paranoá ORIGINAL ARTICLE
DESIGN AND PLANNING

2025
v.18, e57493

Landscape Information Modeling (LIM): a framework for responsive landscape design

Modelagem da Informação Aplicada à Paisagem (LIM): um quadro referencial para o projeto de paisagens responsivas

Modelado de Información del Paisaje (LIM): un marco para el diseño de paisajes responsivos

Tainah Frota Carvalho*
Universidade Federal do Ceará; Departamento de Arquitetura e Urbanismo e *Design*; Programa de Pós-Graduação em Arquitetura e Urbanismo e *Design*.
Fortaleza (CE), Brazil.
tainahcarvalhoarq@gmail.com

Newton Célio Becker de Moura
Universidade Federal do Ceará; Departamento de Arquitetura e Urbanismo e *Design*; Programa de Pós-Graduação em Arquitetura e Urbanismo e *Design*.
Fortaleza (CE), Brazil.

* Corresponding author.

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Authors contribution: Conception; Analysis; Data collection; Investigation; Methodology; Writing – original draft; Writing – review & editing: CARVALHO, T. F.; Conception; Methodology; Supervision; Writing – review & editing: MOURA, N. C. B.

Conflicts of interest: The authors certify that there is no conflict of interest.

Funding: None.

Ethics approval: The authors certify that there was no need for Ethics Committee approval.

A.I.: The authors certify that there was no use of artificial intelligence in the preparation of the work.

Submitted: 10 March 2025 | Accepted: 9 June 2025.

Abstract

Responsive landscape projects use information modeling to design dynamic urban environments, where the built environment continuously interacts with the natural landscape. This article explores the theoretical dimension of Landscape Information Modeling (LIM) through a systematic review of established references and recent scientific productions. The advancement of information technologies demands new paradigms in urban planning, particularly in landscape approaches. The adopted methodology encompasses a systematic review of articles published until 2024, focusing on the period from 2000 to 2024, identified 1,647 studies, from which 15 were selected for detailed analysis. The research discusses the potentialities and limitations of LIM in practice, highlighting its innovation compared to traditional methodologies. As a result, a framework for applying LIM in landscape design is proposed, demonstrating its contributions to urban planning. This study aims to consolidate the concept as a theoretical reference and contribute to the enhancement of contemporary landscape planning and design practices.

Keywords: Responsive landscapes; Landscape Information Modeling (LIM); Urban Planning; Informational technologies; Systematic review; Landscape Design.

Resumo

O avanço das tecnologias informacionais demanda novos paradigmas no planejamento urbano, especialmente na abordagem paisagística. Projetos de paisagens responsivas utilizam modelagem informacional para conceber ambientes urbanos dinâmicos, nos quais o meio construído interage continuamente com a paisagem natural. Este artigo explora a dimensão teórica da Modelagem da Informação Aplicada à Paisagem (*Landscape Information Modeling* – LIM) por meio de uma revisão sistemática de referenciais consolidados e produções científicas recentes. A metodologia fez uma seleção de artigos publicados até 2024, com ênfase no período de 2000 a 2024, dentro do qual identificou 1.647 estudos, dos quais 15 foram selecionados para análise detalhada. A pesquisa discute as potencialidades e limitações do LIM na prática, destacando sua inovação em comparação com metodologias tradicionais. Como principal resultado, propõe-se um quadro referencial para a aplicação do LIM no projeto da paisagem, evidenciando suas contribuições para o planejamento urbano. Este estudo busca consolidar o conceito como referência teórica e contribuir para o aprimoramento das práticas contemporâneas de planejamento e projeto da paisagem.

Palavras-Chave: Paisagens responsivas; Modelagem da Informação Aplicada à Paisagem; Planejamento Urbano; Tecnologias informacionais; Revisão sistemática; *Design* da Paisagem.

