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REVIEW OF TOOLS TO SUPPORT STUDY IMPLEMENTATION AND DATA ANALYSIS USING SPACE SYNTAX THEORY

The article is an attempt to classify selected tools supporting the implementation of studies and research using space syntax theory. The tools have been grouped taking into account the assessment of the state of their availability, the platform for which they were developed and the level of support from the developers for end users. For comparative purposes, the functionalities of the tools are presented, taking into account the types of input data and the available forms of graphical presentation of the obtained results. Information has also been collected about groups and companies that implement surveys and develop IT platforms for their implementation. An additional purpose of the article is to present the directions of development of platforms supporting research, based on the described methodology and tools in conjunction with VR technology. The analyzed literature sources indicate the possibility of using game engines to integrate the described tools with simulation systems. They allow dynamic change of the environment with real-time analysis of results testing different variants of solutions for improvement. Such activities allow gaining higher efficiency of experimental work and satisfaction of users of tested spaces and communication solutions for the construction and modernization of architectural objects with complex functional systems and urban spaces.

Keywords: urban design, space syntax theory, spatial relationships, accessibility optimization, tools overview

Published in 1994, the book ‘The Social Logic of Space’ [Hillier, Hanson 2009] presented a set of theories and techniques for analyzing spatial configurations. The term space syntax brings together an idea developed in the late 1970s and early 1980s by Bill Hillier, Julienne Hanson, and colleagues at The Bartlett University College London, which is an elaboration of insights into the mutually constructive relationship between society and space. The basic syntactic

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measures defined within the completed theoretical work are fundamental to understanding the method that was developed and extended based on them. The four syntactic measures listed below, which can be written in the form of an algorithm and perform the corresponding calculations on them, became the basis for the construction of IT tools to support the process of analysis and visualization of data, obtained in the realized experiments and observations. These are:

- connections (Connectivity),
- depth,
- control value,
- local and global integration.

Although the discussion of the weaknesses of the theory is ongoing, more tools are continually arriving to support research and analysis using the idea described [Spatial network analysis software]. The spread of knowledge about the concepts of space syntax theory has led to the development of a group of tools available for various IT platforms. These are programs that are standalone applications or add-ons to CAD/GIS-type tools. Many of them were developed during or as a result of various types of work carried out by young researchers as part of their doctorate or for research teams. Research in space syntax is an interdisciplinary field that explores the relationships between spatial configurations and social behaviors. Various studies focused on this area encompass a wide range of applications, including examining how architectural layouts in hospitals can influence patient outcomes, urban planning dynamics, and optimizing pedestrian flows through cityscapes. In particular, researchers employ space syntax methodologies to analyze movement patterns, density, and accessibility, providing valuable information on how space affects social interaction. The global scale of these studies showcases the adaptability of space syntax theory across different cultural and physical contexts. Space syntax has gained significant traction in the realm of interior wayfinding, offering a robust framework for understanding how spatial configurations influence human navigation within environments. Recent studies indicate that it not only aids in creating formal descriptions of these environments, but also in predicting wayfinding behaviors effectively. By analyzing movement patterns and spatial relationships, space syntax explores the cognitive aspects of knowledge acquisition and navigation strategies in interior settings. This innovative approach emphasizes human experience and behavior, paving the way for more intuitive building designs and urban planning. Its application ensures that spaces are not only aesthetically pleasing, but also functional and easy to navigate, enhancing the overall user experience. As a result, the space syntax is transforming the way we approach the planning and design of both buildings and public areas, marrying scientific insight with human-centric design principles.

