Generation Model Based on Multicriteria Performance: Applicability in Single-Family Residences of Social Interest

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Abstract. This research aims to develop a prototype of a generation model based on the performance of multiple criteria that can autonomously create single-family projects of social interest. The use of this model aims to help choose the best results, balance performance indices, and identify the most appropriate solution to a design problem. This research is driven by the introduction of new computational techniques to the design process and the need for more theoretical research to better understand these new practices. The proposed model was executed in visual programming software in three stages of creation and testing, each with a specific objective. The model makes it possible to generate and analyze housing of social interest through multiple criteria and to produce discussions about the use of the tool. Demonstrating that its use allows helping explain the design decisions by bringing models and data previously not considered or visualized.

Keywords: Performance Model, Multicriteria, Architectural design, Social Interest Housing.

1 Introduction

The current study aims to introduce a design process model that leverages computer technology and computation to enhance architectural problem-solving by employing a generation model based on multicriteria performance. This investigation is motivated by the recognition that computer utilization can significantly enhance architects' capabilities, enabling them to more effectively express their designs and personal visions. As highlighted by Stangl (2013), architects commonly rely on analogies, metaphors, inspiration, and intuition during their creative processes. To fully harness the potential of architecture and human creativity, it is imperative to integrate these approaches with computational tools, thereby providing an additional avenue for expressing creativity.

The primary objective of the proposed model is to promote the utilization of digital tools strategically, enabling architects to approach their final objectives more effectively rather than diverging from them. Existing studies, including those conducted by De Luca (2020), Szentesi-Nejur, Lucca, and Nejur (2021), and Carallo (2020), assess specific architectural or spatial elements; however, they generally lack comprehensive evaluations encompassing multiple criteria. Addressing this gap, the current study seeks to establish a multicriteria performance model utilizing visual programming and simulation components as its fundamental tools.

To implement this model, single-family social housing projects were selected as a case study. Despite offering viable solutions, these projects often fall short of meeting users' health and well-being needs due to mass production prioritizing cost-effectiveness over quality, as identified by Villa Saramago and Garcia (2015) and Palermo (2013).

The concept of applying and evaluating diverse guidelines aligns with Horváth's (2005) characterization of a multicriteria, multivariable, or multiobjective design process, which involves integrating knowledge from various disciplinary fields. Accumulating significant project data leads to more efficient outcomes, driven by mathematical concepts, management principles, information technology, psychology, and social sciences (Rigo et al., 2020), rather than relying solely on personal architectural perceptions. The proposed model builds upon the performance model structure put forth by Oxman (2006), which possesses qualities well-suited for this purpose.

The foundation for the generation model based on multicriteria performance draws from Oxman (2006) framework, acknowledging the continuous integration of digital practices and theories in architectural works. As a result, a series of ideas and methods are adopted to structure design aided by computational tools.

Based on Oxman's (2006) constructs and stages in the performance model, the proposed Multicriteria Performance-Based Generation Model (MGBDM) consists of three stages. The initial two stages employ parametric modeling and visual programming to create compositions resembling socially significant single-family dwellings, simulate data, and evaluate it against performance criteria. The third stage follows a similar process but places emphasis on multiple criteria: (1) potential cost; (2) daylight penetration; (3) temperature behavior; and (4) power consumption.

The analysis of the developed structure yields discussions and outcomes akin to those presented by Paris, Lopes, and Neuenfeldt Junior (2022). In this context, the structure emerges as a valuable tool for enhancing project planning and execution by incorporating previously unconsidered or not clearly visualized models and data by the designer or the design team.

2 Method

The methodology for developing and analyzing the Multicriteria Performance-Based Generation Model (MGBDM) is structured into three steps, guided by theoretical literature reviews. The procedures, encompassing both program creation and structural examination, were informed by bibliographic investigations, as demonstrated in studies such as Mariano et al. (2021), Mariano and Vaz (2023),[1] and Mariano and Vaz (2023)[2], which aimed to identify relevant subjects within the research themes.

In a broad context, the initial two steps aim to initiate the construction of the visual algorithm to generate initial composition tests, simulate data, and collect results from preliminary analyses. The third stage of the model involves selecting outcomes through the simultaneous consideration of multiple criteria.