Resumen

Los proyectos de paisajes responsivas utilizan la modelización informacional para diseñar entornos urbanos dinámicos, donde el entorno construido interactúa continuamente con el paisaje natural. Este artículo explora la dimensión teórica de la Modelización de la Información Aplicada al Paisaje (*Landscape Information Modeling* – LIM) a través de una revisión sistemática de referencias consolidadas y producciones científicas recientes. El avance de las tecnologías informacionales exige nuevos paradigmas en la planificación urbana, especialmente en el enfoque paisajístico. La metodología direcciones una revisión sistemática de artículos publicados hasta 2024, con énfasis en el período 2000-2024, identificó 1.647 estudios, de los cuales 15 fueron seleccionados para un análisis detallado. La investigación discute las potencialidades y limitaciones del LIM en la práctica, destacando su innovación en comparación con metodologías tradicionales. Como principal resultado, se propone un marco para la aplicación del LIM en el diseño del paisaje, evidenciando sus contribuciones a la planificación urbana. Este estudio busca consolidar el concepto como referencia teórica y contribuir al mejoramiento de las prácticas contemporáneas de planificación y diseño del paisaje.

Palabras clave: Paisajes responsivas; Modelado de Información Aplicado al Paisaje; Planificación Urbana; Tecnologías informacionales; Revisión sistemática; Diseño de Paisajes.

1 Introduction

Models for visualization and simulation of scenarios and data analysis are not new to the field of landscape planning and design. In early years, they coincided with the dawn of the digital visualization era, and since then, they have contributed to advances in representation, evaluation, decision-making, and also to establishing new ethics which have been progressively used as a main base since the earliest approaches to ecology (Lange, 2011). Following McHarg's land-use suitability analysis methodology, the application of computer technology to landscape planning, the availability of SIG ("*Sistemas de Informação Geográfica*" or Geographic Information System), and the creation of new environmental legislation for the prevention and recovery of environmental impacts, many possibilities became available for landscape architects to assess and act on larger scales, connecting the environmental and design dimensions of landscape (Yang; Li, 2016).

However, the basic interface commonly used in SIGs lacks simple tools for projecting scenarios and simplifying the systematization of urban patterns, which is most evident in landscape planning, especially at detailed scales. SIG, which is often used in large-scale design phases and followed by traditional CAD programs for more precise detailing, faces the challenge of the static nature of city design, and it is incapable of reflecting automatic changes in inputs. This is particularly problematic for urban planning, considering the constant cities' dynamics and facing recurring events such as droughts and floods.

Meanwhile, in the field of Architecture and Engineering, Computer-Aided Design (CAD) emerged in the early 1960s as a graphical interface for building design, and offered creative freedom in the human-computer interaction, although limited to vector representation. In 1975, the proposal for Building Information Modeling (BIM) overcame this limitation for the launch of ArchiCAD in 1983. From BIM creation, a range of information that had remained hidden or lost in traditional design processes has become accessible (Eastman *et al.*, 2008; Pentillä, 2006). In 2012, Beirão proposed the concept of City Information Modeling (CIM), a hybrid model between SIG and CAD aimed at urban modeling, capable of integrating different territorial layers and generating scenarios more quickly and efficiently, connecting databases, CAD software and visual programming interfaces (Lima, 2017; Sousa, 2018).

Currently, responsive landscape projects (Cantrell; Holzman, 2015) use parametric modeling to create a non-static urban landscape, in which the urban environment interacts dynamically with the constantly changing of the natural landscape. The adoption of information technology-based systems represents a significant advance for professionals involved in the management and planning of contemporary cities (Moura *et al.*, 2018; Lima; Freitas, 2016). Modeling Information (MI) emerges as a promising field of research and practice, enabling complex simulations of proposed solutions and considering time, phasing, and entropy (Cantrell; Holzman, 2015).

New paradigms are needed in urban planning, especially those about the urban landscape. This article aims to explore the theoretical dimension of Landscape Information Modeling (LIM) through a narrative review of established references and recent scientific literature. This work expects to contribute to the advancement of urban planning by consolidating the concept of Landscape Information Modeling (LIM) as an innovative approach to responsive landscape design. In addition to proposing a framework for its application, the research highlights the potentials and limitations of LIM, providing a theoretical basis for future researches and the improvement of contemporary landscape practices.

