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Dajana Papaz, University of Banja Luka, dajana.papaz@aggf.unibl.org
Maja Ilić, University of Banja Luka, maja.ilic@aggf.unibl.org
Tijana M. Vujičić, University of Banja Luka, tijana.vujicic@aggf.unibl.org

IMPLEMENTING PARAMETRIC METHODS FOR ANALYSIS AND DESIGN TOWARDS SUSTAINABLE URBAN DEVELOPMENT: A CASE STUDY OF ČESMA SETTLEMENT

Abstract

Paper explores the implementation of parametric methods for urban analysis and examination of sustainable development strategies, with a specific focus on Česma, a suburban settlement in Banja Luka municipality. Field surveys combined with residents' engagement gather comprehensive datasets on Česma's current state. Utilizing the parametric software *Grasshopper* and *Rhinoceros 6,* various urban and rural factors influencing the settlement's dynamics are evaluated. Subsequently, by employing a *parametric decision-making process,* optimized potentials are detected to improve residents' living standards and urban development of the settlement. As a quantitative research method, parametric tools are essential in generating a comprehensive set of maps, 2D and 3D visual data. The collected data are subjected to qualitative analysis and adapted to context as well as sustainability and resilience criteria in the built environment.

Keywords: parametric tools, data visualization, Česma, Grasshopper, Rhinoceros 6, environmental sustainability, iterative optimization

ПРИМЈЕНА ПАРАМЕТРСКИХ МЕТОДА ЗА АНАЛИЗУ И ДИЗАЈН У ПРАВЦУ ОДРЖИВОГ УРБАНОГ РАЗВОЈА: СТУДИЈА СЛУЧАЈА НАСЕЉА ЧЕСМА

Сажетак

Рад испитује примјену параметарских метода при анализи и процјени одрживих урбаних стратегија, са фокусом на приградско насеље Чесма у општини Бања Лука. Теренским истраживањем и учешћем становништва, прикупљају се обимни подаци о тренутном стању насеља. Користећи параметарске софтвере, *„Grasshopper“* и *„Rhinoceros 6“*, процјењују се различити урбани и рурални фактори који утичу на динамику насеља. Затим, процес доношења одлука регулацијом параметара резултује оптимизацијом потенцијала који би могли подићи животни стандард становника и подстаћи урбани развој насеља. Као квантитативна метода истраживања, параметарски алати су кључни за генерисање значајног броја мапа, као и 2D и 3D приказа. Добијени подаци се затим подвргавају квалитативној анализи и теже прилагођавању контекстуалним условима, као и критеријумима одрживости и отпорности грађене средине.

Кључне ријечи: параметарски алати, визуелизација података, Чесма, Grasshopper, Rhinoceros 6, одрживост грађене средине, итеративна оптимизација

1. INTRODUCTION

The concept of sustainable urban development has increasingly become a focal point for researchers and practitioners alike, driven by the urgent need for cities to adapt to environmental, economic, and social changes. This paper introduces the Česma settlement, located on the outskirts of Banja Luka, as a case study to explore the application of parametric methods in enhancing urban sustainability. The historical context of Česma is important, from its earliest settlement in the 18th century to its development through various socio-political changes, underlining the importance of studying sustainable urban development in such a dynamic and historically layered environment.

Prior research has laid a solid foundation on the principles of sustainable urban development, highlighting the significance of integrating environmental considerations with urban planning and design. Despite advancements, there remains a gap in effectively utilizing technological tools in the planning process, particularly in suburban contexts. The main focus of urban analysis used to be mainly on the urban areas, city center, and other more attractive places in the city.

The core problem addressed by this research is the need for comprehensive tools and methods that support thorough analysis and sustainable planning in suburban settlements like Česma. The objectives include analyzing the settlement's current state, engaging with the community for insights, and employing parametric design methods to propose optimized sustainable urban solutions. The study combines extensive field data collection with parametric modeling. Significant data was collected through fieldwork at the Česma site, including photo documentation, dialogue with locals, and observations, thus constructing a detailed database. Moreover, the aim is to show that parametric analysis offers a visual representation of the desired characteristics of the whole settlement, allowing for a clearer understanding of the data gathered on-site without continuously sifting through extensive listed data.

This study was conducted as part of the parametric design course within the Master's program in Architecture and Urbanism. Both the analytical and designing aspects of parametric methodology were employed, with this paper focusing exclusively on the analytical phase. The research is divided into two main phases. The first phase focuses on analytical mapping and identifying existing potentials that have yet to be fully utilized and optimized. The second phase, to be detailed in later research, will present design proposals and iterations as a logical progression from the initial analysis. This divergence highlights a systematic approach to utilizing existing resources within the settlement, opening the way for innovative urban development strategies.

Additionally, this research investigates specific principles of sustainable urban development, including environmental, economic, and social sustainability. Environmental aspects consider green spaces and ecological balance, economic factors evaluate the efficiency and functionality of urban layouts, and social sustainability focuses on improving living standards and community engagement.

Digital tools like FME, *Grasshopper*, and *Rhinoceros 6* play a vital role in organizing and structuring collected data, enabling the analysis of various factors such as housing density, building heights, green spaces, residential block types, and other valuable urban parameters. This enabled the creation of specialized *Grasshopper* scripts that integrate urban planning parameters with geometrical nodes. These tools also help export significant factors identified through space syntax analysis, providing a comprehensive dataset for future planning and design interventions in Česma.

Parametric modeling offers a structured approach for exploring diverse scenarios for the development of the Česma settlement. By adjusting to new parameters, urban solutions are redefined, aiming for optimal livability and sustainability. Parametric design allows for more compositional variations through algorithm-controlled systems, providing flexibility and adaptability during analysis. This approach, highlighted by Dino (2012), underscores the dynamic and procedural nature of parametric modeling in achieving diverse design configurations [1]. It means that this multidisciplinary strategy enables the provision of practical insights and actionable recommendations for the development of suburban settlements, ensuring their resilience and continued vitality within the broader urban context.

By adopting an iterative approach that integrates data-driven analysis with design-driven synthesis, the aim is to develop holistic and contextually responsive solutions that address the multifaceted challenges facing Česma.

Ultimately, our research aims to contribute to the creation of a more livable, inclusive, and sustainable urban environment not only in Česma but also in other similar suburban settlements. This has implications for the broader field of urban planning and sustainable development, emphasizing the potential of parametric design as a transformative tool in the planning and design education landscape.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The growth and expansion of suburban areas continue to fascinate urban researchers, prompting a multifaceted examination of their emergence, inherent challenges, and latent potential for sustainable development. The literature review synthesizes key findings from prior studies, highlighting the evolving understanding of suburban sustainability, the role of technology in urban planning, and the potential of parametric methods to enhance the livability and environmental performance of suburban areas.