Each stage is illustrated in Figure 1 and is summarized as follows: (1) initiate the multicriteria performance-based generation model by incorporating an initial index and selection criterion, specifically cost; (2) enhance the model by introducing architectural elements like walls, doors, and horizontal enclosures. This expansion entails the inclusion of an additional performance criterion, such as natural light distribution, enabling architectural design selection based on multiple criteria: (3) Integrate further evaluation criteria into the model, ensuring equilibrium among all criteria. This is achieved through a hierarchical approach to selecting the most suitable project.

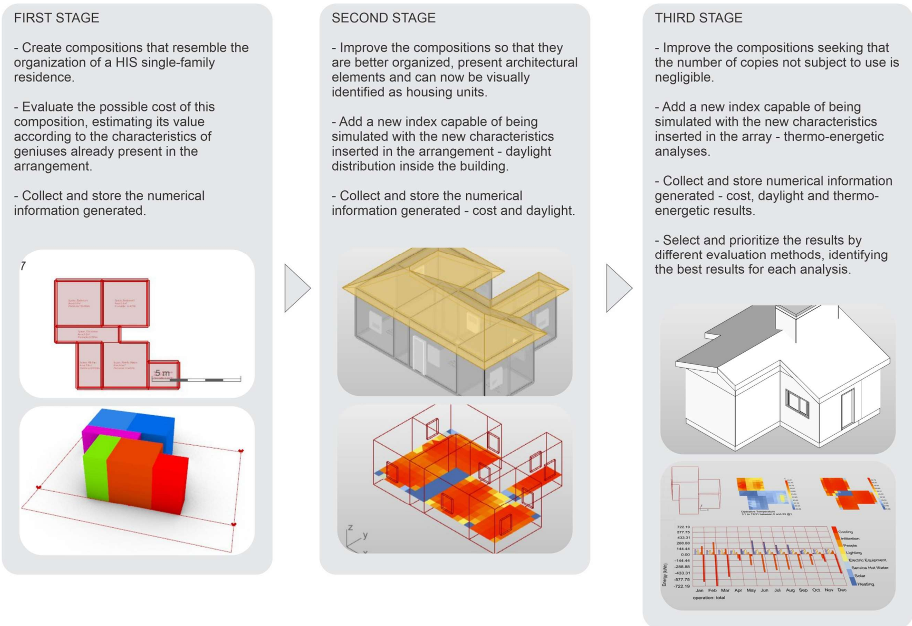

Figure 1. The simplified structure of the method: The authors, 2020.

At the conclusion of each step, the results are collected and utilized to enhance the subsequent phase. This iterative process enhances both compositional and simulation outcomes, as well as the selection of arrangements. As a result, through the refinement of outcomes, it is anticipated that the third stage's consolidation will facilitate discussions concerning its application and outcome selection. Specifically, these discussions will revolve around the model's capability to automatically generate architectural designs for single-family social housing projects and the feasibility of developing a Pareto-based method for prioritizing the selection of generated designs.

2.1 First Stage

The initial phase establishes the fundamental framework of the multicriteria performance-based generation model through the acquisition of familiarity with digital tools, analysis, data collection, and the assessment of employing visual programming. In this manner, it arranges and evaluates information, assigns costs to its program, and independently captures and stores this data. The objective is to create configurations reminiscent of clusters of socially beneficial housing units, accounting for their dimensions and interconnections. This facilitates the collection and storage of geometric data through the utilization of Geometric Unit Cost (CUG) (Lima, 2013) and Basic Unit Cost (CUB) (Lima et al., 2016) methodologies. The application of these indices was evaluated in a study (Mariano and Vaz, 2023), wherein straightforward typologies were employed to compare budget types. Each of these metrics derives the cost of construction through distinct methods: (1) the CUB method utilizes a constant multiplied by the square footage, while (2) the CUG method employs various parameters, including the height of the walls, the areas that are wet or dry, and the number of external and internal walls.

This phase aims to elaborate on compositions, akin to floor plans, within a conceptually defined space constrained by parametrically adjustable setbacks. The quantity, dimensions, and layout of rooms adhere to established rules and references, much akin to the works of Pedro (1999, 2000), Palermo (2009), and Logsdon (2019).

