A regionalist approach to generative design process: From concept to BIM model

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Abstract. This paper presents the implementation of two generative computational architectural design systems integrating regionalist inputs. While the automation of the design process using computational tools has been extensively discussed, the incorporation of regionalism remains limited. To address this, the Design Science Research method was employed to create computerized artifacts generating architectural models in BIM associated to Visual Programming Languages. The innovation lies in considering materiality requirements, building systems, and regional aesthetics as primary inputs for generating parametric shapes. The framework enables the generation of detailed BIM models, automatically documenting them to comply with local construction norms. This paper provides insights into the functionality of the generative algorithms, showcases the produced architectural instances, and presents the automatically generated 2D documentation. Additionally, a framework for a regionalist computational design approach is proposed. The study highlights the importance of incorporating regionalism and provides a foundation for the development of similar artifacts.

Keywords: Computational Design, Generative Design, BIM, Regional Architecture, Regional Computation.

1 Introduction

This paper aims to expand the computational design literature by introducing a regionalist approach to generative architectural design. The primary question addressed is how to effectively integrate state-of-the-art computational technologies while incorporating a regionalist perspective. To advance in this direction, a computational framework is suggested for architectural design processes that can create regionally appropriate artifacts by incorporating local typologies and materiality's.

The first part of the paper exposes the theoretical foundations supporting the implementation of a typological and regionalist design process. It also presents the current paradigm for the computational implementation of generative design algorithms and the state-of-the-art regionalist approach in this field. Following this, the methodology used for developing the framework and an overview of this process are discussed. Additionally, two computational implementations demonstrate the practical application of the proposed framework, leading to conclusions and discussions on the topic.

The concept of typology plays a fundamental role in this approach, acting as a means of synthesizing cultural architectural groupings. Adopting Argan's (2013) proposed concept, typology is seen as “a linguistic system, anchored in its context and linked to the common practices of the designers of a place and the users participating in that context". It manifests as patterns and recurrences that group architectural instances into a cohesive whole sharing common characteristics. These elements, which persist across different buildings, express their shared characteristics, directly relating to the available techniques, materials, and environmental conditions. The use of this typology concept is a relevant means of learning from regional cultures and translating these insights into a digital design process.

Motivated by the need to consider local contexts, the theoretical foundation for the propositions is critical regionalism. Elaborating generative projects with regional knowledge built over time by communities has the potential for enhanced cultural, environmental, social, and economic sustainability. Frampton (1983) characterizes critical regionalism as representing and critically attending to specific populations in which regional 'schools' are embedded.

Yuan (2016) highlights the potential of parametric models driven by local characteristics, such as climate and materiality. This innovative methodology enables efficient operation of construction information and organizational instructions through computational design, transforming the current situation of architectural design and production into a new digital era.

Parametric prototypes build up a connection between architectural geometry and performative parameters of local climate, material, structure and behavior. The decision as to which geometrical parameters matter in architecture becomes the key to the design approach. Regional information can be directly fed into geometric parameters of building elements through purposeful selection and extraction of data.

In this way, the chosen strategy for the implementation of a generative design system was computational design, since in a digital environment it is possible to program a process defined by a set of rules capable of generating results automatically. Mitchell (1998) emphasizes that the goal of the designer's computation is to instantiate the type appropriately for each moment and context. The objective is to create an appropriate framework for generation mechanisms, utilizing definitions and rules derived from regional typologies. For this purpose, Visual Programming Languages (VPL) integrated with Building Information Modeling (BIM) models are adopted, as suggested by Lima (2018), encouraging architects to implement computational design by harnessing the extended power of BIM tools through programming.

The study employs the Design Science Research methodology, as originally presented by Dresch, Lacerda, and Antunes (2015). This approach involves five distinct stages: problem identification, solution proposal, development, evaluation, and conclusion. Subsequent sections provide a comprehensive account of the tasks performed and outcomes achieved in each of these stages.

