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Generative Design in Urban Planning with Regard to Local Zoning Regulations: A BIM Case Study

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Abstract

The development of BIM technology and Generative Design methods supported by artificial intelligence opens up new possibilities in the field of urban planning analyses and the verification of land-use compliance with local regulations. The aim of this study was to assess the potential of the Autodesk Forma Site Design environment, which utilizes BIM technology and generative methods, in streamlining planning processes, using the example of an analysis of the compliance of existing development with local regulations. The research was conducted based on a case study of selected plots located in the Polish city of Włocławek, covered by the 2004 local spatial development plan (MPZP). The scope of work included the analysis of planning documents, parametric modeling in Autodesk Forma Site Design, and the generation of development variants using the Archistar and One Click LCA Generative Design plugins. The results indicate that Generative Design tools can effectively support the early stages of urban planning analyses, enabling the rapid generation and comparison of land-use variants as well as a preliminary assessment of their compliance with planning regulations. At the same time, significant technological limitations were identified, including the lack of full determinism of parameters, difficulties in the automatic interpretation of complex planning regulations, and the need for manual correction of results. Consequently, the current level of development of generative tools allows for a partial streamlining of planning processes, but does not yet provide a basis for the full automation of verifying the compliance of land-use plans with local regulations.

Keywords: BIM; CIM; generative design; autodesk forma site design; local spatial development plan; data annotation

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1. Introduction

1.1. Conditions for BIM Implementation and the Application of Generative Methods in Spatial Planning

The study was conducted based on a case study of selected plots located in the Polish city of Włocławek, covered by the 2004 local zoning plan (MPZP) [1]. Building Information Modeling (BIM) has undoubtedly become one of the key technologies in design and construction processes , enabling the integration of all aspects of a building's design, construction, and operation throughout its entire life cycle [2–4]. As the importance of BIM grows, so does the demand within companies for highly qualified personnel capable of working with advanced 3D models. However, the implementation of this technology entails significant organizational costs, including both the creation of dedicated positions and investments in specialized training necessary to effectively harness its potential [5]. These high costs stem, among other things, from the need for precise data annotation in BIM models—including data supplementation, standardization, and updates—a process that requires not only technical knowledge but also the ability to interpret complex design and construction information [6,7]. Many companies are therefore striving to achieve critical mass at the lowest

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possible cost, i.e., the minimum adoption threshold, above which the standardization of 3D models, data interoperability, and cross-industry synergy generate economies of scale that exceed the initial implementation costs. The ongoing development of BIM technology and its integration with artificial intelligence and analytics methods are creating new opportunities, prompting the construction sector to increasingly seek tools within these solutions that enhance design efficiency—without the need to create new positions and while simultaneously reducing data annotation costs. The automation of 3D model annotation, validation, and standardization processes eliminates tedious manual work, allowing for faster error detection and the optimization of human resources. As a result, companies achieve organizational savings [8,9].

In the context of urban planning, BIM methodology is finding increasingly widespread application as a tool supporting planning analyses, enabling the assessment of a proposed development's compliance with local zoning regulations, the identification of potential non-compliance, and more informed investment decisions [2]. The design process can be further supported in the BIM environment by AI-powered Generative Design, which relies on algorithms and automatically generates many possible solutions based on user-defined parameters and constraints, thereby gaining particular significance as a tool enabling rapid comparison of variants and optimization of land use [10]. The inclusion of GIS data further expands the scope of analysis, allowing spatial and environmental conditions to be taken into account as early as the design phase [3].This forms the foundation of the City Information Modeling (CIM) concept, which extends BIM technology to the urban scale by combining geospatial data with object models. This makes it possible to examine the relationship between actual land use and planning requirements [11].

This study focuses on assessing the potential of the BIM environment and generative tools in identifying inconsistencies between emerging development and the provisions of the Local Spatial Development Plan (MPZP), analyzing the technological limitations of AI-based solutions, and their impact on the efficiency of planners' work under Polish legal and spatial regulations [11].

1.2. Research Question and Objective

Today, spatial planning involves the need to examine a significant volume of documents such as local spatial development plans (MPZP). Their effective analysis could be aided by continuously improving modern technologies, including generative algorithms and artificial intelligence.

Research question:

To what extent can Generative Design tools utilizing AI elements, such as Autodesk Forma Site Design, support the analysis and simulation of land use compliance with local zoning plans?

The aim of this study was to assess the potential of the Autodesk Forma Site Design environment, which utilizes BIM technology and the Generative Design method, in streamlining planning processes, based on an analysis of the compliance of existing development constructed in accordance with the 2004 Local Spatial Development Plan. The study also includes an assessment of Generative Design's potential in streamlining urban planning decisions, the identification of limitations in AI-based tools (such as errors in generating geometric forms or limits on input parameters), and an analysis of the challenges associated with the automatic interpretation of planning standards.

2. Materials and Methods

The research was conducted using a case study method for the area covered by the Local Spatial Development Plan in the Polish city of Włocławek (Figure 1) between the side dam of the barrage on the Vistula River, Płocka Street, Kazimierz Wielki Avenue, the boundary of forest land along the former "URSUS" and "Fabryka Domów"), the emergency dam of the hydroelectric power plant on the Vistula River, Rybnicka Street, and the city boundary," adopted by Resolution No. 50/XXIV/2004 of the City Council of Włocławek on August 30, 2004, in Poland.