For the development of the prototype, a suite of four computational tools was employed: (1) a three-dimensional modeling software, Rhinoceros 3D 6® (Mcnee, 2014); (2) a visual programming component, Grasshopper® (Rutten; Mcneel, 2004); (3) two Wasp plugins (Rossi, 2017); (4) the Colibri component from the TT toolbox (Tomasetti, 2017); and ClimateStudio® (Solemma, 2021).

Wasp facilitates a range of aggregation procedures, enabling the creation, visualization, and manipulation of geometry and data-driven structures (Rossi, 2017). Its implementation allows for stochastic search, serving as a mechanism for generating models rooted in probability concepts and random events likely to occur within specified timeframes and parameters.

Consequently, the integration of this system within the programming framework automates the allocation of fundamental rooms, adhering to a set of simplified rules, within a defined land area to prevent spatial encroachment. Hence, the arrangement's sequencing consistently considers established rules and already utilized spaces, precluding the introduction of new geometries if space is lacking or conflicts with existing elements arise.

2.2 Second Stage

The second stage of model development aims to enhance and expand upon the existing structure by introducing a new simulation index and incorporating BIM architectural elements. This addition provides the three-dimensional representation with an approximate spatial depiction of a single-family residence. The validation of this concept is conducted through a design contest's proposal selection program. A comprehensive account of this program's experience is detailed (details withheld), including evaluator opinions on finalists, enabling the interpretation of features that could complement the model.

The model's objective also extends to the analysis, collection, and preservation of data to facilitate the selection of a proposal that demonstrates optimal budgetary performance (via CUG and CUB metrics), access to natural light (daylight autonomy), annual facade radiation, and a formal configuration that aligns with the characteristics of social housing.

The concept of "daylight autonomy," proposed by the Illuminating Engineering Society of North America (IES) in 2012, serves as a metric to evaluate daylight distribution within the model. This metric involves dynamic simulations and quantifies sunlight. It relies on a predictive model known as "Climate-Based Daylight Modeling" (CBDM), which identifies daylight hours over a specific time interval to capture daily and seasonal variations in light dynamics (Mardaljevic; Christoffersen, 2017).

To deepen the discussion and assess the achieved outcomes' implications, a validation test is conducted at this stage. A project is entered into an architectural competition to determine the best design solution for social housing in Santa Catarina, based on the results obtained during this phase. Participation in this selection process enhances understanding of the model's utilization and limitations in the fields of architecture and urbanism (details withheld).

2.3 Third Stage

The third stage aims to introduce a new simulation criterion, enabling the utilization of diverse outcomes for composition selection through a multi-criteria decision-making framework. Additionally, it aims to enhance the spatial organization structure to expand the scope of successful configurations. This involves mitigating instances where formal constraints hinder the composition, consequently streamlining simulations that would otherwise yield unproductive results for the database.

In summary, this phase involves the creation of a prototype resembling the architectural design of an HIS (Housing for Social Interest). This prototype facilitates the assessment, compilation, and storage of data and allows independent selection of the proposal that demonstrates superior performance. This selection process employs a Pareto-like method as delineated by Pereira, Belém, and Leitão (2020).

During this stage, a decision was made to substitute the ClimateStudio® plug-in (Solemma, 2021) with exclusively Ladybug Tools® components (Albdour; Baranyai, 2019). This adjustment aims to make all Grasshopper tools accessible for professionals and students at no cost. However, it's worth noting that this replacement led to an increase in the number of components employed and overall programming complexity.

3 Results

3.1 Results of First Stage

The validation of the initial phase of the performance-based training model yielded a collection of geometric compositions that showcase the compositional attributes of social housing along with potential budget estimates. These 40 compositions underwent cost analysis utilizing CUG and CUB metrics, resulting in a comparative table highlighting budget discrepancies.

Figure 2 depicts a subset of the 40 compositions generated during the recent validations. This illustration demonstrates instances of compositions with comparable areas that, upon CUG analysis, exhibit distinct budgetary outcomes. This serves to underscore the model's efficacy not only in generating compositions but also in their subsequent evaluation.