Robert Fishman's book traces the history of suburban development from its origins to its evolution. Suburban design initially emphasized privacy and nature connection, but now faces the challenge of sustainability and resilience [2]. The suburb plays a significant role in the city's economy by hosting key enterprises and generating money. Lewis Mumford observed suburbs as private yet collective living, offering an escape from city life, while still allowing people to work there [3]. Suburban areas should be strategically rethought as dynamic components of the urban fabric, capable of contributing significantly to the ecological and economic vitality of the broader urban landscape.

Theories related to sustainable urban development and resilience emphasize the need for a holistic approach that considers interconnectivity, environmental, economic, and social principles. The most common definition of sustainability implies meeting current needs without compromising the ability of future generations to meet their own needs. Urban systems that can adapt to changes and maintain essential functions are called resilient. By combining sustainability and resilience, designers and planners can create adaptable, equitable, and sustainable urban spaces while considering their broader impact on the planet and its inhabitants [4].

Schumacher suggested that incorporating urban morphology and planning on a parametric basis could offer a fresh socio-spatial perspective to parametric design that lacks attention to "social functionalities". This integration would prioritize practical planning necessities, such as socio-spatial cohesion, walkability, and resilience, over abstract formalism that currently dominates parametric urban design [5]. It would bring about a significant transformation in the domain of sustainability and resilience, as the practical needs of planning would be considered as primary themes for design research.

Subsequent discussions extend into the realm of urban planning technologies, with a focus on parametric tools such as *FME*, *Grasshopper,* and *Rhinoceros 6.* The research explores how these tools, through their computational and generative capabilities, allow for a nuanced analysis of urban and suburban spaces. This implies a wide range of urban parameters including the assessment of housing density, green spaces, and community engagement, moving towards a model where urban planning is not only about spatial configuration but also about fostering sustainable communities. The integration of new media in urban design education has enabled a more dynamic and communicative representation of the built environment [6]. The generative interface of parametric systems also provides an effective platform for "learning-by-doing". Speranza explains how digital parametric approaches in urban design education can improve the incorporation of everyday experiential phenomena by systematically examining urban traits. This includes considering experiences as temporal phenomena and exploring urban characteristics in an open-ended manner [7]. As a result, parametric tools can be used not only for urban design but also for ***detailed urban analysis and exploration of urban potentials for future development.***

This background research provides a robust foundation, indicating how tools like *Grasshopper* and *Rhinoceros 6* can be fundamental in analyzing urban potentials. Thus, the primary focus of this study is to delve into the application of these parametric tools for the detection and exploration of potential urban development opportunities.

Algorithms, which are composed of defined components, geometric and spatial operations, and their inter-relationships, play a crucial role in comprehending emerging urban spatial possibilities. Through parametric modeling, designers can access a wide array of customizable options that align with market limitations, while maintaining consistency and cohesion within public design frameworks. Parametric design involves fundamental design thinking operations. Its computational capacity to regulate the variability of form compositions is its primary advantage over analog techniques. The resulting "parametric morphologies" can serve as a basis for creating alternate scenarios and strategies integrating various aspects of planning [8].

Further, the theoretical framework section introduces key concepts and theories that guide the research. Space syntax theory initially developed as an architectural theory, investigates the social functions of spatial configurations. The initial software for Space Syntax analysis, DepthMap, was developed by the late Alasdair Turner. Despite its architectural origins, it is widely applied in urban analysis. The theory originally examines the interconnections between spatial units within buildings and the built environment, using the terms syntax and morphology in a linguistic sense [9]. Space Syntax Theory, particularly in this research, provides a methodological approach to understanding urban connectivity and its impact on social interactions and accessibility.

The Urban Strategy Playground research group at the Chair of Architecture Informatics at the Technical University of Munich is researching densification strategies. Their goal is to support governmental bodies in decision-making by integrating digital and traditional planning methodologies. They are collaborating with DeCoding Spaces, a German company of international architects and urban planners based in Weimar. The organization enhances architecture and urban planning with the DeCoding Spaces Toolbox for *Grasshopper*. This free tool facilitates analysis and generation in this study. There is a growing discussion about urban modeling and simulation tools, particularly in space syntax, solar radiation, and parametric urban design generation. However, the literature lacks a comprehensive approach that incorporates multiple analytical methods in the urban design process [10].

Space syntax methods use maps to display the longest sightlines and translate them into graphs. The graphs reflect the spatial configuration and strongly correlate with movement rates. This approach challenges traditional methods by relying on spatial geometry alone, emphasizing the environment's importance in predicting movement [9]. It is a very helpful tool used in this research to iterate and analyze the connectivity of the suburban settlement with the environment, especially the city center.

Ilić's research proposes using virtual environments for data collection to track pedestrian movements in urban public spaces. The study highlights the importance of space syntax theory, which links public spaces to the configuration of the urban network. Space Syntax theory in her work emphasizes the connection between common areas and urban design, which has enabled the identification of effective interventions to manage pedestrian circulation. Using parametric modeling and *Grasshopper* software, the study provides a framework for exploring alternative development scenarios for urban areas [11].

Lastly, the review seeks to consolidate findings from studies that have integrated the concepts of suburban sustainability, resilience theory, and the application of parametric tools. Despite the proven advantages of parametric design techniques within engineering and manufacturing processes, architects have not applied these methods in their creation tasks to address urban design issues at a higher level of understanding [12]. It critically assesses their methodologies, outcomes, and the gaps they leave unfilled, aiming to draw a nuanced understanding of how digital innovation intersects with the quest for sustainable suburban development.

2.1. ČESMA SETTLEMENT'S HISTORICAL, URBAN AND ENVIRONMENTAL CONTEXT

The settlement of Česma is a distinct suburban enclave of the city of Banja Luka, surrounded by rivers and challenged by inadequate transportation links. Despite its vulnerabilities, it offers a rare blend of proximity to urban conveniences while maintaining a sense of seclusion. Its historical evolution underscores a complex narrative of resilience and adaptation. The settlement's struggle with unauthorized constructions and the informal economy highlights the broader challenges of urban planning in post-conflict societies. The settlement offers a peaceful living environment with a blend of historical richness and contemporary challenges. Its community has faced demographic changes and property ownership transitions. Today, it is a resilient and adaptive community, integrating refugees and reorganizing families.

The settlement's development was hindered by industrialization and pollution downstream. The main street was established in the mid-1960s, but investments to improve it have been insufficient. The only connection to the city is via a bridge built by the Trappists. Suburban settlements emerged with public lighting and a bus line. The Česma-Madjir settlement was unplanned despite partial coverage in planning documents. The construction method indicated that it was a lawless playground during the chaotic process. Existing plans were only followed in certain principles due to the developmental expansion of the neighborhood. Urban planners could do nothing as the foundation and walls were already significantly underway, preventing them from taking any action or reaction to the situation. [13].

