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Measuring the Spatial Dimension of a Smart City: A New Tool for Measuring and Evaluating a Smart City's Urban Form

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Abstract

This study discusses the link between the idea of the Smart City and urban form. The paper aims to fill a research gap in terms of the physical structure of a Smart City by investigating how its spatial dimension can be evaluated and measured. The methodology used is based on a comparative and interpretive analysis of logical argumentation based on analysis and synthesis. The main aim of this research was to develop a method to evaluate the spatial dimension of a smart city. In order to achieve this, a four-step process was formulated: Step 1. Extracting elements of urban form and the Smart City as a concept. Step 2. Examining the possible correlations between each component of a Smart City and urban form elements. Step 3. Creating a Smart City urban form evaluation tool. Step 4. Testing the tool on existing smart cities: the Songdo IBD in South Korea, and Aspern Seestadt in Vienna, Austria. The final outcome is a proposed tool for measuring and evaluating urban form which may be applied to future smart city projects.

Keywords: smart city, urban form, sustainable Smart City, spatial dimension of a smart city

1. Introduction

As popular the idea of the Smart City is, it still remains mostly an amorphous phenomenon. In the light of one of the most recent state-of-the-art definitions of the concept by Gracias et al. (2023), there are three basic levels of understanding the term. These are: 1. ICT (information and communication technology) implementation, 2. resource, traffic, data, people etc. management methods as well as GIS (Geographic Information System) data analysis and 3. enhancement of quality of life and sustainable development based on levels 1 and 2. This understanding of the Smart City seems insufficient to create a successfully functioning urban environment. In fact, due to rapid ICT advancement as the core of the concept, even they may not be sufficient as there is a strong possibility that they may quickly become obsolete. The author believes that the urban form of a smart city is a *sine qua non* condition for obtaining an optimal urban environment. However, studies on the urban form of smart cities are still very few. Therefore, the correlation between urban form and the notion of the Smart City is a key factor and merits investigation. The main question explored in this research is whether it is possible to measure and evaluate the urban form of a smart city, and if so, then by which tool.

Given the existing research gap, the primary purpose of this paper was to find a method that would enable the measurement of the spatio-functional potential of a smart city with a particular focus on its urban form. It was also to propose an original, universal tool for analysing and evaluating the urban form of a smart city. Secondly, this paper is intended to highlight the need to incorporate the issue of urban form into the S City idea.

This study is divided into five sections. The introduction focuses on formulating the problem and the study's aims. Section 2 presents the methodology and presents Steps 1 and 2 of the research. Section 3 presents Step 3 and introduces the measurement tool. The results producing with the use of the original measurement tool are presented in Section 4. Section 5 presents the conclusions.

This paper is a continuation of previous research presented in a PhD thesis by Gorgol (2021).

2. Methodology

The research methodology is based on a comparative and interpretive analysis of logical argumentation based on analysis and synthesis. The main aim of the research was to develop a tool to evaluate spatial the dimension of a smart city with a particular focus on its urban form. The research consisted of the following steps:

Step 1: Extracting elements of urban form and categorising them into three major groups: A. tangible factors that refer to the city's physical structure, B. intangible factors C. the synergy of factors. In this step, the measurable definitions of the Smart City were selected for further comparative analysis.

Step 2: Examining the possible correlation between each Smart City component and urban form element and, as a result, selecting Smart City features that correlate with urban form on a mutual, interrelated and measurable level.

Step 3: Creating a Smart City urban form evaluation tool by pointing out the specific components of urban form and the Smart City idea which fulfil the requirements of Step 2 and by defining the optimal, model characteristic of their mutual correlation based on the indicators presented in Table **3**.

Step 4: Testing the tool on existing smart cities: the Songdo IBD in South Korea and Aspern Seestadt in Vienna, Austria, and comparing the outcomes with the spatio-functional conditions in the smart cities as well as with their users' perception of space.