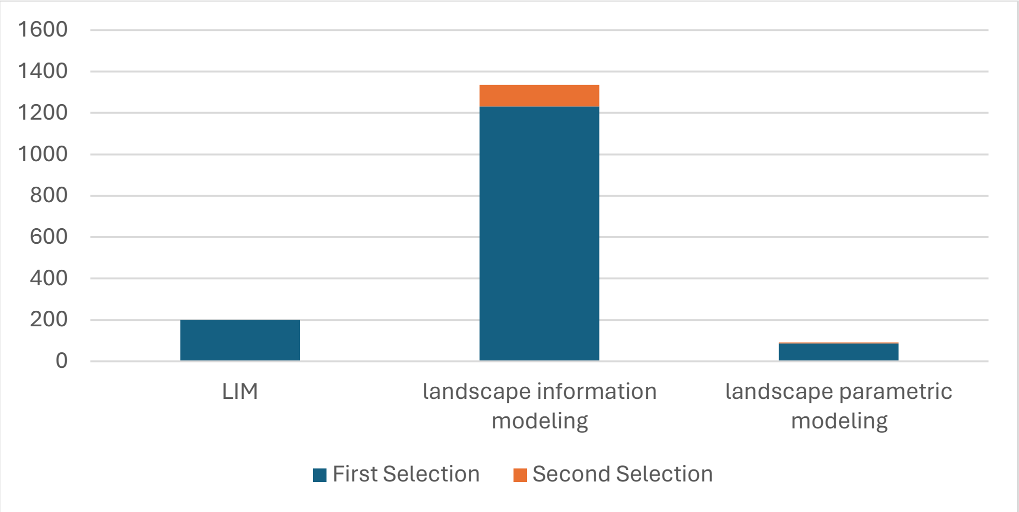
2 Methodology

The methodology adopted includes a non-linear literature review conducted with seven articles selected for their theoretical relevance and potential contribution, even if they fell outside the traditional systematic review criteria (see Table 1). In the second stage, two systematic searches were conducted on the Science Direct portal (with a timeframe between 2019 and 2024) and Capes Periódicos (with no time limit). The following criteria were applied:

a. Exclusively research articles;
b. Language in English or Portuguese;
c. Publications in peer-reviewed journals;
d. Exclusion of journals with unrelated topics such as mathematics and agriculture.

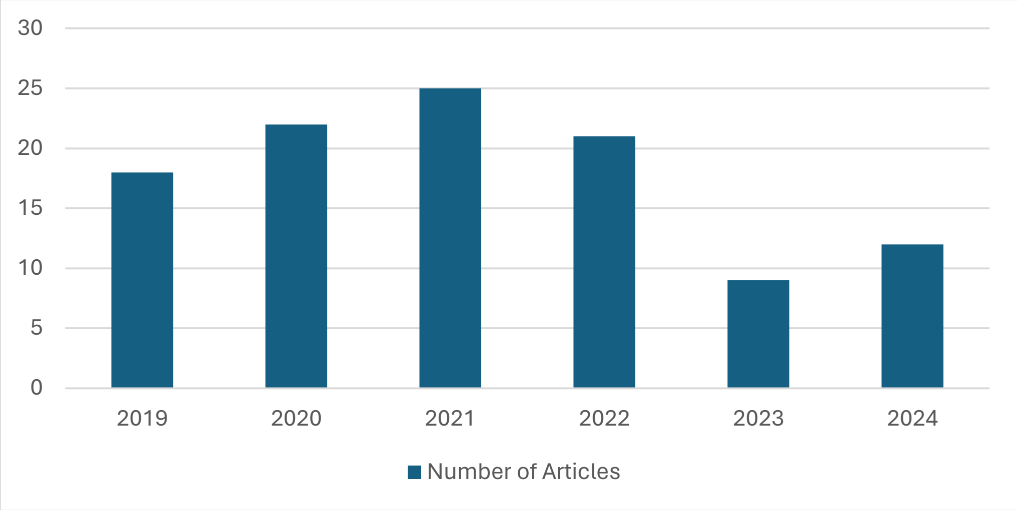
The keywords were: “LIM”, “Landscape Information Modeling”, “*Modelagem da Informação da Paisagem*”, “*Modelagem da Informação Aplicada à Paisagem*” and “Landscape Parametric Modeling”. In this search, initially, 1647 results were found (see Figures 1 to 4).