Banja Luka's General Plan designated this area for industry, urban greenery, recreation, and sports. Traditional rural-style housing wasn't included or considered necessary. Vernacular builders couldn't afford planning documents, architectural projects, or construction permits, leading to informal construction due to their financial situation.

The settlement is situated between the Vrbas River to the west and the Vrbanja River to the south and southeast, making it flood-prone. This combined with its unregulated infrastructure makes it a suitable research application for Sustainability and Resilience theory.
We may be able to simulate the settlement's standards with statistical data, using *Rhinoceros 6* and *Grasshopper* software. Česma settlement is a good candidate for applying parametric design. This method can help create sustainable and resilient urban environments that work with Česma's context. Our field observation is recorded with photographs and the diagram below. (*Figure 1*)

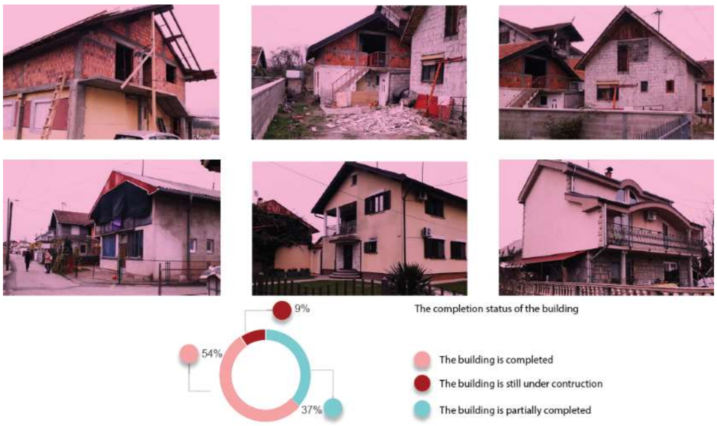


Figure 1. Photographs of the buildings in the settlement, with the diagram showing its' level of construction

3. METHODOLOGY

The research and data collection for this project was conducted as part of the master's program in "Architecture and Urbanism" at the Faculty of Architecture, Civil Engineering, and Geodesy. Multiple student and professor groups were involved in gathering data, with each group focusing on specific areas and thoroughly mapping and analyzing them.

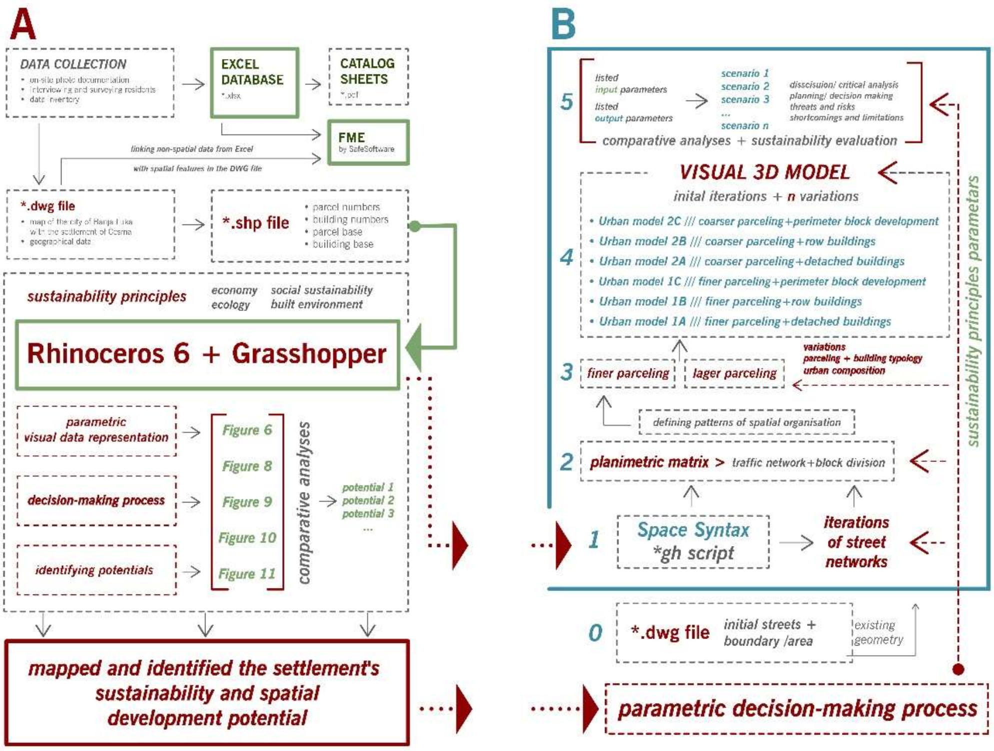


Figure 2. Methodology workflow A phase (left) and the B phase (right)

The methodological approach began with the selection of a location, Česma settlement, a suburb of Banja Luka. The Geodetic Archive of Republika Srpska provided a DWG map of Banja Luka and its settlements. The task was to map the existing condition and potential of the Česma settlement, providing detailed information for every parcel and building within the settlement.
Two main phases of the general research are:

- data collection, analysis, and visualization
- generating new proposals using parametric tools

The main focus of this research is the initial phase (*Figure 2A*), which involves mapping the existing conditions and identifying key parameters that will later influence the design process. Following data analysis, the second phase includes parametric design to generate and evaluate a range of development scenarios (*Figure 2B*),. Both phases are based on predetermined parameters that reflect sustainability and resilience objectives. The sustainability criteria include energy efficiency, economic impact, social-community well-being, and ecological impact. [10]