2.1. Step 1

The extraction of the elements of urban form required the analysis of the state of the art on urban form. The selection of the components was based on the references listed in the Table **1**. Secondly, the specific features were categorised into three groups: A. tangible factors that refer to physical structure, B. intangible factors, C. a synergy of factors that refers to the total impact of all urban form elements. This allowed to systematise the specific elements types which facilitated he further qualitative and quantitative assessment of the specific features of smart city in each category. The final selection of the urban form components with the references to their theoretical background will be listed in columns 3 and 4 in Tables **3**, 4 and 5.

Creating the proposed tool required the selection of a measurable yet holistic definition of the Smart City. Among the dozens of established Smart City definitions there are those either with a specific focus or a holistic approach, e.g., those by Albino, Berardi, Dangelico (2015), Chen (2010), Harrison (2010), Washburn, Sindhu (2010), Komninos (2011), Nam and Pardo (2011); Marsal-Llacuna et al. (2014); Giffinger et al. (2007), Caragliu, Del Bo and Nijkamp (2011), Bakıcı et al. (2012), Barrionuevo et al. (2012), and the ISO definition (2014). The systematics proposed by Giffinger (2007) was ultimately chosen, and supplemented by Boyd's Smart City wheel (2018). The reason for choosing these two approaches was motivated by the specific catalogue of Smart City components that they feature. Both of these definitions name six elements of the idea: smart economy, smart people, smart governance, smart mobility, smart living and smart environment. The differences are noticeable at the characteristic features of each of the six values. The Boyd systematic is seen as supplementary. To each six smart factors defined by Giffinger, only these specific components by Boyd were added, which might be seen as an additional aspect.

Table 1. References of research tools – step 1

References of research tools – step 1			
Reference	**Selection of features based on**	**Feature/Tool**	**Indicator**
Borie, Denieul (1984)	'Méthode d'analyse morphologique des tissus urbains traditionnels'	material factors/physical structure	urban form components
Conzen (1969)	'Alnwick, Northumberland: A Study in Town-Plan Analysis'	material factors/physical structure	urban form components
Williams, Jenks, Burton (2000)	'Achieving Sustainable Urban Form'	sustainable urban form components: density, size, configuration, detailed design and quality, material factors/physical structure	urban form components
Wejchert (1974)	'Elementy kompozycji urbanistycznej'	tangible factors/physical structure	urban form components
Tołwiński (1939)	'Urbanistyka. Tom I. Budowa miasta w przeszłości'	intangible factors	urban form components
	'Urbanistyka. Tom I. Budowa miasta w przeszłości', (the urban composition factor)	synergy of factors	
Lynch K. (1991)	'Quality in City Design' [in:] 'City Sense and City Design, Writings and Projects of Kevin Lynch'	holistic definition of urban form, synergy of factors	urban form components

References of research tools – step 1			
Reference	**Selection of features based on**	**Feature/Tool**	**Indicator**
Giffinger (2007)	'Smart cities – Ranking of European medium-sized cities'	Smart City features in the correlation with urban form: smart mobility, smart environment , smart living, smart governance, smart economy, smart people	smart city elements/ features
Cohen (2018)	'Smart city wheel'	supplementary smart city features in the correlation with urban form: smart mobility, smart environment , smart living, smart governance, smart economy, smart people	smart city elements/ features

Source: own elaboration

2.2. Step 2

In the second step, the possible correlation was thoroughly examined between each smart city feature, including its detailed components, and each urban form component. To keep the paper short, only the final outcomes are presented, whereas a detailed analysis can be found in Gorgol (2021). As a result, four main smart factors: smart mobility, smart environment, smart living and smart governance, were chosen as the ones which correlate with urban form on a mutual, interrelated and measurable level. For each of the smart factors, specific subcategories were selected. The detailed selection will be presented in rows 3 and 4 in Tables 3, **4** and **5**.