2 Problem identification

The initial stage, referred to as "problem identification," involved conducting an exploratory literature review on the CumInCAD website using the search term "regionalism." This investigation revealed several studies utilizing generative approaches in architecture, particularly with an emphasis on regionalism. Notably, Tabbarah's (2014) work explored contemporary systemic and generative methodologies adapted to local materiality and culture, highlighting a gap in the realm of digital architecture concerning how form conveys cultural significance. Additionally, Wu, Wu, and Li (2021) presented a method for analyzing regional spatiality, emphasizing the intrinsic pursuit of regional uniqueness within all cultures and the architectural domain.

The literature on generative architecture is extensive (Álvarez, Bernal, Caceres, 2020), with various models and methods of design generation. According to these authors, two aspects are important for the construction of the regional approach: first, the methods of apprehension of design algorithms in existing artifacts, that means, how to apprehend existing process definitions to create a new regional-based generative process; and second, the existing computational frameworks, their digital processes, and tools.

In this context, influential works serve as references for the computational implementation of significant architectural typologies throughout history. These works not only provide guidance on representing existing typologies but also highlight the technologies employed. Figueiredo et al. (2013) successfully identified and implemented Alberti's typology using shape grammar in a VPL. Similarly, Jorge, Fiuza and Cardoso (2017) achieved the same with Mies van der Rohe's typology. Vaz (2012) focused on Burle Marx's landscape typology, also utilizing VPL. Alassaf and Clayton (2021) implemented the typology found in Le Corbusier's work through a Building Information Modeling (BIM) interface, highlighting the advantages of this technology in facilitating the design process.

In conclusion, the research identified a significant gap within generative architectural literature, specifically regarding the limited number of approaches with a regionalist emphasis. Consequently, the research gap detected was the absence of a generative architectural design system with a syntax structured around regional aspects. Furthermore, the literature highlights the substantial contributions made by the state-of-the-art implementation of this approach, particularly through the integration of visual programming languages (VPL) with Building Information Modeling (BIM).

3 Solution suggestion

In the second stage, referred to as "solution suggestion," a computational framework for generative architecture was proposed, integrating regionalist aspects as its definitions and inputs (Figure 1). This proposed innovation encompasses three key considerations: (1) materiality requirements; (2) typical building systems; and (3) regional aesthetics, serving as the primary inputs for generating parametric shapes.

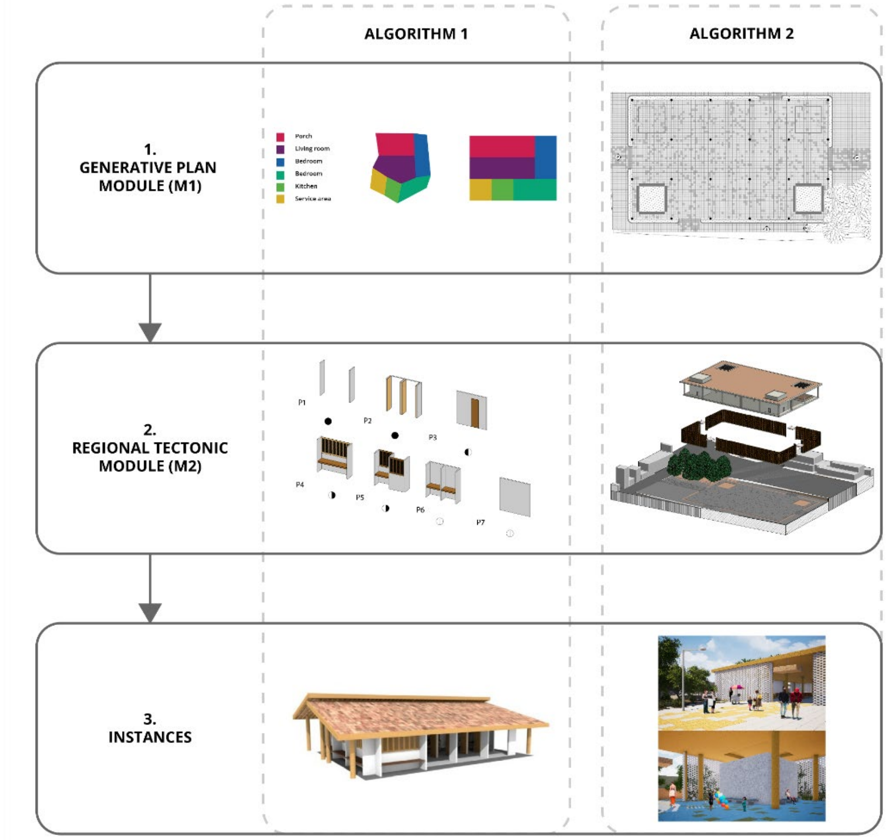

Figure 1. Workflow for the regional generative framework. Source: Authors, 2023.