All data collected on-site, including photographs, internet research, discussions with local residents, and field notes, was entered into an Excel spreadsheet and categorized accordingly. The spreadsheet comprised several sheets, each serving a specific function. The mapping effort culminated in catalog sheets for the parcels and their associated buildings within the settlement.
These catalog sheets provide insights into ground condition mapping outcomes, offering a clear depiction of the existing state at the respective locations.
The main tools used for the methodology focus on using parametric design tools, specifically ***Grasshopper*** **and** ***Rhinoceros 6*** software, enabling the manipulation of design parameters influenced by urban, environmental, economic, and social factors. (*Figure 3*)
Unlike the GIS-focused Esri CityEngine, which transforms 2D data into 3D city models, *Rhinoceros* does not primarily handle geospatial data. However, its versatility across multiple disciplines, especially when combined with the *Grasshopper* plugin, has established it as a staple in urban design practices. *Grasshopper* extends the functionality of *Rhinoceros*, enabling complex urban development projects with flexible design and analysis tools that set it apart from traditional GIS software such as Esri CityEngine [10]. This approach emphasizes the simulation of human movement, interactions, and spatial accessibility by focusing on spatial configuration and urban dynamics. In contrast, traditional GIS methods prioritize static spatial data representation, geographical analysis, and spatial relationships. Furthermore, traditional GIS predominantly operates in 2D, whereas the parametric methods utilized here offer 3D presented data, allowing for a more dynamic and behavior-oriented analysis. Supported by theories of spatial cognition and architectural principles, and utilizing advanced tools like Grasshopper, this methodology presents a comprehensive and dynamic approach that extends beyond the static, geographically focused scope of traditional GIS.
For the purpose of creating a .shp file, we used *FME by Safe Software*. We merged an Excel database, containing details like parcel numbers and ownership information, with a DWG map of the Česma settlement to create a comprehensive spatial dataset. This process involved linking non-spatial data from Excel with spatial features in the DWG file, such as buildings and roads, based on common identifiers like parcel numbers. The resulting integrated dataset provided a detailed geographical context for further analysis and planning, showcasing FME's efficiency in automating complex data workflows.
Furthermore, *Grasshopper* models enable real-time analysis and simulation, enhancing the exploration of complex design alternatives. Consequently, simulation tools such as Ladybug, Honeybee, and *DeCoding Spaces*, were employed to assess designs based on essential factors like geometry, accessibility, visual integration, and environmental efficiency [10].
It has to be noted that these tools in urban analysis are dependent on the completeness and quality of input data, which represents a significant drawback. Incomplete or erroneous input data, encompassing building configurations, human behavior patterns, and spatial characteristics, may result in erroneous simulation and analysis outcomes. Furthermore, the parametric models' complexity may limit their applicability for wider use in urban planning by making them challenging to utilize without specific training and understanding. Another disadvantage of parametric design may be its high computational cost. The complexity of simulations necessitates significant time and processing power, which may present a challenge for projects with broader scope or shorter deadlines.

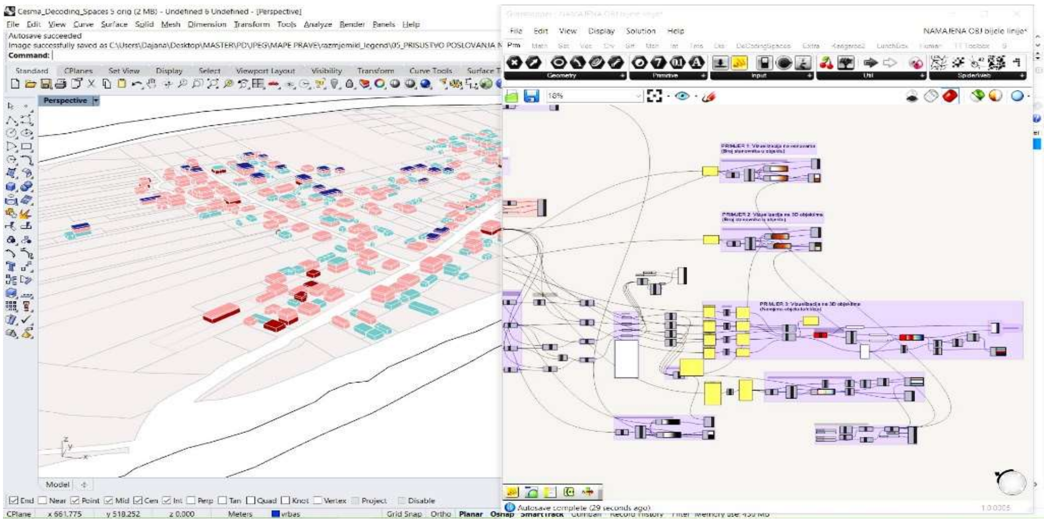


Figure 3. Part of the Grasshopper script and Rhinoceros 6 data visualisation

The objective of this process is to create a comprehensive data set on the current state of the Česma settlement. This will cover various factors such as housing density, green spaces, infrastructure quality, community needs, and aspirations, all of which are influenced by sustainability principles. The overall methodology outlined in this research represents a groundbreaking integration of parametric design with empirical urban research, aimed at advancing the practice of sustainable and resilient urban development. Through the case study of the Česma settlement, the paper demonstrates the potential of this approach to produce nuanced, adaptable, and sustainable urban design solutions that respond to the specific needs and conditions of suburban settlements.

RQ1. How can *Grasshopper* and *Rhinoceros 6* software, as parametric design tools, facilitate the planning and development process to achieve sustainable urban development in various settlements through the implementation of advanced data visualization techniques?

This research question examines the impact of *Grasshopper* and *Rhinoceros 6* software tools on the sustainability of urban and suburban development projects. It focuses on the ability of these tools to import data from Excel spreadsheets and Shape-files, generate maps based on specific criteria, and perform analyses to assess the potential of settlements like Česma. The goal is to understand how these software tools help identify sustainable development opportunities, engage stakeholders, and support evidence-based decision-making in diverse settlement contexts. By examining the case study of the settlement of Česma - considered as a test polygon - the research underlines the adaptability of these methodologies for broader application in other suburban or urban areas, highlighting the transformative potential of *Grasshopper* and *Rhinoceros 6* in urban planning and the pursuit of sustainability.

This analysis will initiate further research on exploring the role of *parametric tools* in supporting sustainable urban development through an iterative design process, generating multiple design options in the Česma settlement. The final goal is to establish a methodological framework applicable to different urban contexts, demonstrating the versatility of parametric design in urban development.

4. RESEARCH AND RESULTS

4.1. MAPPING AND DATA COLLECTION AT THE PARCEL AND OBJECT LEVEL

Due to the lack of detailed data on buildings and parcels in the area from government institutions, we initiated the creation of our own database (*Figure 4*). This effort led to the development of a catalog sheet for each parcel and building (*Figure 5*), while also producing geospatial .shp files essential for further research processes in *Rhinoceros 6/ Grasshopper*.

Before exporting the catalog sheets that contain all the important information about the parcels and building structures, the data collected during the visits to the Česma settlement were input into the Excel table. The table itself has sheets and each sheet serves a distinct purpose, from providing detailed listings of building levels to offering comprehensive data on land parcels and structures. The data listed, essential for identification, were subsequently utilized as parameters for later stages in the workflow. Catalog sheets for parcels and objects are directly generated from field visits, which involve mapping ground conditions through visual observation and discussions with the residents of the Česma settlement, supplemented by data from the land registry. These catalog sheets provide insights into the ground condition mapping outcomes, clearly depicting the existing state at specified locations.