Smart mobility. This factor is closely related to the development of the road system and transport connections. Therefore, it significantly influences urban form. In principle, it can be assumed that the transport and circulation system permanently dictates the division of space, and therefore also affects development. Smart mobility is mainly related to the material aspects of urban form and the intangible effects of the city management model. It also affects the composition of the urban form. All subcategories of smart mobility are related to the effects of the city management model in the sense of striving to ensure conditions for the development of sustainable means of public and individual transport. However, clean and non-motorised mobility; sustainable, innovative and safe transport systems, and local accessibility reveal the strongest connection with the material aspects of urban form. For this reason, these subcategories were selected for further research.

Smart environment. The smart environment factor consists of the following subcategories: attractivity of natural conditions, pollution, environmental protection, sustainable resource management (Giffinger, 2007), in addition to green building (smart buildings) and green urban planning defined by Boyd (2018). Almost all of these subcategories correlate to an urban form element related to natural conditions (topography, greenery, water and outstanding landscape elements), the effects of the legal regulation system and the effects of the management model. The smart environment factor is one of the most important elements that correlate with urban form. Mainly due to B. Cohen's inclusion of the subcategory of spatial planning (green urban planning). This subcategory determines the potential for ensuring spatial order.

However, while analysing the subcategories in detail, there are some categories which are either hard to measure or require an individual approach towards the study of each case. The pollution (air quality) subcategory is in fact directly related to the shaping of urban systems, including: ensuring optimal city ventilation. However, the form of buildings that allows this requires an individual approach for each development. It depends namely on local topographic and aerodynamic conditions. Adopting a universal, model method of shaping urban tissue to ensure good ventilation seems to be an impossible task. Due to the individualised nature of this subcategory, it was rejected for further research.

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Ecological awareness, environmental protection, and the management of renewable resources correlate with urban form indirectly. They support, among other things, investments in energy-independent, intelligent buildings and the implementation of sustainability, but they go beyond the architectural and urban scope. At the same time, the level of their impact on the urban form remains difficult to measure. For this reason, these factors were omitted as elements that significantly interact with urban form. In summary, the following factors were defined as directly influencing urban form: attractivity of natural conditions, spatial, green building (smart buildings), green urban planning.

Smart living. The smart living factor includes: cultural facilities, health conditions, individual safety, housing quality, education facilities, touristic attractivity, social cohesion, culturally vibrant & happy subcategories. The factors correlating with urban form and having mutual impact on each other are: cultural and education facilities; individual sense of security, housing quality and inclusive society, social cohesion. At the same time, in the set of elements constituting smart living, the strongest relationship and mutual influence on the urban form can be attributed to (the methods of creating) the individual sense of security and the quality of the development. The social cohesion factor may be seen as the outcome of these subcategories. The other subcategories, despite numerous connections with the urban form, are factors difficult to grasp in a rational and measurable way in the context of their influence on shaping the urban form.

Smart governance. The smart governance factor plays a crucial role in shaping urban form and impacts it directly. All of the subcategories of this smart value: participation in decision-making, public and social services, transparent governance, political strategies and perspectives, transparency and open data, ICT and Gov are related to the management model, listed as an intangible factor of urban form.

Analysis of the correlation of urban form and the Smart City found that the following subcategories play a special role: political strategies and perspectives, open government, and participation in decision-making. The first one affects all factors of the urban form, except for the existing natural conditions (outstanding landscape elements). This subcategory determines the vision of implementing the Smart City idea, and therefore effects that adapt or create a city's urban form. It also defines the principles on which the vision is to be achieved, in particular in terms of the regulation of local law, the role of urban planners and planning instruments. Political awareness and participation in decision-making are inextricably linked to the bottom-up approach to city governance and social participation. This subcategory depends on the potential for active participation in decision-making resulting from a given legal system. The other subcategories are of a secondary nature to the subject of the study. Their correlation with the urban form largely concerns the effects of the management model and its indirect influence on the shape of the urban form.