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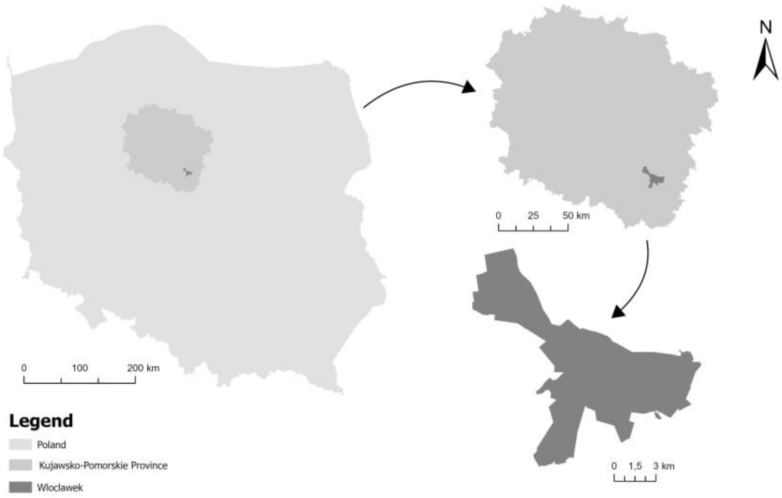

Figure 1. Map showing the location of the city of Włocławek in relation to the country and the province (source: author's own work based on the State Boundary Register).

2.1. Research Material

The research material included:

- the textual and graphic components of the current Local Spatial Development Plan,
- spatial data obtained from the city's Geoportal: geoportal.wloclawek.eu,
- orthophoto maps dated September 7, 2024,
- cadastral data for selected parcels,
- the Autodesk Forma Site Design environment and the Archistar and One Click LCA Generative Design plugins available within it.

Areas with a predominant single-family residential function were selected for the study. The criteria for selecting specific locations were the long validity period of the Local Spatial Development Plan (LSDP)—over 20 years (meaning that over two decades, residents had managed to make changes to the original land use without regard to the LSDP provisions)—and the presence of noticeable discrepancies between the existing conditions and the planning provisions.

The detailed analysis covered the following selected cadastral parcels: 046401_1.1170.8/8 (Figure 2), [NW2.1]046401_1.1190.39/1 (Figure 3), 046401_1.1190.22/4 (Figure 4).

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Figure 2. Inventory of the existing land cover of cadastral parcel 046401_1.1170.8/8 (source: Author's own work, based on an orthophoto map as a WMTS service and the National Land Registry Integration Service ( ) as a WMS service available at www.geoportal.gov.pl, in ArcGIS Pro).

Figure 3. Inventory of the existing land cover of cadastral parcel 046401_1.1190.39/1 (source: Author's own work, based on an orthophoto map as a WMTS service and the National Land Registry Integration service as a WMS, available at www.geoportal.gov.pl, in ArcGIS Pro).

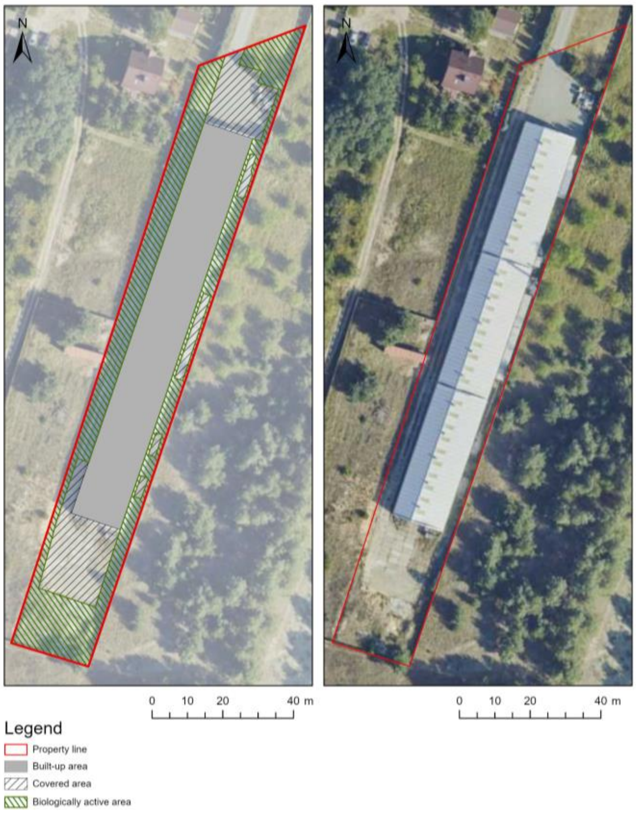

Figure 4. Inventory of the existing land cover of cadastral parcel 046401_1.1190.22/4 (source: Author's own work, based on an orthophoto map as a WMTS service and the National Land Registry Integration service as a WMS, available at www.geoportal.gov.pl, in ArcGIS Pro).