1. PURPOSE OF THE STUDY

Using leverage space syntax theory can indeed present challenges, particularly for individuals who may not be well-versed in the nuances of the theory or familiar with the specific software applications required. Notable tools utilized in this domain include Rhino, Grasshopper, Depthmap, and Syntactic, among others. Each of these tools has its own learning curve, necessitating a solid understanding of both the theoretical frameworks underpinning space syntax and the technical skills to navigate the software effectively. For those new to space syntax, the integration of architectural design and human behavior analysis can be complex. Therefore, engaging in comprehensive training programs or workshops can be beneficial. Many institutions and organizations offer dedicated courses that aim to impart the essential skills and knowledge required to harness these tools effectively. Additionally, collaborating with experts or joining community forums can provide valuable insight and support, facilitating a smoother and more productive experience in applying space syntax principles to analyze spatial layouts and human activity patterns in various environments. Ultimately, while there may be an initial learning curve, the insights gained from using these tools can significantly enhance the design and functionality of spaces, aligning them more closely with user behaviors and needs. Many of the available tools are characterized by a problematic usability. This is due to the abandonment of their development and support by the authors and the loss of compatibility with new development libraries available for current and supported versions of operating systems (iOS, Windows, Linux). The complicated process of installing and pre-configuring tools to work is a barrier and challenge for new users. Therefore, the task of the presented materials is to collect and present information about available and developing tools that can support research and experimental work.

2. CLASSIFICATION AND EXAMPLES OF TOOLS

The tools selected have a wide variety of support. Many offer access to instructional videos on platforms such as YouTube or Vimeo, as well as support and educational materials on websites built by groups of researchers and authors who use them for ongoing work. These include presentations, files of sample applications, and other materials, including publications about completed research. During the development of the article, the author decided to distinguish several categories of tools in order to assess their usefulness to users. The tools presented were divided into two categories. The first group includes sets of add-ons for the platform that is Rhino and Grasshopper. The second group (Others) is applications that function independently. In the group of tools available on the food4Rhino website (as Grasshopper-only plug-ins), five selected tools were evaluated. They are shown in table 1 and are sorted according to user ratings. The evaluation value consists of the

number of votes and the number of downloads. The tools in this group are characterized by a large difference in the number of ratings and downloads. The tool with the highest number of downloads at more than seven thousand is Syntactic. In addition, the study included information on the type of license and its cost, the availability of the software, the year the tool was developed, and data on the current version of the software, as well as additional information such as the tool's website and implementations and practical applications. For the purpose of the article, studies were also conducted to identify the most important groups of researchers and centers that have formed around the issue of urban design and other topics implemented using Space syntax theory. These groups are associated with universities and organizations that implement cooperation in multidisciplinary teams – table 2.

Tab. 1. Applications supporting analysis using space syntax theory implemented in the Rhino/Grasshopper environment

	Proper name	Developed	Year of creation	Author(s)	Available version	Implementation category	License type	Price per license	User rating	Number of downloads
1	SpaceChase	Yes	2021	https://spacechase.app/about-us/	v036 - 2021.11.02	Architecture, Urban Planning & City Modeling	Other	free	5/5 (4 votes)	941
2	SYNTACTIC	No	2018	Pirouz Nourian and Samaneh Rezvani at TU Delft, Faculty of Architecture, Department of Architectural Engineering + Technology	2.7 - 2018-10-27	Architecture, Urban Planning & City Modeling	Other	free	4/5 (25 votes)	7785
3	Termite Nest	Yes	2020	Mohammad Hassan Saleh Tabari, Homan Jafar Kermani	Termite_Nest V.1.0,0.beta.4	Architecture	Proprietary	free	5/5 (24 votes)	3925
4	UrbanX-Tools	Yes	2021	Tao Yang, Weizhen Luo, Xuhui Lin, Chengru Deng, Yufei Dong	UrbanX-Tools_v3.0.1	Urban Planning & City Modeling	LGPL 3.0	free	5/5 (4 votes)	625

	Proper name	Developed	Year of creation	Author(s)	Available version	Implementation category	License type	Price per license	User rating	Number of downloads
5	Grasshopper Reach Analysis Toolkit	No	2019	Chen Feng	bd	Analysis & Simulation, Architecture, Environmental Design, Urban Planning & City Modeling	Other	free	4/5 (5 votes)	1252
6	PlanBee	Yes	2021	Marco Juliani	Updated v0.0.2 PlanBee Sample Files	Analysis & Simulation, Architecture, BIM, Programming Tools	Proprietary	free	5/5 (11 votes)	4308
7	LeafVein	Yes	2021	Dachuan	LeafVein_alpha0.6	Architecture, General, Mathematics, Modeling, Urban Planning & City Modeling	Other	free	5/5 (12 votes)	4678
Other										
1	sDNA_GH	Yes	2022	James Parrott	sDNA_GH v2.02022-09-20	Analysis & Simulation, Architecture, Urban Planning & City Modeling	MIT	free	bd	168
2	Urbano	Yes	2019	Timur Dogan	20.09.2022	Analysis & Simulation, Architecture, Urban Planning & City Modeling	MIT	free	bd	bd
3	depthmapX	Yes		Tasos Varoudis	v3.2.4	Analysis & Simulation, Architecture, Urban Planning & City Modeling	GPLv3	free	bd	bd