Figure 1: Selection of articles by keyword on the ResearchGate portal.



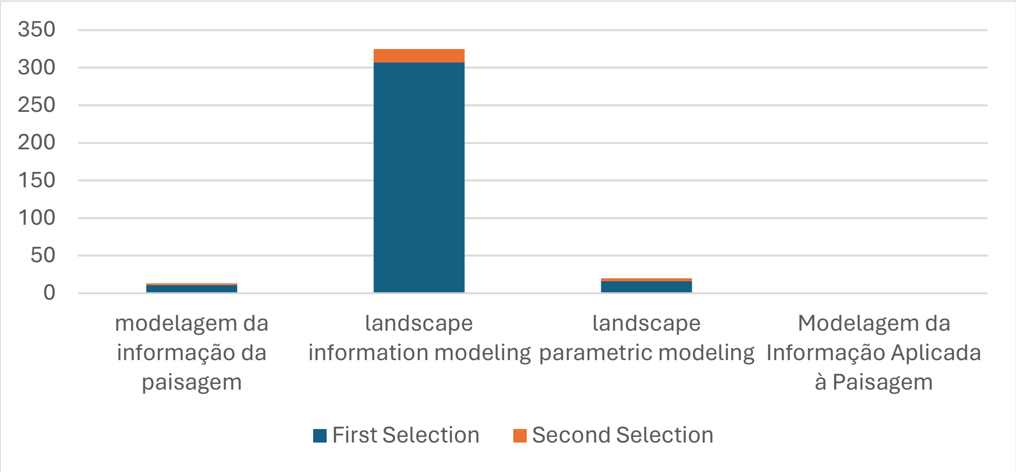
Source: Authors (2025).

Figure 2: Number of articles from the third selection per year selected on the ResearchGate portal.



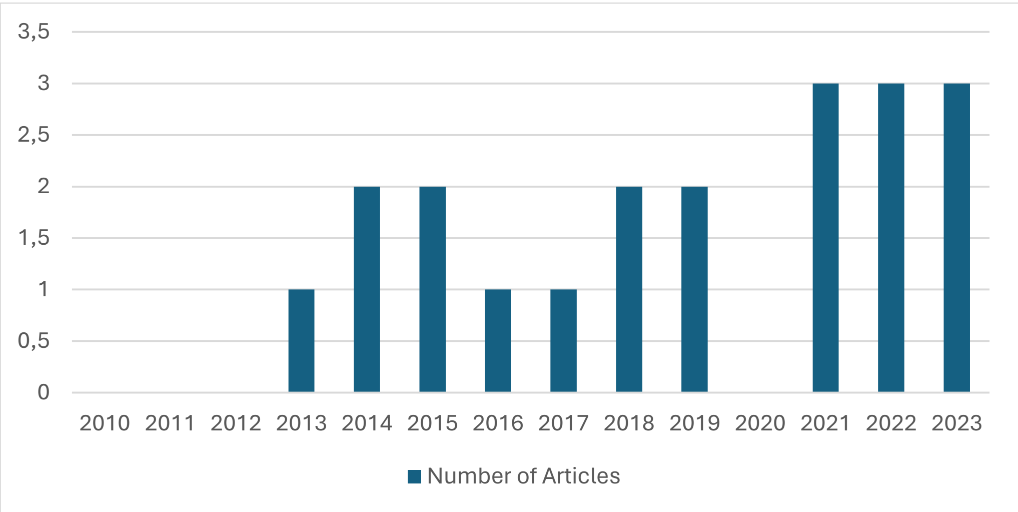
Source: Authors (2025).