2.2. Research Methods

The research procedure was divided into the following stages:

(a) Analysis of planning documents

An analysis of the provisions of the Local Spatial Development Plan (MPZP) was conducted, covering land use designations, planned urban planning indicators, maximum building heights, and requirements for biologically active areas.

(b) Spatial analysis in a GIS environment

Calculations were performed in the GIS environment regarding plot areas, built-up areas, impervious areas, and the actual proportion of biologically active areas. Discrepancies between the existing conditions and the plan provisions were identified.

(c) Modeling in the Autodesk Forma Site Design environment

Based on spatial data and the provisions of the 2004 plan, model plots were developed in the Autodesk Forma Site Design environment. Parameters derived from the Local Spatial Development Plan (MPZP) were entered into the system, including: minimum registered plot area, mandatory proportion of biologically active area, permissible building height, and land use designation.

(d) Generation of design variants

Variants were generated using the Generative Design tools available in Autodesk Forma Site Design. The following plugins were used: Archistar and One Click LCA Generative Design. Using these tools, sets of land-use variants were generated that met the specified formal constraints. The variants were subjected to environmental analyses, including a preliminary assessment of the biologically active area balance.

(e) Comparative Analysis

The actual state, the provisions of the Local Spatial Development Plan (MPZP), and the results generated by the Autodesk Forma Site Design software were compared. The analysis examined the degree of compliance of the designs with the plan, the consistency of the results, the stability of the algorithms, and the quality of the visualizations.

(f) Tool evaluation

In the next stage, a qualitative evaluation was conducted of the technological limitations of Autodesk Forma Site Design, including parametric errors, limitations of the tool's trial version, solution generation time, and the level of automatic interpretation of planning provisions.

(g) Export of a design variant from Autodesk Forma Site Design to the Revit environment

This stage involved transferring the best land development variant (9-MN/UR), generated in the Autodesk Forma Site Design environment, to Autodesk Revit software. The Autodesk Forma Add-In for Revit was used to transfer data between the design environments.

(h) Semantic enrichment of the BIM model

This section focused on the process of semantically enriching the model in the Autodesk Revit environment, which involves assigning descriptive, functional, and planning information to model elements.

3. Case Study

A key stage in preparing for analyses of the effectiveness of Generative Design tools was the identification of actual urban planning issues in the study area. To accomplish this, a comparison was made between the provisions of the Local Spatial Development Plan (MPZP) and the actual land use of registered plots (Tables 1–3) (Figures 3–5). This analysis serves as the basis for further simulations in the BIM environment. Planning parameters, with particular emphasis on the minimum proportion of biologically active area, were implemented in the Autodesk Forma Site Design tool as design guidelines.

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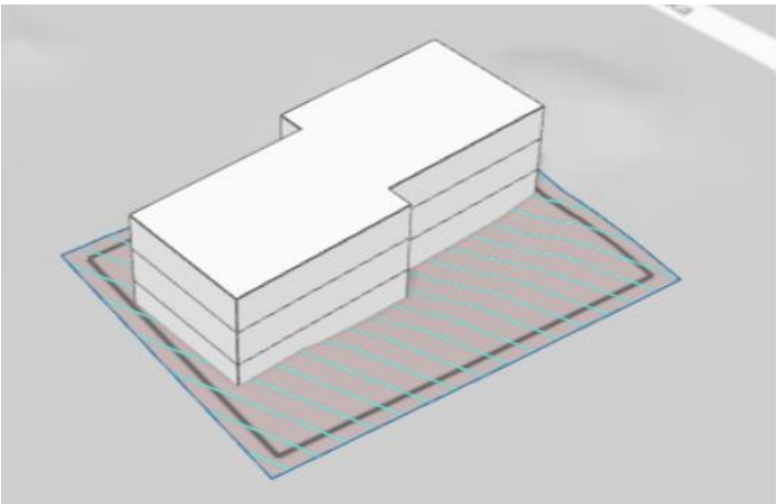

Figure 5. Building model generated in the Autodesk Forma Site Design environment for parcel 046401_1.1170.8/8 (source: author's own work).

3.1. Analysis of Cadastral Plot 046401_1.1170.8/8

A detached single-family home is located on the analyzed area, which is consistent with the land use designation in the Local Spatial Development Plan (MPZP). However, significant discrepancies exist regarding the biologically active area. The survey revealed that its share relative to the registered plot area is approximately 25.5%, whereas legal regulations require this ratio to be at least 50%.

Table 1. Local Master Plan provisions for registered plot 046401_1.1170.8/8 (source: Author's own compilation based on the plot inventory and the analyzed Local Master Plan).

Area 6-MN/UR/U/P		
Parameter	Local Master Plan Provisions	Actual status
Cadastral plot ID	-	046401_1.1170.8/8
Land Use	Primary: Single-family detached housing Supplementary: Non-intrusive services, internal transportation	Single-family, detached residential development
Area of the registered plot	Min. 1,000 m²	1,069.08 m²
Building area	-	322.56 m² (30%)
Cured surface	-	474.19 m² (44.5%)
Biologically active area	50%	272.33 m² (25.5%)

3.2. Analysis of Cadastral Parcel 046401_1.1190.39/1

An analysis of the area revealed that the function of the existing building is inconsistent with the zoning regulations. The Local Spatial Development Plan (MPZP) designates this area for single-family housing, whereas in reality, the registered plot is occupied by commercial and service buildings. Furthermore, the inventory revealed that the biologically active area covers only 12% of the site. Planning regulations require that this ratio be at least 50%.