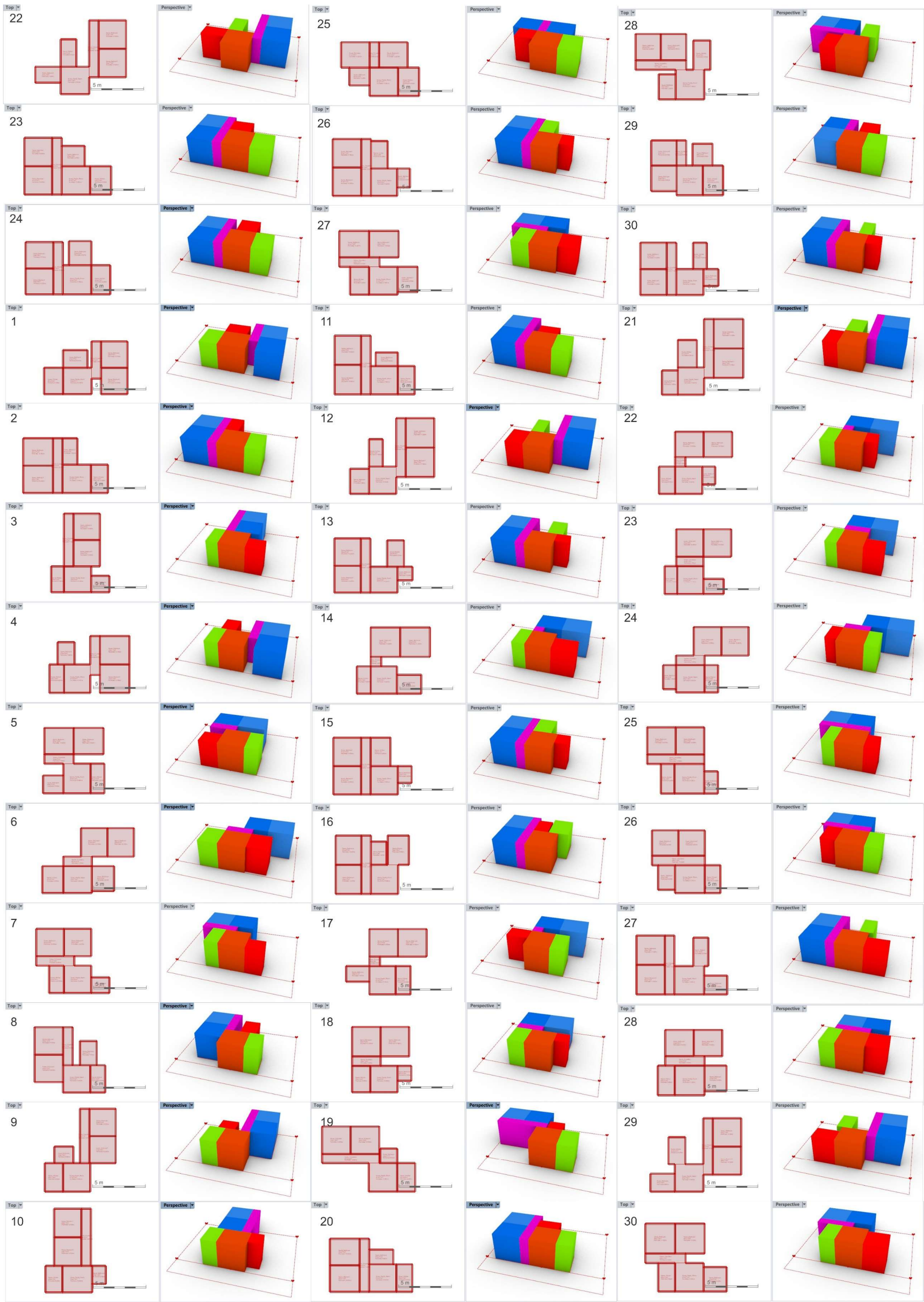

Figure 2. A sample of the compositions created by the first step: The authors, 2020.

3.2 Results of the Second Stage

In the subsequent phase, the model was employed in the formulation of a single-family residence project designated for participation in a competition organized by the Council of Architects and Urban Planners of Santa Catarina (Cau-SC). The programmatic requirements outlined within this solicitation aligned seamlessly with the metrics established within the model.

Furthermore, specific stipulations from public sources, pertinent to the project, were subjected to scrutiny through simulations. These encompassed parameters encompassing functionality, sustainability, performance, viability, and economic feasibility. Notably, an economic threshold of BRL 105,000 was imposed, encompassing all project stages, materials, and services, as stipulated by Cau-SC (2021).