Figure 3: Selection of articles by keyword on the Capes Periódicos portal.



Source: Authors (2025).

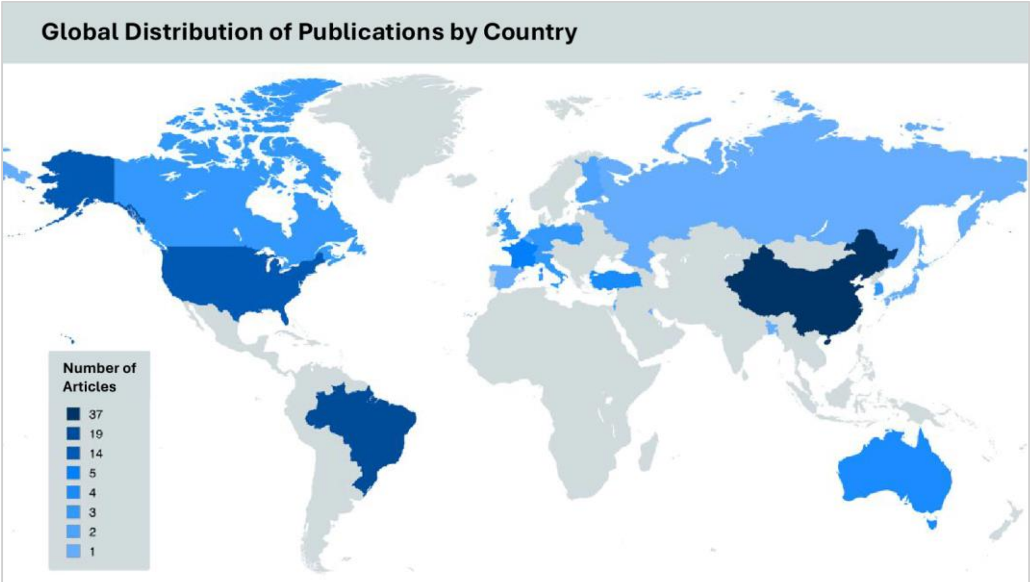
Figure 4: Number of articles from the third selection per year selected on the Capes Periódicos portal.



Source: Authors (2025).

After the initial survey of articles, a third step was taken that involved a subjective selection based on the reading of titles and abstracts. At this stage, articles that addressed or would be relevant to the topic of urban landscape information modeling were selected, because this is the specific focus of this work. The review collected 123 articles from various journals around the world (Figure 5). Ultimately, 15 articles considered relevant to this study were selected: the 7 initially selected in the non-linear review and another 8 from the screening of the 123 articles identified in the systematic stage (Table 1). Based on the analysis of these works, it was possible to structure a consolidated definition of the concept of Landscape Information Modeling (LIM), highlighting its main theoretical foundations, applicability, and limitations.

Figure 5: Global distribution of publications by country of affiliation of the main author (of the 123 selected articles).



Source: Authors using the MapChart program (2025).

Table 1: Methodology and results of articles considered relevant for understanding of LIM.