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Table 2. Local Master Plan provisions for cadastral parcel 046401_1.1190.39/1 (source: Author's own compilation based on the cadastral parcel inventory and the analyzed Local Master Plan).

Area 7-MN/UR		
Parameter	Local Master Plan Provisions	Actual status
Cadastral plot ID	-	046401_1.1170.8/8
Land Use	Primary: Single-family detached housing Supplementary: Non-intrusive services, internal transportation	Retail and service development
Area of the registered plot	Min. 1,000 m²	1,380.18 m²
Building area	-	179.52 m² (13%)
Covered area	-	1,034.52 m² (75%)
Biologically active area	50%	166.14 m² (12%)

3.3. Analysis of Cadastral Parcel 046401_1.1190.22/4

The actual condition of the cadastral parcel deviates from the provisions of the Local Spatial Development Plan (MPZP) in terms of land use and the biologically active area ratio. Instead of single-family residential development , the area in question contains a commercial structure in the form of a warehouse. Despite the relatively large area of the plot, the current proportion of biologically active area is lower than required by local regulations and amounts to 41%.

Table 3. Local Master Plan provisions for cadastral plot 046401_1.1190.22/4 (source: Author's own compilation based on the cadastral plot inventory and the analyzed Local Master Plan).

Area 9-MN/UR		
Parameter	Local Zoning Plan Provisions	Actual status
Cadastral plot ID	-	046401_1.1190.22/4
Land Use	Primary: Single-family detached housing Supplementary: Non-intrusive services, internal transportation	Utility buildings (warehouse)
Area of the registered plot	Min. 1,000 m²	4,358.01 m²
Building area	-	1,702.52 m² (39%)
Covered area	-	879.91 m² (20%)
Biologically active area	50%	1,775.58 m² (41%)

4. Results

The use of the Autodesk Forma Site Design tool enabled the generation, on selected cadastral parcels, of buildings with simple geometric forms, most often in the form of cuboids. In the analyzed case, the parameterization process was limited mainly to defining the dimensions of the designed objects (Table 4-6). It is worth noting, however, that parameters such as width or length are treated by the software as suggested values, and as a result, the generated solid may deviate from the assumed dimensions. This discrepancy can be seen in the first of the analyzed examples (Figure 5), where the building, despite the specified dimensions of 12 x 15 m, occupies the entire width of the lot. An analysis of the local zoning plan provisions indicates, among other things, the need to maintain a specific percentage of biologically active area, which cannot be directly defined as a parameter in Autodesk Forma Site Design. The only available solution is then to appropriately shape

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the building's dimensions so that it occupies the correct portion of the plot. However, this process may be complicated due to the aforementioned discrepancies between the specified values and those actually generated by the software.

Table 4. Input parameters for generating a development concept in Autodesk Forma Site Design for cadastral plot 046401_1.1170.8/8 (source: author's own work).

Cadastral plot 046401_1.1170.8/8	
Parameters	number of floors: 3 floor height: 3 m building width: 12 m Building length: 15 m

Due to the limited area of the plot, the program very often generated a building with a compact, cubic form (Figure 6). This orientation allowed for optimal use of the available space and maintained the required distances from the plot boundaries. The proposed building form complies with the provisions of the Local Spatial Development Plan (MPZP), both in terms of the building's geometry and development parameters.

Table 5. Input parameters for generating a development concept in Autodesk Forma Site Design for cadastral plot 046401_1.1190.39/1 (source: author's own work).

Cadastral plot 046401_1.1190.39/1	
Parameters	number of floors: 3 floor height: 3 m Building width: 12 m Building length: 15 m

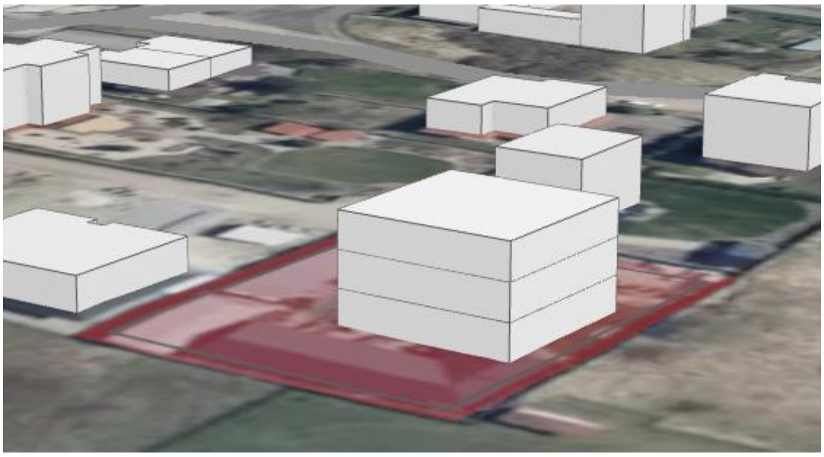

Figure 6. Building model generated in the Autodesk Forma Site Design environment for cadastral parcel 046401_1.1190.39/1 (source: author's own work).