Tab. 2. Research and tool development groups using space syntax theory

	Proper name	University/Firm	Software tool(s)	Link to the group's homepage
1	Space Syntax Laboratory	Bartlet UCL (University College London)	depthmapX, QGIS_depthmap	https://www.ucl.ac.uk/bartlett/architecture/research-projects/space-syntax-laboratory
2	Spatial Morphology Group	Chalmers University	Place Syntax Tool - QGIS	https://www.smog.chalmers.se; https://www.smog.chalmers.se/pstl https://github.com/SMoG-Chalmers/PST/releases/tag/v3.2.4
3	Urbanism	TU Delft (University of Technology)		https://www.tudelft.nl/en/architecture-and-the-built-environment/about-the-faculty/departments/urbanism
4	Urban Form Lab in Washington	University of Washington (UFL)		https://sites.uw.edu/ufl
5	City Form Lab	MIT		http://cityform.mit.edu
6	Genesis Lab		SYNTACTIC	https://genesis-lab.dev/publications/
7	ESLAB	The College of Arts, Architecture and Planning (AAP) and the School of Civil and Environmental Engineering (CEE) at the College of Engineering at Cornell University	Urbano	https://es.aap.cornell.edu

Tab. 3. Comparison of the types of analysis that can be performed with selected applications running as plug-ins in the Rhino/Grasshopper environment

Application	Types of input data	Types of analysis	Visualizations
SpaceChase	3D models of space, resource information, traffic data	Spatial analysis, asset analysis, urban simulation, 3D model visualization	3D maps, spatial visualizations
SYNTACTIC	Textual Data, Spatial Descriptions	Text analysis, semantic analysis, natural language processing, sentiment analysis	Visualizations of Text Data

Application	Types of input data	Types of analysis	Visualizations
Termite Nest	Agent models, social interaction data	Agent behavior analysis, social interaction simulation, group dynamics modeling	Interaction Analysis, Agent Visualizations
UrbanX-Tools	GIS data, urban plans	Geographic analysis, spatial data analysis, urban planning	Urban maps, GIS visualizations
Grasshopper Reach Analysis Toolkit	Architectural plans, accessibility data	Range and accessibility analysis, parametric design, spatial-functional modeling	Coverage maps, parameter visualizations
PlanBee	Design Guidelines, Data on Urban Processes	Process analysis, planning optimization, performance analysis, scheduling	Process visualizations, analysis graphs
LeafVein	Structural data, flow information	Structural analysis, flow modeling, biomimetic optimization	Flow maps, structural visualizations

To carry out analyses and simulations using applications from the space syntax group, the following provides information on the input data groups needed for each application listed below:

1. sDNA_GH

Required data:

- 3D model of buildings and urban spaces (e.g., in CAD or Rhino format),
- Spatial grid (e.g., street segmentation, spatial ties),
- Traffic information from pedestrians and vehicles (traffic volume data),
- Additional contextual information (e.g., space dedication, service availability).

2. Urbano

Required data:

- Urban plans and maps (ajdplot, GIS),
- Spatial structure (roads, buildings, streets, green areas),
- Land use information (e.g., purpose of buildings),
- Demographic and traffic data (population data).

3. depthmapX

Required data:

- Architectural plans or 3D models of the space (DWG, DXF, or SVG format),
- Structured information about spatial elements (walls, doors, windows),
- Visibility parameters (view range, viewing angles),
- Data on user movement and interaction in a given space.

Each of these applications has its own specific data requirements, which are necessary for proper analysis and reliable results. Before starting an analysis, it is a good idea to read the documentation of the specific application to ensure that all the necessary data is available and properly formatted.

The sDNA_GH application allows you to perform various analyses that support urban planning and urban design processes, providing visualizations and results that can improve the quality of urban spaces.