Year	Author(s)	Methodology	Results about LIM
2019	Baeza *et al*.	Urban vulnerability modeling framework based on institutional decisions.	It emphasizes the exploration of uncertainties and mediation between stakeholders in urban settings.
2019	Hou *et al*.	Simulates stormwater processes with SWMM and SIG, using a split-window model.	Proposes 4D integration between SIG and SWMM for detailed space-time representation.
2020	Ma *et al*.	Virtual reality tool applied to urban infrastructure dynamics.	Facilitates spatial visualization and decision-making for infrastructure management.
2020	Rasoulkhani *et al*.	Simulates interaction between risk, infrastructure and decision-making with a static computational model.	Integrates human and environmental elements into urban resilience scenarios.
2020	Wanghe *et al*.	Collaborative digital platform with 3D simulation of designed spaces.	Provides an integrated framework for viewing and evaluating landscape projects.
2021	Sandre; Pellegrino.	Open source toolbox in ArcSIG based on the gravity model.	Facilitates the mapping of urban green corridors with customizable parameters.
2021	Borkowski; Wyszomirski.	Expansion of IFC models for integration with SIG data.	Proposes joint use of BIM and SIG in landscape modeling.
2021	Gobeawan *et al*.	Workflow between BIM and Grasshopper for incorporating vegetation.	Promotes interoperability and creates parameterized vegetation libraries.
2021	Guo *et al*.	Study of parametric design in landscape architecture based on big data.	Enhances integration with SIG for urban analysis at multiple scales.
2021	Hadar *et al*.	Integrates ecological empirical data and imagery with 3D modeling.	Translates scientific knowledge into models applicable to management and planning.
2021	Na.	Comparative analysis of parametric and traditional workflows.	Suggests BIM libraries for natural elements for greater accuracy.
2022	Li *et al*.	Evaluate urban views with CIM and machine learning.	Generates automated visual indices to qualify built environments.
2022	Hughes *et al*.	4D visualization of landscape evolution over millennia.	Highlights how historical data influence environmental perception and management.
2023	Chen; Zheng; Yan.	Parametric modeling of historic districts with genetic algorithms.	Balances urban heritage and contemporary demands with spatial precision.
2024	Sharifi *et al*.	Review on AI in digital twins and applications in urban drainage.	Optimizes real-time decisions and planning with AI support.

Source: Authors (2025).

3 Results

LIM has evolved since the 1970s, driven by the need to connect data from different sources, such as topographic surveys, aerial photographs, and archived information (Earle; Brownlea; Rose, 1979). Initially, the lack of adequate data on exogenous variables compromised the effectiveness of simulation models for land use management. With technological advances, new approaches have emerged to improve digital topographic representation and expand the possibilities of landscape modeling, mainly the collaboration between computer scientists and urban planning experts to develop more effective algorithmic methods (Ervin, 2001).

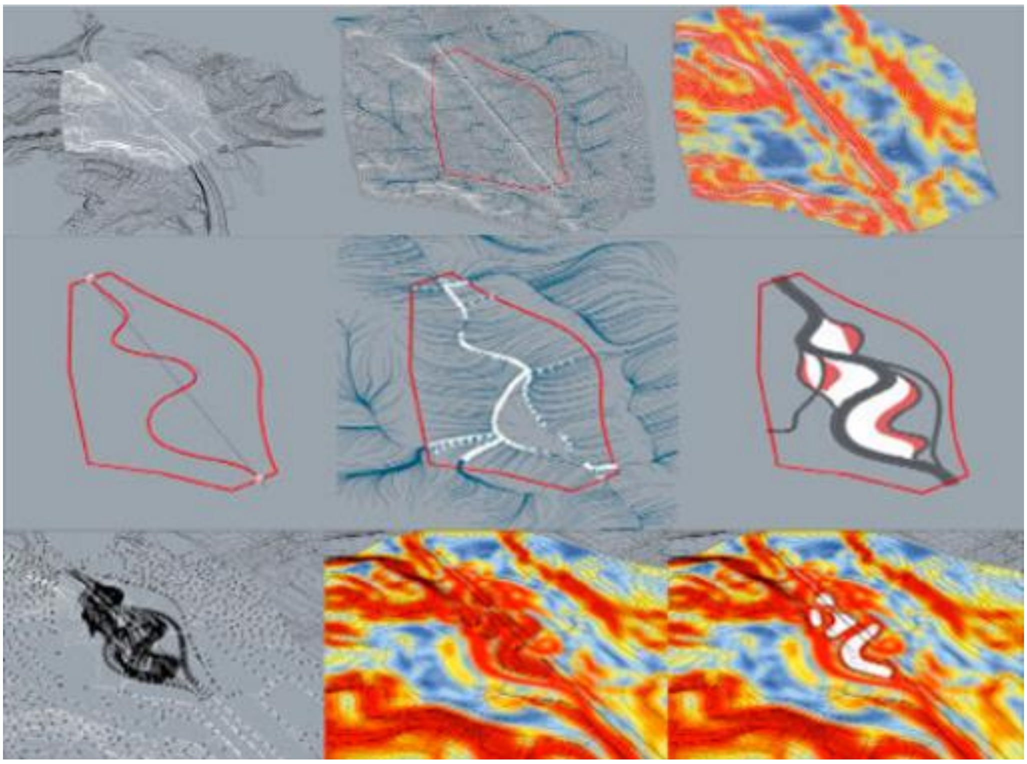
The integration of 3D visualizations and Geographic Information Systems (SIG) was a major milestone in landscape modeling, enabling more realistic and accessible representations for experts and the general public (Lange, 2001). These models were later combined with simulations of floods, climate change, and economic factors, and they became essential tools for sustainable urban planning (Lange, 2011). Furthermore, parametric landscape urbanism has established itself as an innovative approach, using evolutionary algorithms to optimize master plans based on criteria such as sustainability and population density (Yazici, 2016). Figure 6 shows a graph of the use of keywords in the articles studied, including: geoprocessing, landscape model, simulation, and geographic information system.