According to Argan (2013), the typological generation process closely resembles the architect's design process, progressing from plan development to volumetric exploration and culminating in the consideration of texture, materiality, and tectonics. The proposed framework comprises three sequential modules: the plan generative module (M1), the regional tectonics module (M2), and the instance generation module.

4 Development

During the development stage, the workflow of the framework was structured, and two practical applications were subsequently implemented using regional typologies, employing generative algorithms.

The initial step involved designing the plan generative module (M1). To accomplish this, research was conducted on the studied typologies to gather data on building patterns, floor plan formation, and morphology. Based on the collected data, the generative computation and composition processes for the floor plan were defined for both cases. Numerous processes exist for creating floor plans, and each regional context possesses distinct characteristics that contribute to its environmental identity. Incorporating the regional floor plan composition process is a strategy employed within the regionalist approach. At this stage, it was crucial to analyze the architectural program elements, neighborhood relationships, proportions between spaces, and formal compositions found in samples of the typology. Consequently, the algorithms first determined the spatial divisions, topology, and dimensions of the floor plan before establishing the material surfaces that would delimit the spaces.

Subsequently, the regional tectonic generator module (M2) was designed to address the material delimitation between these spaces. Information regarding regional architecture within the context of the artifacts was gathered to construct a library of components. This library compiled existing materials specific to the regional context along with their syntactic constraints, defining the appropriate situations for deploying each library component. Each component consisted of a combination of constructive elements varying in opacity, permeability, accessibility, and functionality. Furthermore, each component within the library possessed defined functions, materiality, and morphology, ensuring proper placement and use. Components could include walls with windows, panels of perforated elements, spaced column plans, roof, floor plans, among others. The floor plan developed in the plan generative module, determined which items should be released for each boundary of each space, as the functional relationships of each neighborhood served as input for launching the tectonic divisions from the library.

Each boundary between rooms in the floor plan demanded a specific type of component, determined through a selection matrix, which acted as a filter for the disposition of library items, thus providing materiality to the floor plan. The user defined within the matrix the appropriate library component for each neighborhood situation between rooms. The computational implementation of M2 enabled automatic changes in the morphology and materiality of the divisions whenever there were modifications to the floor plan. The user-defined rules within the selection matrix facilitated the adaptation of M2 accordingly. It could accommodate changes in the floor plan shape or even alterations in the room's function, dynamically adjusting based on the predefined selection matrix.

The subsequent phase involved generating instances by varying the system inputs, thereby creating multiple individuals of the same typology. The computational chain established by the framework allowed the generated models to be connected to real-time rendering interfaces, enabling the rapid representation of multiple instances with photorealistic qualities.

4.1 Implementation

In the subsequent sections, two implementations of the framework will be discussed, outlining the development process of two distinct generative algorithms with a regionalist approach in architecture. The first case pertains to a vernacular housing design along the Brazilian coast, while the second case focuses on a popular market in the same coastal region. The computational implementation of these projects utilized Archicad as the BIM software, Grasshopper for Rhinoceros as the visual programming language (VPL) software, and Twinmotion as the rendering software.

4.2 Case 1: Vernacular house

The first case is a generative algorithm implementation of a vernacular housing typology on the Brazilian coast. The first step was to collect data from examples of the typology, to get the basis for the design of the generative process. The list of rooms of the typology and how they relate to each other, the description of neighborhoods and accesses was found in the data collected. The list of rooms seized consists of: balcony, living room, kitchen, bedrooms, bathrooms and service area, which are related as shown in the graph (Figure 2). It was noticed that the rooms of the houses were always contained in a rectangle perimeter of different proportions, where the balcony is the main entrance, and the living room is the connecting element between most environments, keeping the rooms more private, and service always connected with the kitchen.

