration into a smart city system might be a beneficial tool for real estate developers to assess the planned project at the initial idea development stage, outline clear guidelines and aspects of special attention for further development phases. It is recommended to consider the smart real estate project development concept ensuring all building systems interoperability and integrity with the networks of the smart city. Collection, analysis, and processing of real-time data enable BMS and city management platforms to make the most energy efficient, mobile, and ecological decisions, while ensuring a high quality of life and work for the individuals both within the buildings and the city.

Future research perspectives might be expanded to smart real estate project integration into a smart city digital modelling and forecasting by applying machine learning techniques.

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