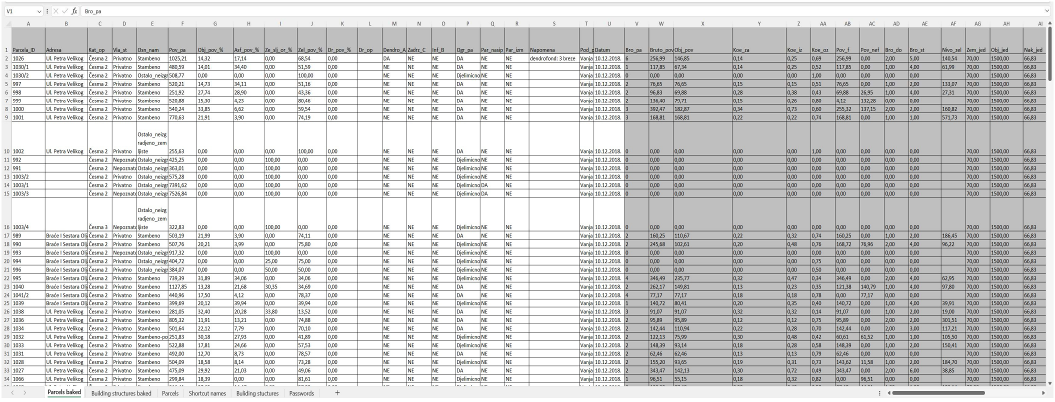
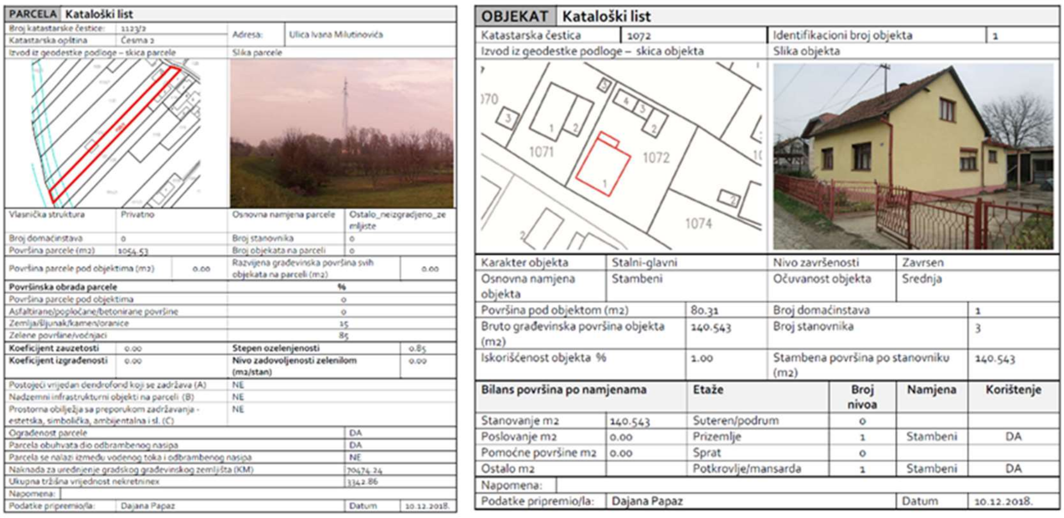


Figure 4. Excel data base (parcels and buildings)

The total number of catalog sheets for parcels stands at 278 for the whole area, and 90 for the part that is particularly analyzed. Additionally, the observed coverage yielded 321 catalog sheets for objects for the whole area and 77 for the part of the location.

Catalog Sheets for various parcels, provide comprehensive information such as parcel numbers, cadastral municipality, sketches of the parcels, addresses, ownership structure, primary purpose of the parcel (e.g., residential, business, undeveloped land), household numbers, population numbers, surface area measurements (in square meters) for the parcel overall and specifically for structures on the parcel, developed construction surface area, surface treatment of the parcel, occupancy and construction coefficients, greenery levels, satisfaction level with greenery (measured in square meters per resident), existing valuable tree resources to be preserved, above-ground infrastructure objects on the parcel, spatial features with retention recommendations (aesthetic, symbolic, ambient, etc.), parcel enclosure, parcel inclusion of defensive embankment parts, parcel location in relation to water streams and defensive embankments, fees for the arrangement of urban construction land (in KM), and total market value of the real estate.

This meticulous documentation provides an in-depth look at the parcels, offering vital data for urban planning, real estate assessment, and environmental considerations. Each parcel is uniquely identified and described, highlighting the importance of sustainable development, green areas, and the valuation of property within the urban and suburban settings of the specified cadastral municipality.



PARCELA Kataloški list

Broj katastarske čestice:	1123/2	Adresa:	Ulica Ivana Milutinovića
Katastarska opština	Česma 2		
Izvod iz geodetske podloge – skica parcele		Slika parcele	
Vlasnička struktura	Privatno	Osnovna namjena parcele	Ostalo_neizgradjeno_zemljište
Broj domaćinstava	0	Broj stanovnika	0
Površina parcele (m2)	1064.53	Broj objekata na parceli	0
Površina parcele pod objektima (m2)	0.00	Razvijena građevinska površina svih objekata na parceli (m2)	0.00
Površinska obrada parcele		%	
Površina parcele pod objektima		0	
Asfaltirane/popločane/betonirane površine		0	
Zemlja/šljunak/kamen/oranice		15	
Zelene površine/vočnjaci		85	
Koeficijent zauzetosti	0.00	Stepen ozelenjenosti	0.85
Koeficijent izgrađenosti	0.00	Nivo zadovoljenosti zelenilom (m2/stan)	0.00
Postojeći vrijedan dendrofond koji se zadržava (A)		NE	
Nadzemni infrastrukturni objekti na parceli (B)		NE	
Prostorna obilježja sa preporukom zadržavanja - estetska, simbolička, ambijentalna i sl. (C)		NE	
Ograđenost parcele		DA	
Parcela obuhvata dio odbrambenog nasipa		DA	
Parcela se nalazi između vodenog toka i odbrambenog nasipa		NE	
Naknada za uređenje gradskog građevinskog zemljišta (KM)		70474.24	
Ukupna tržišna vrijednost nekretnine		1342.86	
Napomena:			
Podatke pripremio/la:	Dajana Papaz	Datum	10.12.2018.

OBJEKAT Kataloški list

Katastarska čestica	1072	Identifikacioni broj objekta	1
Izvod iz geodetske podloge – skica objekta		Slika objekta	
Karakter objekta	Stalni-glavni	Nivo završenosti	Zavrsen
Osnovna namjena objekta	Stambeni	Očuvanost objekta	Srednja
Površina pod objektom (m2)	80.31	Broj domaćinstava	1
Bruto građevinska površina objekta (m2)	140.543	Broj stanovnika	3
Iskorišćenost objekta %	1.00	Stambena površina po stanovniku (m2)	140.543

Bilans površina po namjenama		Etaže	Broj nivoa	Namjena	Korištenje
Stanovanje m2	140.543	Suteren/podrum	0		
Poslovanje m2	0.00	Prizemlje	1	Stambeni	DA
Pomoćne površine m2	0.00	Sprat	0		
Ostalo m2		Potkrovlje/mansarda	1	Stambeni	DA
Napomena:					
Podatke pripremio/la:	Dajana Papaz			Datum	10.12.2018.