Tab. 4. sDNA_GH application functionalities and the types of result presentations that can be obtained

Features	Description	Results/Analysis
Accessibility analysis	Assessing the accessibility of various points in space based on distances and connections	Accessibility maps, pedestrian and vehicle accessibility indicators
Traffic simulations	Modeling the movement of pedestrians and vehicles in space	Traffic volume prediction, analysis of movement patterns
Spatial network analysis	Assessment of spatial structure and connections between different segments	Integration maps, topological analysis, and spatial linkages
Route optimization	Analysis and recommendation of optimal routes to move through a given space	Optimized routes for different types of users
Three-dimensional visualization	Visualization of spatial models in 3D form and presentation of analysis results on maps	3D models, interactive visualizations, and graphic reports
Evaluation of the quality ofthe sharrowspace	Analysis of qualitative features of the space, such as comfort, lighting, and greenery	Reports on space quality and recommendations for improvement

The Urbano application supports urban analysis, producing results that can be useful in urban planning and management processes. It uses a variety of data to evaluate the effectiveness of urban layouts and the impact on their users.

Tab. 5. Urbano application functionalities and types of results presentation that can be obtained

Features	Description	Results/Analysis
Spatial analysis	Evaluating urban layouts, placement of facilities, and their impact on traffic and interactions	Urban layout maps, spatialization reports
Simulation of pedestrian and vehicle traffic	Modeling traffic patterns in urban space, taking into account different scenarios	Traffic volume prediction, pedestrian and vehicle crossing analyses
Accessibility assessment	Investigating the accessibility of key services and facilities for different social groups	Accessibility maps, accessibility indicators for different users
Data visualization	Creating maps and visualizations for traffic data, accessibility, and spatial structure	Interactive visualizations, presentations of highly detailed street maps
Space quality analysis	Evaluating quality parameters of space, such as greenery, lighting, comfort	Reports on the quality of life in urban space, recommendations for improvement

Tab. 6. depthmapX application functionalities and the types of presentation of results that can be obtained

Features	Description	Results/Analyze
Visibility analysis	Assessing which areas are visible from specific points in space	AssessAssess which areas are visible from specific points in space
Spatial integration	Study of links between different segments of space and their impact on traffic	Study of links between different segments of space and their impact on traffic
Spatial and topological analysis	Assessment of the structure of spatial systems in terms of their functions and efficiency	Assessment of the structure of spatial systems in terms of their functions and efficiency
Accessibility assessment	Accessibility analysis of key sites based on paths and spatial connections	Accessibility analysis of key sites based on paths and spatial connections
Agent modeling	Simulations of user movement in space based on defined scenarios	Simulations of user movement in space based on defined scenarios

The studies carried out during the writing of the article have provided insight into new directions for the application of space syntax theory supplemented by contemporary environment simulation tools using virtual reality [Ribeiro et al. 2019; Caldas et al. 2020; Zhang et al. 2019; Dubbeldam, Hausleitner 2017; Jachna, Peng 2018: 17-21] and observation of user perception and wayfinding patterns using "eye tracking" [Wang, Xiao, Wu 2021; Zhang, Liu, Guo 2020; Cao, Lv, Zhu 2020; Sun, Li, Yu 2020; Wang, Luo 2020]. Methods are also being developed to analyze user behavior in space through simulations supported by machine learning and data analysis using AI. Simulations based on agent-based sytems [Naser, Ho, Pettit 2020; Aljazzar, Bougdah, Hadjr 2019: 195-202; Alqadi, Alqahtani, Alkheder 2021; Moghimi, Shokouhi, Mollaei 2020] are being used for such experiments to model human behavior in urban spaces. Combining this technology with space syntax theory makes it possible to analyze the impact of space configuration on pedestrian movement and interaction. Such models have many applications, including designing more functional and friendly public spaces, as well as understanding and predicting human behavior in various urban contexts [Moghimi, Shokouhi, Mollaei 2020]. An example of the use of agent-based simulations in conjunction with space syntax theory is the study of pedestrian traffic flow in an urban center. For this purpose, agent-based models are used to simulate pedestrian behavior and analyze the impact of the space configuration on their movement [Zain, Wahid, Bakar 2021]. This type of study can identify potential crisis areas or barriers that require design changes to improve traffic safety and efficiency. Another example of the use of agent-based simulation with space syntax theory is the study of behavior in public spaces. In this case, agent-based models are used to analyze how various factors, such as the amount of sunlight, wind direction, building types, and tree placement, affect people's behavior in public spaces. These models allow for the design of more user-friendly and customized public spaces. Another example of using agent-based simulation in conjunction with space syntax theory is the study of human behavior inside buildings. Models of this type allow for the simulation of the movement of people inside buildings and the analysis of the impact of room configurations on the movement of their occupants. Such models are particularly useful for public buildings. Among the completed studies using agent-based simulation in conjunction with space syntax theory, it is worth mentioning the study of the effects of different spatial arrangements on pedestrian movement in office buildings and the study of human behavior inside large retail complexes, airports, and hospitals [Cubukcuoglu et al. 2020]. Lessons learned from research using agent-based simulation in conjunction with space syntax theory allow designers and urban planners to solve relationally complex functional arrangements of public spaces and buildings that are better suited to user needs.