In the case of plot no. 046401_1.1190.22/4 (Figure 7), a problem also arose due to the failure to account for the specified building dimensions. As a result, the objects were placed too densely, which made it impossible to meet the requirement specified in the Local Spatial Development Plan regarding the minimum plot area.

Table 6. Input parameters for generating a development concept in Autodesk Forma Site Design for plot 046401_1.1190.22/4 (source: own work).

Cadastral plot 046401_1.1190.22/4	
Parameters	number of floors: 2 floor height: 3 m

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	Building width: 12 m Building length: 12 m

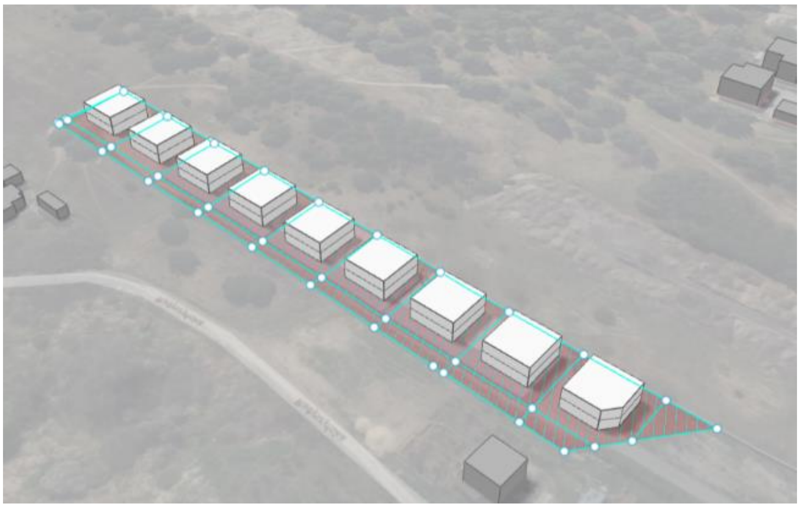

Figure 7. Model of buildings generated in the Autodesk Forma Site Design environment for cadastral parcel 046401_1.1190.22/4 (source: author's own work).

The introduction of the Archistar plugin into Autodesk Forma Site Design expanded the possibilities for parameterizing the generated concepts. In the context of the provisions of the Local Spatial Development Plan (MPZP) for , the ability to define indicators such as the minimum biologically active area and the minimum registered plot area proved particularly important (Tables 7–9). Despite the increased control over parameters, the final result of the building generation was decisively influenced by the building template used, which determined the type and character of the building to be constructed on a given plot. It should be noted that not every available template can be applied to all analyzed cadastral plots, as its applicability depends on the area of the analyzed site. An example of such a situation is cadastral plot No. 046401_1.1170.8/8 (Figure 8), for which the only generated solution turned out to be a semi-detached building, inconsistent with the assumptions of the Local Spatial Development Plan (MPZP). However, it is possible to adapt this concept by combining the two segments into a single structure, which allows for the further use of the generated form as a starting point for subsequent design work.

Table 7. Input parameters for generating a development concept in Archistar for cadastral plot 046401_1.1170.8/8 (source: author's own work).

Cadastral plot 046401_1.1170.8/8	
Parameters	development template: duplex minimum plot area: 1000 m² 50% biologically active area

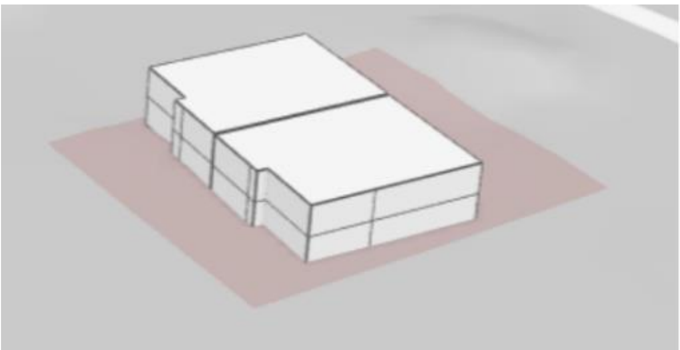

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Figure 8. Model of buildings generated in the Archistar plugin for plot 046401_1.1170.8/8 (source: author's own work).

On plot 046401_1.1190.39/1 (Figure 9), using the Townhouse template, a detached building with a simple, cuboid form was generated, which complies with the provisions of the Local Spatial Development Plan.

Table 8. Input parameters for generating a development concept in Archistar for plot 046401_1.1190.39/1 (source: author's own work).

Cadastral plot 046401_1.1190.39/1	
Parameters	development template: townhouse minimum plot area: 1,000 m² 50% biologically active area

Figure 9. Building model generated in the Archistar plugin for plot 046401_1.1190.39/1 (source: author's own work).