Figure 5. Catalog sheets (parcels and buildings)

Catalog Sheets for various building structures contain detailing information such as cadastral parcel numbers, sketches of the structures, object identification numbers, images of the objects, and their characteristics. Each entry provides specific details, including the nature of the object (permanent-main, permanent-auxiliary, or temporary-auxiliary), the level of completion (finished, partially finished), primary purpose (residential, auxiliary), condition of the object (good, medium, bad), the surface area under the object, gross construction area of the object, usage percentage, residential area per resident, and balance of areas by purposes across different levels (basement, ground floor, upper floors, attic/mansard) with specified uses (residential, business, auxiliary, other). Additionally, it lists the number of households, and the number of residents, and provides notes on the usage and preparation details including the preparer's names and dates. This detailed cataloging offers insights into the physical characteristics and usage specifics of various structures within the cadastral parcels, contributing valuable data for urban planning, real estate evaluation, and architectural considerations. Each structure is meticulously documented, reflecting its role and value within the urban or rural landscape, and indicating its occupancy, structural integrity, and functional distribution across its floors.

4.2. SPACE SYNTAX ANALYSIS

The purpose of using Space Syntax Analysis is to examine the integration level of the settlement with the surrounding environment.

Space Syntax analysis offers the possibility to check the integration of the settlement with the environment through mathematical logic and in relation to the given parameters. It works on the principle of calculating the distance from the central point of each segment (street) to every other segment individually, within the specified area. It also demonstrates the degree of street connectivity - how many times a traffic user passes through a particular street to access other streets in the city [10]. If the radius of 1km is considered - only the connections with segments within that distance are simulated.

Enclaves that function independently are singled out if they are not well integrated into the surroundings - this is the case with Česma - ***it stands out as a decentralized settlement.***

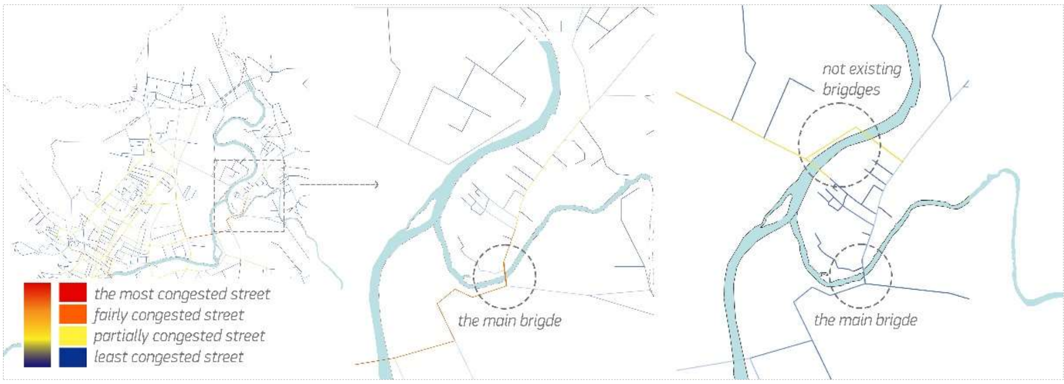


Figure 6. Space syntax analysis: a) city of Banja Luka with the Česma settlement, b) current state of Česma c) Česma settlement with new bridges added

The main bridge connecting Česma with the city center (*Figure 6*) is the most congested because the entire Česma settlement network depends on it. All other bridges and connections to the center are less congested because they are not the shortest route to the city center. Depending on the scope, different results are obtained. The scope is the radius, and the importance of streets is calculated within that radius. Angular measures (*angular*) show which directions are the most congested.

If the *length* parameter is set as the relevant measure, the metric shortest distances between paths are calculated, while *angular* prioritizes the least number of turns from point A to point B. In this case, the maps illustrate how proximity is prioritized in metric calculation, whereas angular calculation prioritizes directions regardless of distance. (*Figure 7*)

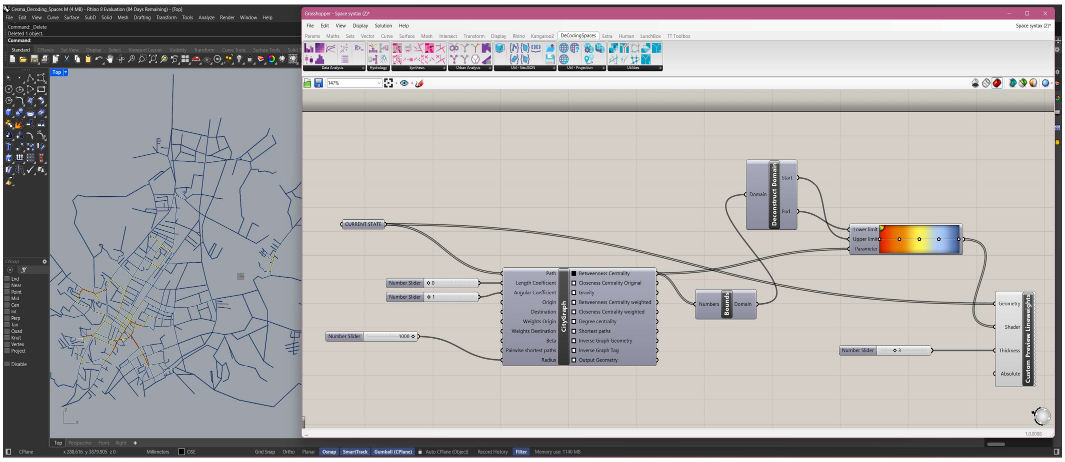


Figure 7. Space Syntax script in Grasshopper and Rhinoceros 6

In real context, users will choose their paths based on various parameters. However, given that traffic in Banja Luka is generally poorly managed, with significant congestion, it's evident that the shortest paths will be preferred. Depending on the coverage, different results are obtained. This coverage is referred to as the *radius*, within which the importance of streets is considered during calculation.

The analysis computes from every element in the system to every other element, but only up to 5km. The value of streets in a decentralized system is determined, revealing a different frequency distribution compared to the entire coverage. Česma emerges as a distinct system, existing independently, indicating decentralization as it is not fully integrated into the overall system.

The densest street system in the city center represents the best integration and logically, this part is treated as the center, the central component of the entire system.

A difference can be noticed between the current state (without bridges) and the potential state with new bridges in the Česma settlement. The difference is in its integration into the environment, the main bridge on the main street in the settlement is less congested, and traffic concentration shifts to the northwest. The analysis is very useful for the future planning of states and streets; it is clear that a reorganization of the street network within the settlement is necessary, followed by the regulation of bridges and connections with other parts of the city.

4.3. IDENTIFICATION AND ASSESSMENT OF SUSTAINABILITY PARAMETERS IN THE ČESMA SETTLEMENT

This section presents and analyzes the outputs of applying *Grasshopper* and *Rhinoceros 6* software to input data from the Česma settlement. These tools assisted us in visualizing complex urban and rural factors, revealing patterns and potentials within the settlement that could guide sustainable urban development. Our observations, based on the generated maps and data visualizations, aim to explain the complex dynamics of Česma. This offers insights into how parametric methods can inform and improve urban planning and design strategies.