3. SUMMARY

To effectively present the results of space syntax analysis in 3D, leveraging specialized 3D visualization tools becomes essential. These tools not only facilitate the creation of visually compelling representations but also allow for interactive and immersive experiences that enhance understanding of spatial structures. When it comes to effectively collaborating between space syntax tools and game engines, the process can be quite rewarding and opens up new avenues for understanding spatial dynamics in immersive environments. You can begin by utilizing space syntax tools such as AJAX (Accessibility Analysis of Junctions and Axial Lines), the QGIS Space Syntax Toolkit, and depthmapX. These tools enable in-depth spatial network analysis and statistical evaluations, delivering valuable insights into how different spatial arrangements impact user movement and experience. Once you have gathered relevant spatial data, the next step is to integrate this information into a game engine. Popular choices for game engines include Unity, Unreal Engine, and Godot – each offering unique strengths and capabilities. Unity, for instance, is well-known for its user-friendly interface and versatility, making it a great option for real-time simulations. Unreal Engine, with its high-fidelity graphics, is ideal for projects that prioritize realistic visualizations, while Godot is an open-source choice that is particularly appealing for developers who appreciate a high degree of customization. To bridge your analysis and the game engine, you might need to export spatial data in compatible formats (like JSON, XML, or CSV) that the game engine can readily utilize. Programming APIs provided by these engines allow you to manipulate the spatial data to create interactive scenarios that reflect the findings from your space syntax analyses. Ultimately, this collaboration allows for the visualization of spatial behavior in a dynamic and engaging manner, providing users and designers with a richer understanding of how spatial arrangements influence movement and interaction in virtual environments. This multidisciplinary approach enhances the design of both physical spaces and digital experiences, leading to better usability and functionality. The techniques and software available today make it possible to correct design solutions in real time. An example of this can be found in the material presented by Michal Gath Morad in his work "A Vision-Based Cognitive Agent to Simulate Wayfinding by Architecture". The experiment described therein demonstrates how large an impact analysis of the consequences of actions and decisions can have on the optimization of proposed solutions during the project phase. Thanks to the feedback obtained as a result of the simulation and its evaluation carried out in real time during the experiment and the work carried out in control groups, it was possible to improve the final results of the concept by increasing the level of motivation of the authors. The effect was achieved through the use of the research team's proprietary tools. Another aspect presented in the publication is the possibility of using a computer game environment to simulate a space that, when changed in real time, is evaluated and optimized with its features in response to the defined needs of users.

Another interesting direction of research development using space syntax theory is the use of game engine environments that allow simultaneous modification of the environment and observation of simulation results [Altaweel, Al-Ibrahim, Al-Sughayer 2021; Raza et al. 2021; Deshpande, Nagwekar, Pandey 2021; Zhang, Zhang, Li 2021; Al-Rifai, Khutaba, Al-Sarayreh 2020].