Smart economy. There are certain correlations between this smart feature. However, the economic conditions of a city are a factor that is difficult to grasp in a rationalised and measurable way in terms of its influence on shaping the urban form. The category also goes beyond the research area of this paper, which is why it was omitted from analysis.

Smart people. Similarly to smart economy, the smart people category is difficult to measure in terms of its possible correlation with urban form and remains outside the research area of this paper. For this reason, this factor was excluded from further research.

3. The measurement tool proposal

3.1. Step 3

Step 2 narrowed down the list of smart factors and their subcategories to the ones that correlate with and have a mutual interdependence with the urban form. All the correlating elements of the Smart City and urban form were set together in a tabular form. Step 3 consisted of the identification of a model correlation pattern based on the literature in presented in Table 2. Furthermore, the selection of the model features was supported by an analysis of positive trends in the development of modern cities. This was a necessary step to reference desired characteristics and analyse specific urban forms of smart cities. The original measurement tool was produced as a result.

Table 2. References of research tools – step 3

References for research tools – step 3		
Reference	**Selection of features based on**	**Feature/Tool**
WCED (1987)	Report of the World Commission on Environment and Development: Our Common Future	definition of sustainable development
Lehmann (2010)	*The 15 guiding Principles of Green Urbanism*	Principle 1, Principle 2, Principle 4, Principle 5, Principle 6, Principle 8, Principle 9, Principle 10, Principle 12
Vale B. R. (1991)	*Green Architecture*	pro-environmental solutions based on the use of alternative energy sources, energy efficiency, the 3R principle (reduce, reuse, recycle) and respect for the environment and the user of architecture
Nawratek (2014)	*O denerwującej niemożliwości inkluzywnej architektury*	the inclusiveness of space: 1. technical – as an adaptive ability of space for changing its functions; 2. spatial as a possibility of dynamic modification/ manipulation of space or 'diagonal geometry' (public spaces on roofs), 3. time (or the process of space usage) – the presence of different activities and uses in the same location, but at different times
Gehl (2013)	*Life between buildings*	the quality of city space demonstrated by the presence of people
Gyurkovich (2007)	*Miejskość miasta*	urban character of the city, understood as public spaces which encourage social use and activities in them

Source: own elaboration

The measurement tool was designed as a set of model correlation patterns. It can serve as a reference while analysing a specific feature. The division of the urban form elements into three categories: A. tangible factors that refer to physical structure, B. intangible factors and C. synergy of factors, allows us to examine either each set of features separately or as a whole. Namely, the method consist of assessing and evaluating each particular correlation by assigning points. A single point is given if the requirements of a model correlation pattern are fulfilled, half a point is given if they are partially fulfilled, and no points are given when there is no fulfilment or no correlation observed. The total amount of points for each urban form category is compared to a maximum fulfilment level shows a synthesis of correlation. The total correlation level is based on comparing the total sum of points collected to the maximum general fulfilment level.

The research tool is presented in Tables 3, **4**, **5**.

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4. Results

4.1. Step 4

The accuracy and efficiency of the proposed tool was tested on two cases of smart cities. The following cases were selected: the Songdo IBD in South Korea and Aspern Seestadt in Vienna, Austria.

The testing phase required a high granularity. This is why, it was based on mixed methods and extended database as presented in Table 6.

Table 6. Database and methods for the assessment of the case study smart cities

database and methods for the assessment of the case study smart cities.		
Method	**Tool**	**Source**
1. analysis of literature	critical review and analyses of the literature	printed and online sources: - city's reports, polices and planning documents, - official websites of smart city projects - official websites of the municipal authorities of Songdo, Vienna; - archival (in terms of Vienna)
2. case study	urban analyses, data analyses	- masterplan analyses - authorial urban analyses based on global data base a.o.: https://www.openstreetmap.org/;https://earthengine.google.com/timelapse/; https://www.mapz.com/ - authorial urban analyses based on local databases including: statistical data from the databases of the municipal authorities of Songdo, Vienna; scientific resources from libraries
3. observation methods	authorial observations	site visits (Aspern Seestadt), Google Earth walks (Songdo IBD)

Source: own elaboration

Fig. 1. The synthesis of the evaluation of Aspern Seestadt's and Songdo's urban form by using the authorial measurement tool (Source: own elaboration)

To keep the paper short, the final outcomes have been presented as a synthesis of results in Illustraion 1.