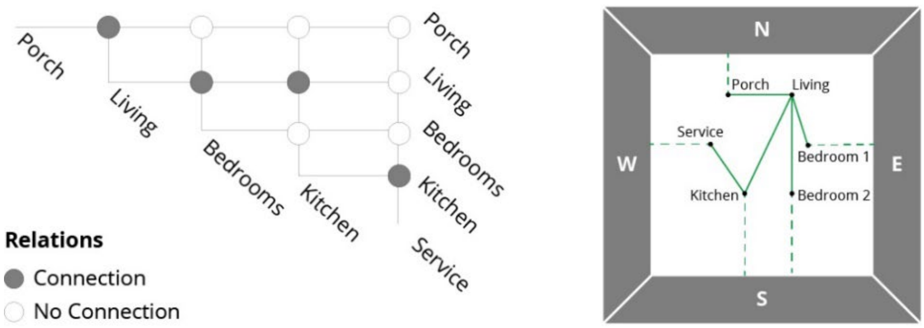

Figure 2. Relation matrix and graph, defining the topology of the floorplan of the house. Source: Authors, 2023.

The generative floor plan module (M1) was developed using a Grasshopper plugin called Space Syntax, created by Nourian (2017). In it, it was possible to automate the generation of floor plans, having as input the graph taken from the local typology, listing the rooms, their neighborhood relationships, and the relationships that the rooms eventually established geographic coordinates (important for sun and wind orientation in the regional context); and having as an output a rectangular floor plan that respects the conditions given in the inputs. The output data of this module is a floor plan composed by a list of polygons that delimit each room, and a list with the corresponding rooms names (Figure 3).

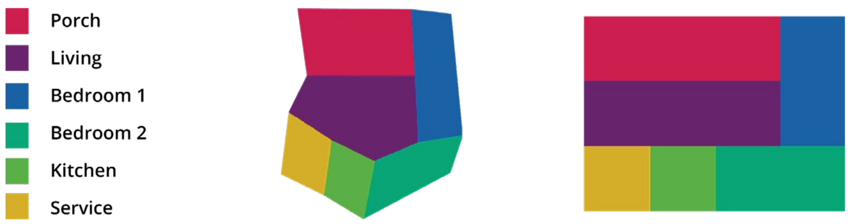

Figure 3. Automated plant image. Source: Authors, 2023.

For the implementation of the regional tectonics generative module (M2), two key steps were undertaken. Firstly, samples of the typology were researched to construct a component library. Secondly, the selected components were modeled in BIM/VPL, and the selection matrix was completed to indicate the appropriate choices for all possible neighborhood configurations. This ensured the automation of M2 (Figure 4).

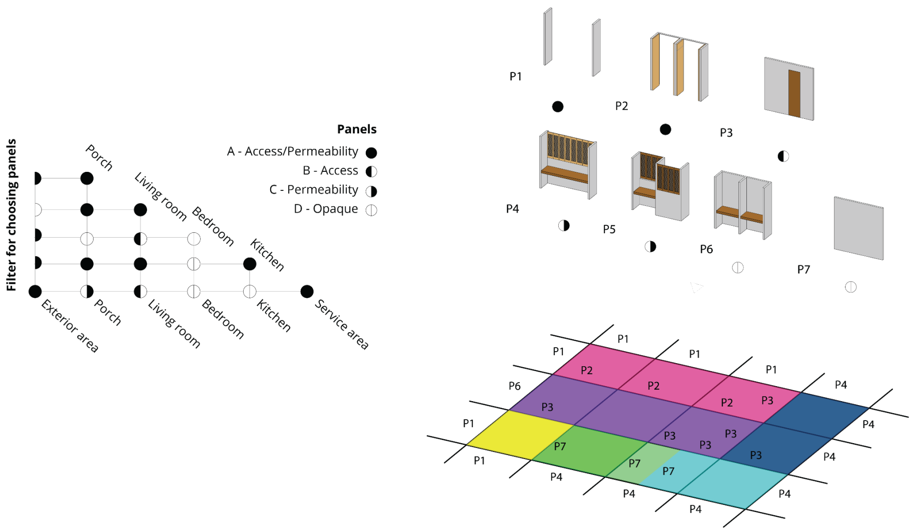

Figure 4. Matrix, component library and plan with components markers. Source: Authors, 2023.