Upon adaptation to the program's specifications, notably those pertaining to the number of rooms, the iterative process was executed two hundred times. During each iteration, the algorithm autonomously crafted a composition adhering to the predefined spatial relationships and connections. This culminated in the generation of architectural configurations, alongside a comprehensive analysis encompassing cost, natural illumination, and radiation simulations. Refer to Figure 3 for a representative selection of these outcomes.

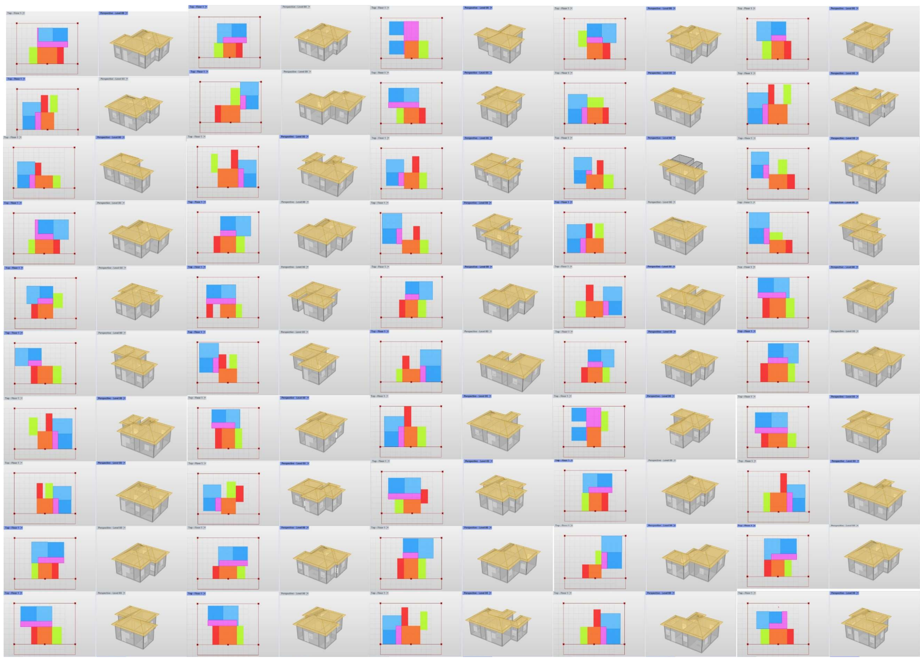

Figure 3. A representation of the results presented by the second stage. Source: The authors, 2021.

3.3 Third Stage Results

To validate the model during this concluding phase, a series of iterative tests was conducted to, akin to previous stages, detect errors and subsequently enhance its precision. These testing iterations occurred on three distinct instances: (1) An initial trial involving 21 instances aimed to affirm the proper functionality and autonomous operation of the system— encompassing simulation, image capture, data generation, and storage. (2) Subsequently, a more comprehensive trial involving 201 units was executed to identify potential issues within the established rules. (3) Finally, the model underwent an additional 201 trials to fortify its structure, aimed at reducing instances where errors occurred or where deviations from the desired outcome were observed. This process also verified the robustness of other automated functions.

Notably, among the latter trials, no erroneous configurations were identified. This observation serves to affirm that the implemented adjustments have effectively ameliorated the compositional arrangement. Consequently, after the establishment of a comprehensive database comprising compositions and relevant data, a hierarchical analysis, following the Pareto principle (Pereira, Belém, and Leitão, 2020), was undertaken. This methodology facilitated the identification of instances characterized by the highest attributes, as determined by the prioritized criteria. The synthesized results of this hierarchical analysis are succinctly illustrated in Figure 4.