LITERATURE

Aljazzar M., Bougdah H., Hadjri K., 2019, *Agent-Based Simulation Model of Spatial Configuration and Movement Behaviours in Urban Spaces*, in: *Proceedings of the 10th International Conference on Ambient Systems, Networks and Technologies (ANT 2019)*, Leuven, Belgium, pp. 195-202, https://doi.org/10.1016/j.procs.2019.04.027.

Alqadi R., Alqahtani S., Alkheder A., 2021, *Developing Agent-Based Models Using Space Syntax Analysis to Assess Pedestrian Movement in Urban Areas*, "Sustainability", vol. 13, no. 2, p. 787, https://doi.org/10.3390/su13020787.

Al-Rifai F., Khutaba A., Al-Sarayreh A., 2020, *Game Engines Integration of Space Syntax for Architectural Design: A Review*, in: *Proceedings of the 2020 5th International Conference on Education and Technology (ICET)*, Amman, Jordan, pp. 1-6, https://doi.org/10.1109/ICET49287.2020.9377936.

Altaweel A.A., Al-Ibrahim S.M., Al-Sughayer O.M., 2021, *A Comprehensive Overview of the Integration of Space Syntax into Game Engines for Architectural Design*, "Advances in Science, Technology and Engineering Systems Journal", vol. 6, no. 1, pp. 150-159, https://doi.org/10.25046/aj060119.

Caldas L., Masera G., Vieira D.M.A.C.A., Barros A.P., 2020, *Exploring Spatial Configurations using Virtual Reality and Space Syntax*, "Intelligent Buildings International", vol. 12, no. 2, pp. 119-135, https://doi.org/10.1080/17508975.2020.1730706.

Cao J., Lv G., Zhu Y., 2020, *An Eye-Tracking Study of Wayfinding in an Urban Shopping Center Based on the Integration of Space Syntax and Graph Theory*, "Sustainability", vol. 12, no. 14, p. 5814, https://doi.org/10.3390/su12145814.

Cubukcuoglu C., Nourian P., Tasgetiren M.F., Sariyildiz I.S., Azadi S., 2021, *Hospital layout design renovation as a Quadratic Assignment Problem with geodesic distances*, "Journal of Building Engineering", vol. 44, 102952, https://doi.org/10.1016/j.jobe.2021.102952.

Deshpande A., Nagwekar R., Pandey R., 2021, *Space Syntax Analysis in Game Engine Environment: A Review*, in: *Proceedings of the 2021 International Conference on Computing, Communication, and Security (ICCCS)*, New Delhi, India, pp. 81-86.

Hausleitner B., 2017, *The Integration of Virtual Reality and Space Syntax in the Design Process*, in: *eCAADe 2017: ShoCK! – Sharing Computational Knowledge! – Proceedings of the 35th eCAADe Conference*, vol. 2, Rome, Italy, pp. 407-416.

Hillier B., Hanson J., 2009, The Social Logic of Space, Cambridge University Press, Cambridge, https://doi.org/10.1017/CBO9780511597237.

Jachna T., Peng H., 2018, *Space Syntax, Virtual Reality and the Built Environment*, in: *Proceedings of the 2018 International Conference on Information and Computer Technologies (ICICT)*, Singapore, pp. 17-21, https://doi.org/10.1145/3187716.3187723.

Moghimi M.M., Shokouhi N., Mollaei M., 2021, *Designing for Pedestrian Friendly Public Spaces through an Agent-Based Simulation Model with Space Syntax Analysis*, "Sustainable Cities and Society", vol. 70, 102939, https://doi.org/10.1016/j.scs.2021.102939.

Naser A.F., Ho C.K.W., Pettit C., 2020, *Simulating Pedestrian Spatial Behavior in Urban Environments Using an Agent-Based Model: Incorporating Space Syntax Theory into the Pedestrian Simulation*, "ISPRS International Journal of Geo-Information", vol. 9, no. 6, p. 401, https://doi.org/10.3390/ijgi9060401.

Raza S.M., Akhter Z., Humayun M., Sarim M., 2021, *Integrating Space Syntax with Game Engines for Architectural Design*, "International Journal of Advanced Computer Science and Applications", vol. 12, no. 5, pp. 345-351, https://doi.org/10.14569/IJACSA.2021.0120544.