The data from the typological research shows that the roof of the building would always be ceramic, arranged in a way that would cover the whole rectangle of the floor plan with overlaps, and with a number of planes normally of 1, 2 or 4 (Figure 5). The roof modeling process involved developing an automated algorithm that took the floor plan as input and generated the corresponding roof model.

Upon completing the implementation of all modules, multiple instances could be generated and rendered in real-time by varying the input parameters. The resulting artifacts demonstrated distinct characteristics while maintaining a direct typological relationship, showcasing the influence of the design process modeling. Regionalism played a significant role, as the implemented typology incorporated various elements from regional culture in a novel form and shape.

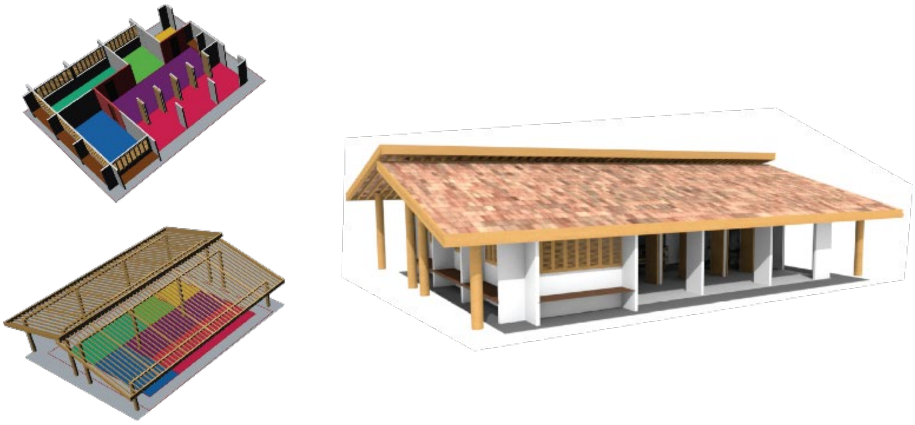

Figure 5. Tectonic generation with components taking place, roofing system, and generated instance. Source: Authors, 2023.

4.3 Case 2: popular market

The second implementation of the framework involved developing a generative algorithm for a popular market along the Brazilian coast. The initial step was to conduct typological research to identify the standard characteristics of the selected focus. In the Brazilian coastal region, a market typically comprises a large roofed space with fixed service points and access areas such as gates, stairs, and bathrooms. The sale points within the market are flexibly distributed, often utilizing ephemeral structures.

Therefore, the floor plan generative module (M1) was defined with the following considerations: the spatial distribution begins with determining a general shape for the perimeter, typically rectangular or circular, followed by placing the fixed service points and access areas. The remaining space is then allocated for the arrangement of vendors.

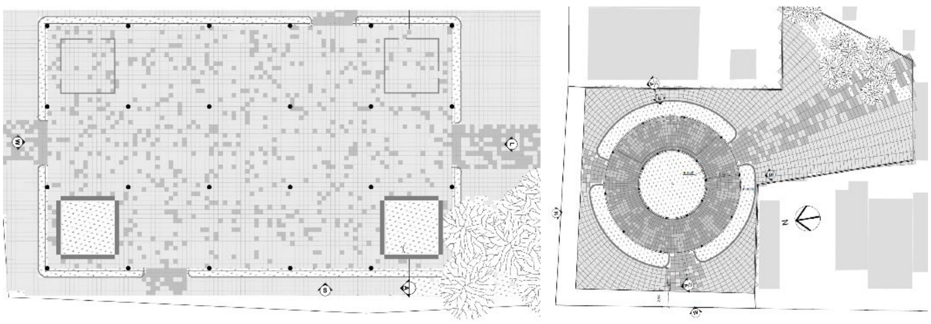

Figure 6. Floor plans of the rectangular and circular popular markets. Source: Authors, 2023.

Next, with M1 working, the typological research sought to identify the closing components used in the local context, and what their function was. The main element of the building was identified on the roof, always following the determination of the general perimeter. Its materiality could be varied, based on the material availability of the site of implementation. A flat reinforced concrete slab was adopted for the implementation to close the roof plane.