In the case of plot no. 046401_1.1190.22/4 (Figure 10), the use of the Single Detached template allowed for the generation of several building structures within a single parcel. The main objective of this action was to subdivide the plot into several smaller parcels with a minimum area of 1,000 m², designated for single-family detached housing. This objective was achieved while adhering to all key parameters specified in the Local Spatial Development Plan.

Table 9. Input parameters for generating a development concept in Archistar for cadastral plot 046401_1.1190.22/4 (source: author's own work).

Cadastral plot 046401_1.1190.22/4	
Parameters	Development template: single detached minimum plot area: 1000 m² 50% biologically active area

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Figure 10. Model of buildings generated in the Archistar plugin for cadastral parcel 046401_1.1190.22/4 (source: author's own work).

The One Click LCA Generative Design plugin for Autodesk Forma Site Design enables the generation of development concepts by defining specific parameters across several key categories (Tables 10–12). The most important parameters for the analyses include, among others, the height and width of the building, as well as the proportion of biologically active surface area ( ). Unfortunately, in the analyzed cases, each of the obtained concepts showed discrepancies with the provisions of the Local Spatial Development Plan (MPZP). On plot 046401_1.1170.8/8 (Figure 11), two buildings were generated that occupy nearly the entire area of the plot. Such land development results in a significant exceedance of the permissible building parameters, particularly regarding the biologically active surface area and the limit on the number of buildings located on the property.

Table 10. Input parameters for generating a development concept in One Click LCA for plot 046401_1.1170.8/8 (source: author's own work).

Cadastral plot 046401_1.1170.8/8	
Parameters	maximum height: 15 m 50% biologically active area

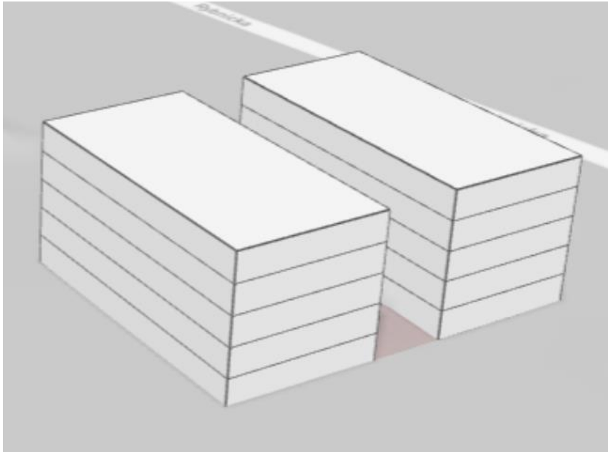

Figure 11. Building model generated in the One Click LCA plugin for cadastral plot 046401_1.1170.8/8 (source: author's own work).

For the next cadastral plot (Figure 12), an excessive number of buildings was again generated. Theoretically, the presented concept meets the requirement for the minimum share of biologically active area; however, this value is at the threshold of the acceptable minimum. This means that the design does not include a reserve for other land-use elements, such as access roads, walkways, parking spaces, or paved pathways, which in practice would further reduce the biologically active area.

Table 11. Input parameters for generating the development concept in One Click LCA for cadastral parcel 046401_1.1190.39/1 (source: author's own work).

Cadastral plot 046401_1.1190.39/1	
Parameters	maximum height: 10 m 50% biologically active area

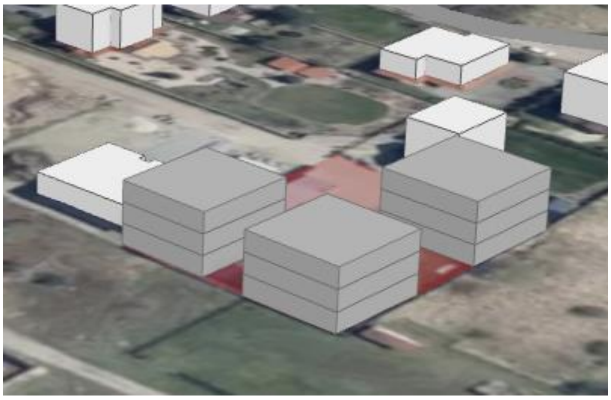

Figure 12. Building model generated in the One Click LCA plugin for cadastral plot 046401_1.1190.39/1 (source: author's own work).

On cadastral plot 046401_1.1190.22/4 (Figure 13), still assuming that it will be divided into several smaller parcels, a larger number of structures may be considered acceptable. However, the buildings were arranged in a random and uncoordinated manner, and the walls of two of them were located directly on the boundary of the cadastral plot, which is inconsistent with applicable planning regulations and the principles of building design.

Table 12. Input parameters for generating a development concept in One Click LCA for cadastral plot 046401_1.1190.22/4 (source: author's own work).

Cadastral plot 046401_1.1190.22/4	
Parameters	maximum height: 8 m 50% biologically active area

Figure 13. Building model generated in the One Click LCA plugin for cadastral parcel 046401_1.1190.22/4 (source: author's own work).