The on-site condition regarding the ratio of built to unbuilt space was identified and evaluated. This condition was interpreted at the coverage area level by presenting key parameters. The presentation is given cartographically and through graphs. Results include parcel occupancy by buildings, construction level of the parcel, usage level of buildings within (a part of) the coverage area, and the relationship between residential and other functions at the building level. At the parcel level, the highest occupancy coefficient within the entire location is 0.83 for the most occupied parcel. The observed location is characterized mainly by residential and auxiliary buildings, then auxiliary ones which are the dominant backbone of the informal economy, especially at the level of the entire settlement. Housing is concentrated along the street, while auxiliary buildings in the back of the parcel serve agricultural purposes. (*Figure 8*)

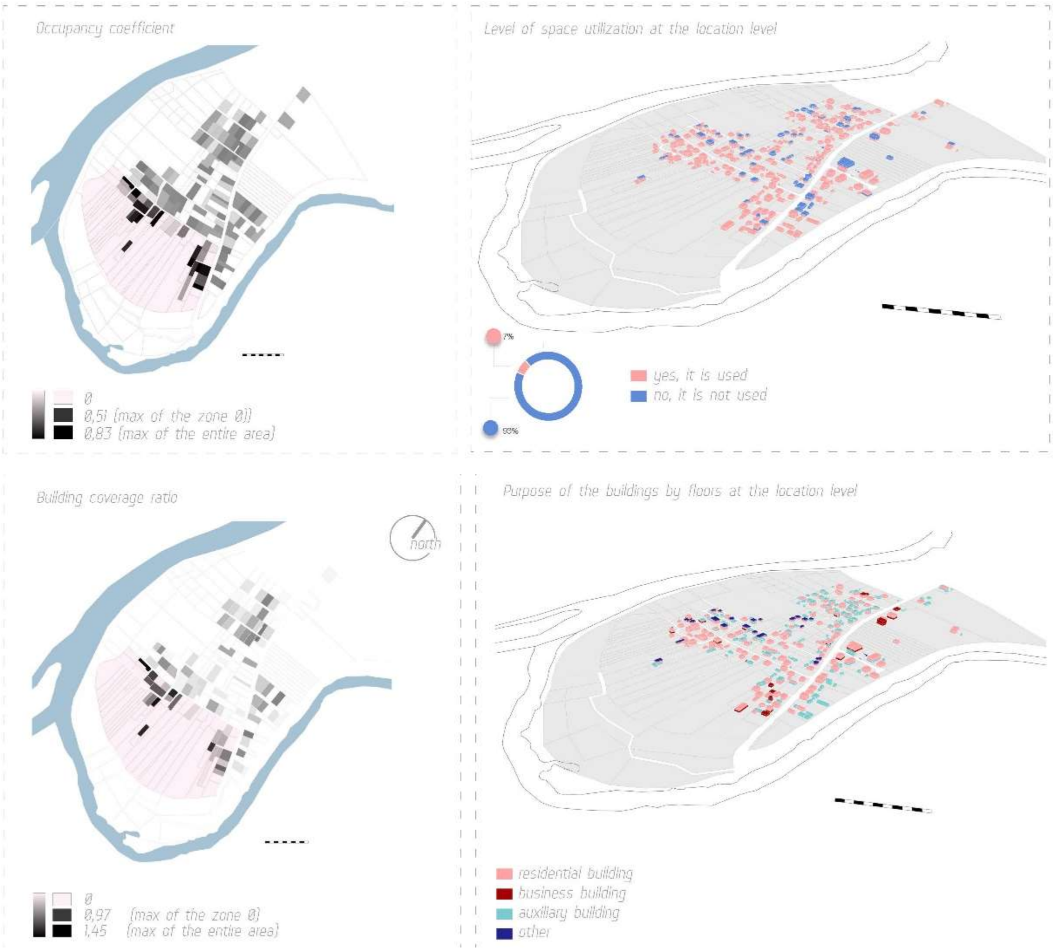


Figure 8. The maps of the ***Built environment, usage, and functionality*** *generated from the GH script*

Business buildings (mainly hospitality) dominate the entrance to the settlement itself. Maps and diagrams clearly show that the utilization rate of buildings is high, and a small number of squares are unused, however, if the number of inhabitants is considered in individual buildings, it is clear that "surplus of squares" is a case and it is one of the indicators of the current unsustainability of the settlement. The social state is low, and many rooms within the building are not used daily. (*Figure 8*)

The Greenery Coefficient represents the ratio of green spaces to the total area, while Greenery Satisfaction indicates the area allocated per inhabitant. The settlement is mostly undeveloped with a Greenery Coefficient of 0.65, and it is concentrated in the central part, away from the river. The average satisfaction with green areas is 89.04m² per inhabitant, depending on the number of inhabitants and plot size. A small number of residents + a large parcel results in lower green satisfaction and vice versa. 69% of the observed zone is green meadows and orchards, presenting potential for construction and improving greenery. Only 15% is under buildings, 9% of the area includes land, gravel, stone, and fallow land and 7% is paved. Although the settlement appears green, the tree preservation area of the settlement is poor. (*Figure 9*)

Regarding the state and evaluation of Social Sustainability, the area has a high population density concerning the built environment. Parcels near the embankment are suitable for agriculture but lack access roads and connections to the rest of the settlement. The built parcels along the street are closely packed, leaving most structures 'exposed'. Only a few buildings serve a commercial purpose. (*Figure 10*)