It was found that the lateral perimeter of the shape was normally closed by a permeable to light and wind component, such as a hollow element, but only accessible in sections with a door. It was also noticed that the fixed elements are usually closed by opaque components, isolating them in closed volumes, only open in their accesses. Therefore, the component library consisted of two types of enclosures: (1) demarcation of the building's perimeter with a hollow surface, with large portals in the accesses; (2) the perimeter of the fixed service elements was closed by opaque walls, having components with doors for access.

In this way, the ruleset of the regional tectonics generative module (M2) was computationally defined, as shown in figure 7. Any changes made to M1 are automatically made to M2, too, so the materiality of the building adapts to the change.

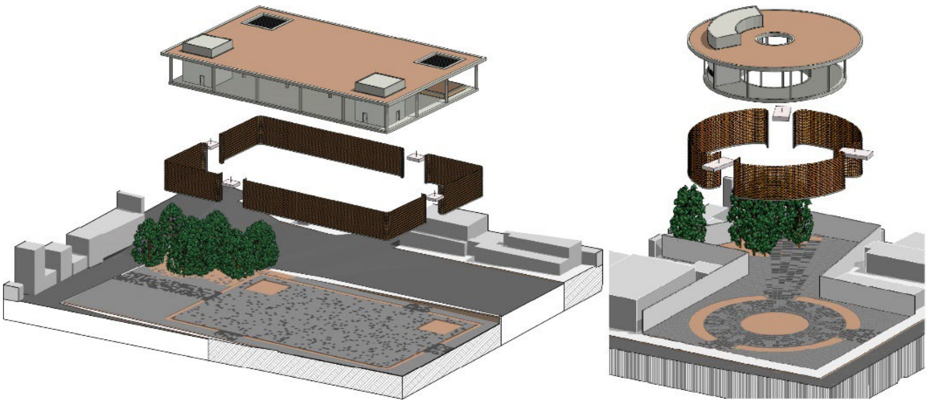

Figure 7. Tectonic selection and generation of the rectangular and circular popular markets. Source: Authors, 2023.

Next, with the generative algorithm implemented, two distinct instances were generated, which inserted different inputs in the code to generate two buildings with individual characteristics, rendered in real time. The products are recognizable as instances of the same typological frame.

5 Evaluation

In the verification and validation phases, the algorithms underwent extensive internal and external feedback to assess functionality (Black Box) and structure (White Box) as outlined by Dresh, Lacerda, and Antunes (2015).

Functionality testing involved generating multiple algorithm instances and scrutinizing their compliance with programmed criteria. Any deviations were rectified, leading to optimization of tool functionalities.

For system validation, or structural test, the tools were published as two undergraduate projects in the Architecture and Urbanism course at the Federal University of Ceará. The digital tool's relevance in addressing the core issue of a generative architecture system with regional emphasis was evaluated. Peer reviews and technical considerations highlighted the framework's potential for regional projects, adding a contemporary dimension to regionalist design discussions. Possibilities for applying the same process to different architectural typologies were also identified. Peers suggested creating interfaces for input management to streamline the system and enhance processing performance, currently reliant on VPI exclusively.

6 Conclusion and discussion

The structured framework in the work made possible a generative design process that kicks off from regional aspects, generating instances that meet the design problems in the two cases studied. It is possible to recognize the regionalist belonging of the products, due to the typological contextualization approach given in the creation of the algorithms. In this way, the proposed framework proves to be an innovative and adequate strategy for the implementation of computational technologies and automation in design processes, in contexts in which cultural aspects play a fundamental role.

The practical contribution of this work was to design a framework that can be adapted and reproduced for different regional typologies. From this work it is possible to create generative systems of regional typologies and propose innovative designs. The three-step generative process presented can be implemented in other typologies by computerizing a regional logic that regulates the floor plans and a tectonic vocabulary of panels that divide the zones of the spaces. Therefore, researchers and designers can systematize new regional generative systems describing spatial and tectonic logic.

Design systems that emerge from contextualized logics may be a more appropriate solution for the constructive and cultural reality of countries in the global south. Furthermore, for future projects, from the implementation of the generative design process, automated optimization models can be generated, in which the instances can be evaluated, varied, and selected based on performance criteria.

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