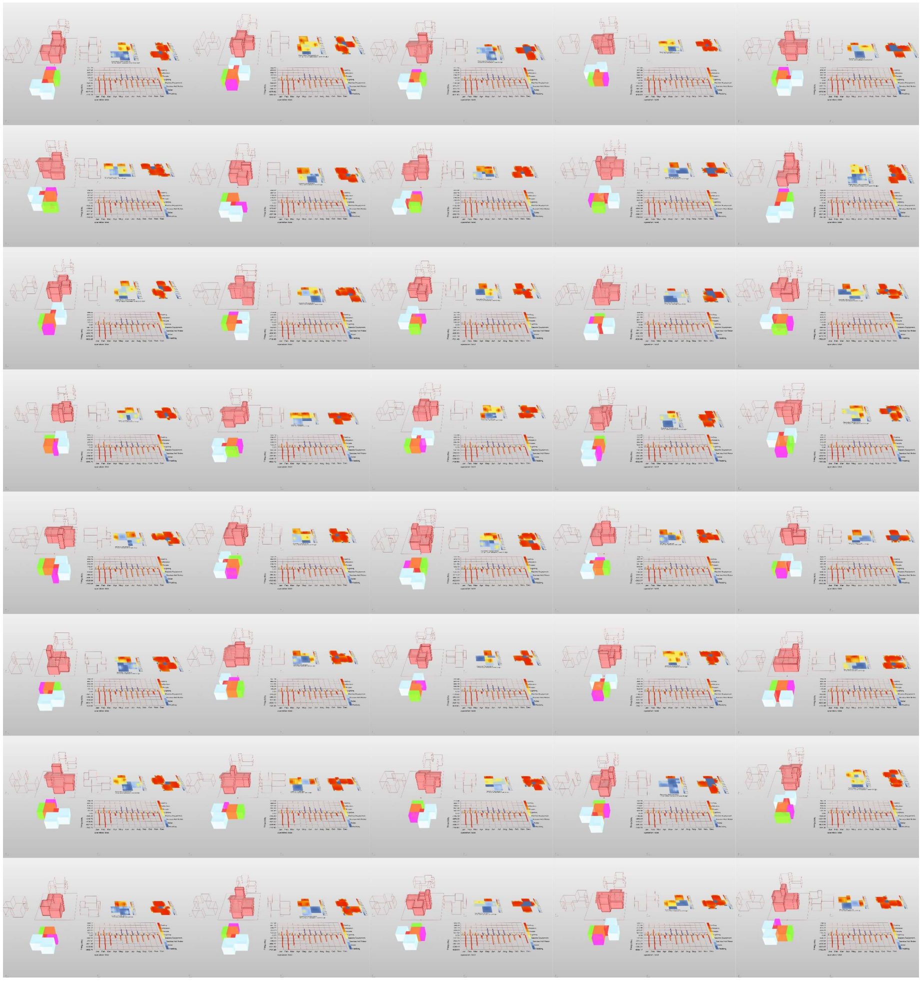

Figure 4. A sample of the results of the Third stage. Source: The authors, 2023.

4 Discussion

The elaboration of the model thus far has the potential to instigate preceding discussions, including: (1) whether the generation model based on multicriteria performance can inherently generate architectural schemes for single-family housing projects of social relevance; and (2) the feasibility of devising a Pareto-based methodology to effectively prioritize the selection of schemes generated by the model.

The initial discussion posits that the presented model can partially fulfill the principal objective of this study, as evidenced by its capacity to autonomously generate single-family social housing projects. The model's efficacy is underscored by its demonstrated ability to create individual dwellings and to amass diverse data from the ensuing outcomes. Furthermore, it was ascertained in the final stage that none of the schemes engendered by the system deviated from suggested compositional guidelines.

The outcomes stemming from the analysis and simulations of these schemes led to the formulation of a method for ranking the models based on the relative significance of criteria. This approach, akin to the Pareto principle (Pereira; Belém; Leitão, 2020), can potentially signify a prospective decision-making tool for project teams. The method facilitates the precise determination of final and intermediary scores for architectural typologies, thereby enabling the selection of an initial scheme grounded in well-defined and articulated criteria. This stands in contrast to the subjective intuition often associated with architects' choices, as discussed by Terzidis and Mitchell (2003).

Following the completion of the three stages of programming development, potential avenues for future research and improvement have been identified. Subsequent to its implementation, certain aspects and evaluations have proven to be inadequately addressed or necessitating enhancement. These areas encompass considerations related to novel research sources, as well as the creation and ongoing maintenance of new programs. Presently, there remain topics requiring refinement, including: (1) verification of the simulation parameters and outcomes through expert assessment to ensure concurrence with reality and industry standards; (2) validation of the results of schemes generated by the program with the assistance of external volunteers, encompassing both architects and non-architects, thereby assessing alignment with existing examples of single-family and multifamily architectures; and (3) the execution of additional testing endeavors aimed at refining and augmenting the employed Pareto methodology.

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