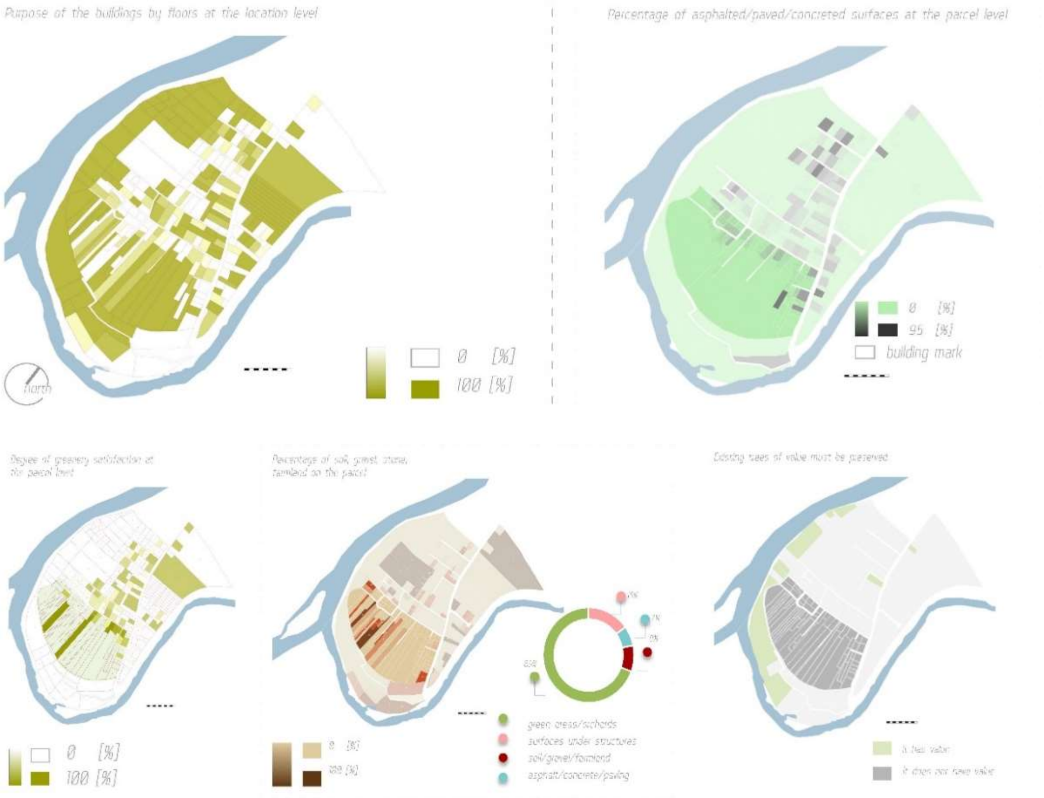


Figure 9. The maps of the Ecological sustainability of (a part of) the settlement generated from the GH script

***Figure 10.** The maps **of the Social Sustainability** generated from the GH script*

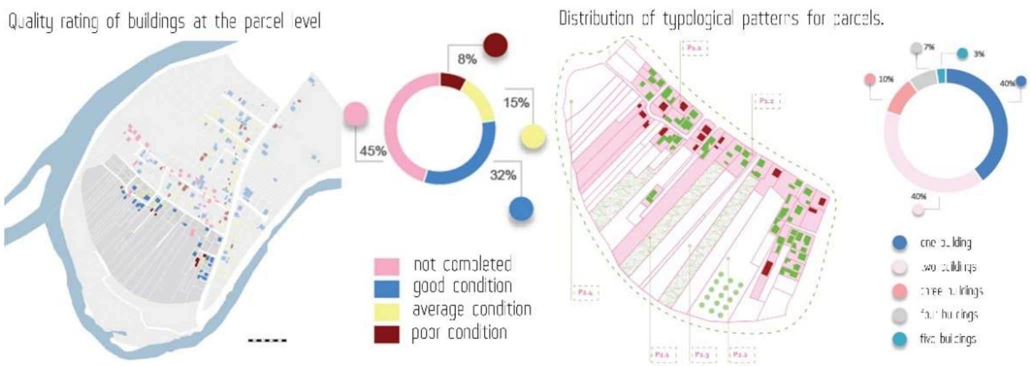


Figure 11. The maps of the quality rating of the buildings at the parcel level and the distribution of typological patterns for parcels generated from the GH script

The map distinguishes between two main categories of parcels: undeveloped and developed. Undeveloped parcels can be further divided into agricultural parcels, parcels with orchards, verdant meadows, and overgrown shrubbery. Developed parcels are categorized based on the presence of one or more buildings, as well as whether they are enclosed or open. Maintaining privacy is of great importance to the local population. (*Figure 11*)

The data visualization above reveals a clear dichotomy between built and inbuilt parcels, highlighting the need for strategic urban planning that combines housing needs with ecological preservation. The concentration of the settlement in central areas and the predominantly undeveloped surroundings presents a clear opportunity to design public spaces that support community engagement while respecting the natural landscape. The distribution of typological patterns among parcels suggests the need for careful consolidation that balances agricultural and green spaces with development. Additionally, the presence of auxiliary buildings as a foundation of the informal economy highlights the importance of incorporating diverse functions into the urban fabric to enhance livability and economic vitality. This analysis showcases Česma as a model for sustainable suburban development, promoting inclusive and environmentally conscious planning approaches that can adapt to the changing urban landscape.

5. CONCLUSION

This research paper emphasizes the importance of parametric decision-making processes in the sustainable development of suburban settlements, with a particular focus on Česma. The study utilized a detailed workflow that integrated field surveys, citizen engagement, and advanced software tools such as *Grasshopper* and *Rhinoceros 6* to navigate the complexities of urban and rural dynamics and uncover the inherent potentials within the Česma settlement. The utilization of parametric tools not only facilitated a comprehensive analysis of various urban factors but also enabled the creation of detailed maps and visual data. This serves as a basis for identifying areas of improvement and opportunities for sustainable development.

The research also demonstrates the effectiveness of combining traditional data collection methods with advanced computational tools to gain a deeper understanding of the settlement's current state and future possibilities. This study demonstrates how optimized potentials can be detected to enhance the living standards of residents and guide the urban development of the settlement towards sustainability and resilience by employing a parametric decision-making framework.

Although this workflow includes a great amount of automation in analyzing urban parameters, it is important to note that architects and urban designers still play a key role in decision-making in specific phases of the analytical and design process. The design-making process in this research phase is crucial, as the author interprets the results, providing a critical review and making informed decisions. This involves evaluating the given results and determining the best course of action based on the analysis, ensuring well-founded conclusions and design proposals. This methodology provides a more comprehensive and in-parallel insight into the location using visual data and enables us to compare the possible results that will lead to more grounded conclusions.

The paper lays a solid foundation for future research, highlighting the importance of parametric tools in urban analysis and design. The findings from Česma are an important reference for future studies that will investigate the use of these tools to develop iterative design solutions that align with the principles of sustainable urban development. This research identifies potential for innovative approaches to suburban planning, advocating for a harmonious integration of technology, community needs, and environmental sustainability to improve the quality of urban life.

The primary limitations of parametric tools in urban analysis include dependence on the quality of input data, the need for specialized knowledge and training, and computational intensity. Rhino/Grasshopper plug-ins may not account for all real-world variables, potentially leading to discrepancies between simulations and actual results. The process can be complicated for inexperienced users, and plugin calculations may not always be accurate, requiring validation against empirical data. One solution to these limitations is to develop a more user-friendly software or plug-in that simplifies the interface and minimizes the need for extensive manual calculations. The creation of such a plugin in Grasshopper is a consideration for future research.

In conclusion, the exploration of Česma through parametric methods has provided valuable insights into the settlement's development potential and showcased the transformative power of digital tools in urban planning. Moving forward, it is imperative to continue leveraging these technologies to foster sustainable and resilient communities, ensuring that our urban environments are prepared to meet future challenges. This research highlights the importance of an interdisciplinary approach that considers the complexity of urban systems. It advocates for strategic interventions that are informed, inclusive, and forward-thinking.

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