Analyses conducted using the Archistar plugin have shown that Autodesk Forma Site Design enables the generation of development variants that comply with imposed planning regulations; however, in practice, this tool also encounters certain problems resulting mainly from its sensitivity to the accuracy of input data, limitations in interpreting complex planning provisions, and difficulties in generating results in the case of incomplete or ambiguous site parameterization. For each of the analyzed plots, the software correctly interpreted key parameters derived from the Local Spatial Development Plan (MPZP), including minimum and maximum building areas, building lines and contours, permissible heights, intensity ratios, and the required biologically active area. Based on this, the system automatically generated a set of development variants that met all imposed formal

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constraints. The generated models enabled the comparison of alternative urban layouts in terms of geometry, volume proportions, functional distribution, and relationship with the surroundings, which significantly reduced the time required for manual design iterations.

The One Click LCA plugin allows users to define basic building parameters by entering custom prompts or selecting one of the predefined options across several categories, such as: the degree of plot coverage by buildings, the distance of the structure from the boundaries of the cadastral plot, and the proportion of green areas and open spaces. This allows the user to quickly define key urban and spatial assumptions that serve as the starting point for generating development concepts. The tool generates variants that aim to maximize the specified parameters and, in some cases, even exceed them. For this reason, when defining threshold values—such as the minimum biologically active area—it is important to leave an appropriate margin in the parameter values. This helps avoid situations where the generated concept formally exceeds the permissible ratios specified in the Local Spatial Development Plan (MPZP).

During the semantic model enrichment phase, the Autodesk Forma Add-In for Revit enabled the direct transfer of building solids generated in the Autodesk Forma Site Design environment to Autodesk Revit. The import process did not include only the designed volumetric objects. Along with them, spatial context was included in the form of surrounding buildings and a terrain model (Figure 14), which were generated based on external datasets used for the general representation of the spatial development status. The selected variant, compliant with the provisions of the Local Spatial Development Plan (MPZP), was exported for further modeling in a BIM environment with a higher level of detail. During the process, key geometric parameters, spatial relationships, and relevant planning constraints—including building lines, building density, and maximum building heights—were preserved. Integrating the model with Revit enabled a seamless transition from the conceptual phase, based on generative design, to an environment conducive to precise modeling and further enrichment of the model with semantic information.

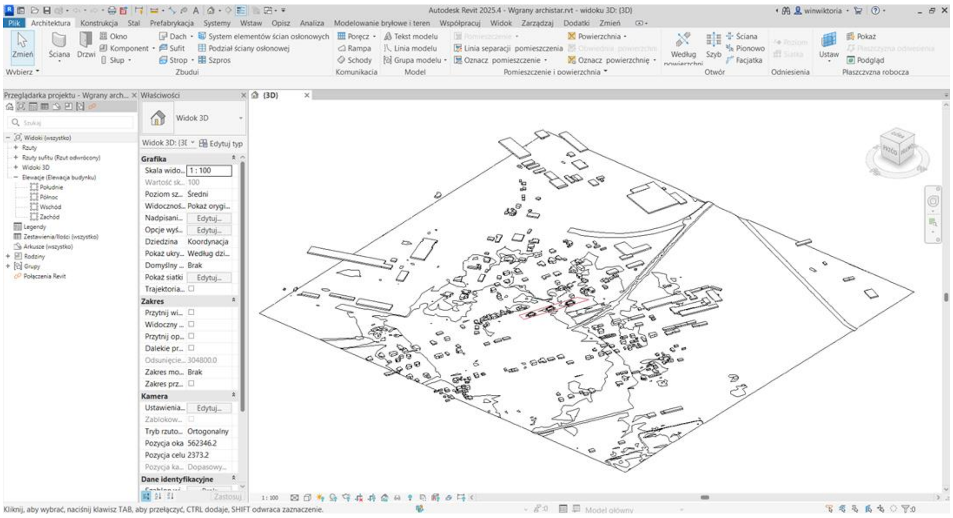

Figure 14. View of imported data in Autodesk Revit (source: author's own work).

The results confirm that the integration of generative processes with analyses of land use forms in the Forma environment significantly expands the possibilities for design evaluation at the conceptual stage. The software enabled a quick comparison of variants in terms of compliance with the Local Spatial Development Plan (MPZP), urban planning indicators, and environmental parameters, which translates into increased design efficiency and a reduction in the number of subsequent corrections.

Furthermore, the semantic enrichment of the property conducted at a later stage enabled the transformation of the BIM model from a purely geometric representation into a repository of knowledge about land use (Figure 15).

Figure 15. Revit model with semantically enriched building lots—visualization of the proposed development's location in relation to the terrain and development boundaries (source: author's own work).

The visualization allows for the analysis of potential development scenarios in relation to the provisions of the Local Spatial Development Plan (MPZP) as early as the pre-implementation stage, including an assessment of the architectural form of the proposed building in the context of its surroundings (Figure 16), which in turn enables planners and designers to assess the spatial impacts of the adopted solutions, test variants, and better understand the relationship between planning regulations and the actual form of development prior to the project's implementation.

Figure 16. Visualization of a proposed single-family home, taking into account planning parameters and its relationship with the surroundings (source: author's own work).