Ribeiro F., Amaral L., Rocha L., Baltazar A.P., 2019, *Integrating Space Syntax and Virtual Reality: An Innovative Methodology for Urban Design*, "Sustainability", vol. 11, no. 19, p. 5278, https://doi.org/10.3390/su11195278.

Stavroulaki G., 2022, *Keynote speech: Directions in Space Syntax. Space Syntax modelling of pedestrian flows for sustainable urban development*, "13th Space Syntax Symposium", Western Norway University of Applied Sciences, Bergen, Norway.

Sun H., Li W., Yu L., 2020, *Analysis of Pedestrian Behavior in Shopping Malls Based on Space Syntax and Eye-Tracking Technology*, "Journal of Coastal Research", vol. 111, no. 1, pp. 89-92, https://doi.org/10.2112/JCR-SI111-020.1.

Wang R., Luo W., 2020, *Eye-Tracking Study on the Visual Perception of Urban Space Based on Space Syntax*, "Proceedings of the 2020 5th International Conference on Education and Technology (ICET)", Amman, Jordan, pp. 48-52, https://doi.org/10.1109/ICET49287.2020.9377927.

Wang S., Xiao S., Wu Q., 2021, *Eye Tracking Based Space Syntax Analysis for Pedestrian Wayfinding in Urban Environment*, "Journal of Ambient Intelligence and Humanized Computing", vol. 12, no. 5, pp. 4435-4449, https://doi.org/10.1007/s12652-020-02863-y.

Zain M.F.M., Wahid M.F.H., Abu Bakar S.A.R., 2021, *Exploring Pedestrian Wayfinding and Navigation Behaviours through Simulation Model and Space Syntax Analysis in Urban Space*, "Journal of Urban and Environmental Engineering", vol. 15, no. 2, pp. 135-148, https://doi.org/10.4090/juee.2021.v15n2.135148.

Zhang F., Liu J., Guo X., 2020, *Investigating the Effects of Spatial Configuration on Human Navigation in Indoor Environments Using Eye-Tracking and Space Syntax Analysis*, "Applied Sciences", vol. 10, no. 24, p. 8841, https://doi.org/10.3390/app10248841.

Zhang J., Zhang Q., Li Y., 2021, *A Review of Space Syntax Integration in Game Engines for Architectural Design*, in: *Proceedings of the 2021 International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, Paris, France, pp. 66-70, https://doi.org/10.1109/AIVR52834.2021.9522887.

PRZEGLĄD NARZĘDZI WSPIERAJĄCYCH REALIZACJĘ BADAŃ I ANALIZĘ DANYCH Z WYKORZYSTANIEM TEORII SPACE SYNTAX

Streszczenie

Artykuł jest próbą klasyfikacji wybranych narzędzi wspomagających realizację studiów i badań wykorzystujących teorię space syntax. Narzędzia zostały pogrupowane z uwzględnieniem oceny stanu ich dostępności, platformy, dla której zostały opracowane, oraz poziomu wsparcia ze strony twórców. W celu porównawczym przedstawione zostały funkcjonalności narzędzi z uwzględnieniem typów danych wejściowych oraz dostępne formy prezentacji graficznej uzyskanych wyników. Zebrane zostały również informacje o grupach i firmach przeprowadzających badania i rozwijających platformy informatyczne do ich realizacji. Dodatkowym celem artykułu jest pokazanie kierunków rozwoju platform wspomagających badania, opartych na opisywanej metodologii i narzędziach w powiązaniu z technologią VR. Przeanalizowane źródła literaturowe wskazują na możliwość wykorzystania silników gier do integracji opisywanych narzędzi z systemami symulacji. Umożliwiają one dynamiczną zmianę środowiska z analizą wyników w czasie rzeczywistym, testując różne warianty rozwiązań w celu ich poprawy. Tego typu działania pozwalają na zyskiwanie wyższej skuteczności prac eksperymentalnych oraz satysfakcji użytkowników testowanych przestrzeni i rozwiązań komunikacyjnych na potrzeby budowy i modernizacji obiektów architektonicznych o złożonych układach funkcjonalnych oraz przestrzeni urbanistycznych.

Słowa kluczowe: projektowanie urbanistyczne, teoria space syntax, powiązania przestrzenne, optymalizacja dostępności, przegląd porównawczy