Songdo IBD. The assessment of this district using the proposed evaluation tool showed that the level of correlation between the elements of the urban form with smart values did not exceed the threshold of 50% for any of the three factor groups. As a result, the synthesis of the correlation level was also below 50%. The strongest correlation was detected for intangible factors whereas the weakest concerned the synergy of factors. This may appear surprisingly low considering that the district was created as a model smart city, as an example for future smart cities. However, observation and a review of the literature found the data to be correct. Songdo's success was only partially achieved in terms of urban form shaping solutions. The literature analysis presented mixed reviews. On the one hand, there are few publications that consider Songdo as a successful project (Chan, 2016; Karma, 2021). On the other, more critical views predominate (Sennett, 2012; Keeton, 2015; Mesmer 2017; Lichá, 2018; Neidhart, 2018; Poon, 2018). The reasons for this can be found in aspects connected to urban form such as: low functional diversity of individual building areas (Keeton, 2015; Sennett, 2012), spatial monotony and lack of individual urban identity (Sennett, 2012; Mesmer, 2017). These observations remain consistent with the data obtained from the research, which means that the proposed tool can be considered efficient.

Aspern Seestadt. This smart city district promotes itself as an ideal living space and as a form of a self-sufficient city-within-a-city. On the one hand, the district's planning process may be considered exemplary, but on the other, the effects remain controversial. In addition, a site visit in 2018 revealed some imperfections in the district's functioning. There was an obvious dissonance between the main goals of the project and the way the district functioned. First of all, there was a very low level of social activity in urban space: on the streets and in public and recreational spaces. This may have been caused by the fact that the project was still in the implementation phase, and perhaps when the entire layout is finished, which is planned for around 2030, an inclusiveness of urban spaces will be achieved. Poklewski-Koziełł (2018) also recommends further observation of the district with the highlight on the effectiveness of its urban model and mobility tendencies. Similarly to the observational conclusions, also, the outcome of the implementation of the evaluation tool show some imperfections in Aspern Seestadt's urban form. The level of correlation of specific urban form elements is generally even and reaches around three-quarters of the fulfilment of model smart city characteristics. This should be considered as quite a high result. The weakest link in the correlation between urban form and smart city values was the synergy of factors, which is characterised by a coherence of two-thirds with the goals presented in the tool. This level of correlation could also be noticed the district's functioning as described in the observations from the site visit.

In summary, the accuracy of the tool was verified in comparing the outcomes with spatial-functional conditions in the two analysed smart cities as well as in the perception of space by their users.

5. Conclusions

This paper fills a gap in existing research on the Smart City idea and its connections to urban form. The main focus of the paper was to examine the possibility of measuring and evaluating the urban form of a smart city and thus to formulate a tool that could do this. As presented, both goals were achieved. The study proposes a tool to measure and evaluate the spatio-functional potential of a smart city as divided into three categories: A. tangible factors that refer to physical structure, B. intangible factors C. the synergy of factors. Tests of the tool on a sample of two existing smart cities verified its accuracy. However, the tool should be tested on additional smart city projects to prove its universality.

The findings of the study open the way to further investigation. The research tool presented in this paper may be used to analyse existing smart cities as well as in the design of new smart cities. In this light, the findings of the study may be found useful by researchers, urban planners, urban policymakers and project sponsors.

Furthermore, the paper highlights the need to incorporate the spatio-functional dimension into the Smart City as a concept.

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