Semantic enrichment of the BIM model can also be achieved by assigning a set of descriptive parameters derived from planning documents to a cadastral parcel. These include, among others, the parcel identifier and minimum area, the required proportion of biologically active area, and the land use designation in accordance with the Local Spatial Development Plan (MPZP). This organization of information enables unambiguous interpretation of planning provisions directly within the design environment. As a result, the BIM model becomes a tool supporting the analysis of the compliance of designed solutions with applicable regulations as early as the initial stage of the investment process (Figure 17).

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Tekst	
ID_DZIALKI_EWIDENCYJNEJ	046401_1.1190.22/4
POWIERZCHNIA_BIOLOGICZNIE_CZYNNA	50%
POWIERZCHNIA_DZIALKI_EWIDENCYJNEJ	min. 1000 m2
POWIERZCHNIA_ZABUDOWY	-
POWIERZCHNIA_ZASKLEPIONA	-
PRZEZNACZENIE_TERENU	Zabudowa mieszkaniowa jednorodzinna, wolnostojąca
UZUPELNIAJACE_PRZEZNACZENIE_TERENU	Usługi nieuciążliwe, komunikacja wewnętrzna

Figure 17. Set of semantic parameters assigned to a registered plot in the model (source: author's own work).

4. Discussion

4.1. Interpretation of Results and Evaluation of the Research Objective

The analyses conducted enabled an assessment of the extent to which Generative Design tools utilizing AI elements can streamline the verification of land-use compliance with the provisions of the Local Spatial Development Plan (MPZP). In response to the research question, it must be stated that although the examined environment accelerates the process of generating development variants, its functionality in the described scope remains limited. These tools can support a preliminary assessment of the consistency between the actual development of a registered plot and the requirements of local law, but the accuracy of the generated results proves insufficient. The lack of full automation and the limitations described in detail in Chapter 3 necessitate manual correction of the results. Consequently, the current state of development of Generative Design tools allows for only a minor improvement in verifying the compliance of land use with the provisions of the Local Spatial Development Plan, which is unsatisfactory from a planner's perspective. It should be emphasized, however, that the research focused on single-family housing. An analysis of multi-family or commercial buildings, which have different characteristics, could yield different results.

4.2. Identified Limitations

Effectively eliminating the identified barriers could significantly improve the usefulness of these tools for spatial planning purposes. It would be necessary to introduce strict geometric constraints in place of the current suggested values. Furthermore, it would be necessary to allow for the inclusion of a greater number of indicators that are considered during the preparation of local zoning plans. Such development of the tools would enable not only visualization but also automatic validation of existing land use against legal requirements, which would lead to a reduction in the time required for analyses.

Another significant aspect revealed during the research is the impact of using Generative Design tools on the process of working with land-use variants. The analyses conducted showed that the ability to quickly generate multiple solutions fosters an exploratory approach to design, in which the emphasis shifts from searching for a single optimal variant to comparing the spatial consequences of various building configurations. The support offered by Generative Design is most evident during the comparative analysis phase, enabling an assessment of the extent to which specific planning parameters influence the form of development. Such an approach can enhance the decision-making awareness of the designer or planner; however, it does not lead directly to unambiguous conclusions but rather broadens the spectrum of solutions under consideration.

4.3. Proposal for Further Research

Further research should focus on developing a technology that allows for the direct implementation of the requirements contained in the Local Spatial Development Plan into a digital environment, which would become a key element of CIM processes. Another area of research should be the expansion of analyses to include a larger number of case studies, covering areas with diverse planning, functional, and spatial conditions, which would allow for an assessment of the universality

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of the observed relationships and their susceptibility to local context. At the same time, it would be valuable to link Generative Design tools with multi-criteria methods for assessing the quality of space, encompassing functional, environmental, and usability aspects such as accessibility, sunlight conditions, and user comfort. Future research could also focus on evaluating the potential for using Generative Design tools in planning procedures in the context of their application, for example, as support for consultation processes, which would allow for a more precise determination of their potential and limitations in spatial design practice.

5. Conclusions

The combination of BIM technology and Generative Design methods holds significant potential for supporting planners and urban designers in the rational shaping of space; however, at the current stage of development, these tools are not yet sufficient for a full, automated analysis of local regulations. One of the key issues revealed in the research is that generative algorithms do not treat the input parameters in a fully deterministic manner. Values such as the width and length of a building, its location on a cadastral plot, or the percentage of biologically active area are interpreted by the system as optimization guidelines rather than rigid constraints, leading to discrepancies between the input data and the actual generated geometry. This limitation is particularly significant in the context of spatial planning, where compliance with legal standards is based on precise numerical thresholds and unambiguous boundaries. The lack of strict enforcement of parameters by generative plugins undermines their usefulness as tools for automatic compliance checking and confirms that, at present, these technologies primarily serve a conceptual support role rather than that of a binding tool for formal legal verification. Undoubtedly, the greatest value of using Generative Design with BIM technology lies in the ability to quickly test multiple development scenarios within defined constraints; however, the final assessment of legal and urban planning compliance must still be performed by a specialist, which underscores the complementary—rather than substitute—role of generative tools in the spatial planning process.

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