Figure 6: The study generated 548 keywords (from the 123 selected articles). Only those mentioned twice or more are being displayed in the image. The most frequently used keywords are represented in larger font.

Source: Authors using the Wordclouds program (2025).

Landscape modeling has also begun to incorporate ecological and conservation elements, allowing for a better understanding of the interactions between biodiversity and spatial changes over time (Scheller, 2017). Recent studies highlight the use of parametric modeling to optimize urban infrastructure, such as retention basins (Figure 7). They combine hydraulic engineering and landscape architecture to create more efficient and integrated solutions (Moura *et al.*, 2018). Other models explore urban vulnerability resulting from sociopolitical decisions. They advocate the kind of approaches that enable a broad analysis of future scenarios and foster discussions among stakeholders (Baeza *et al.*, 2019).

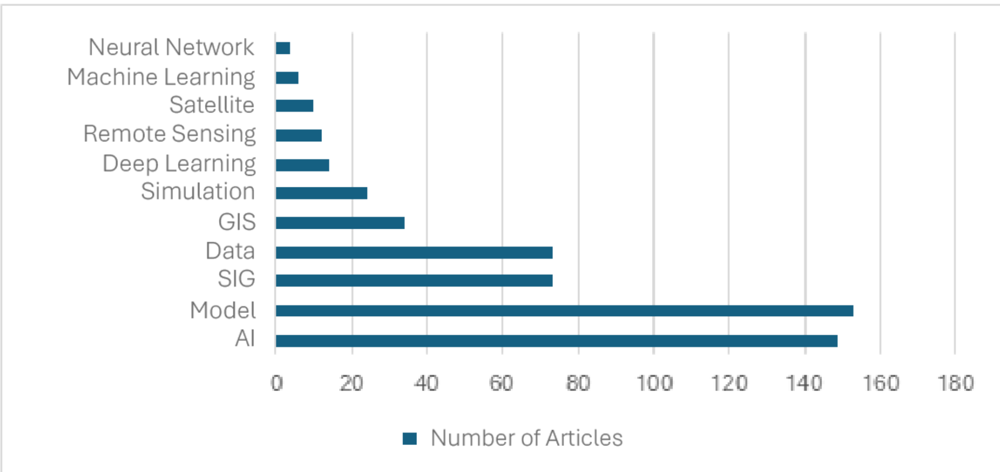
Figure 7: Example of a parametric modeling process for a naturalized river and retention ponds in the city of São Paulo.



Source: Moura *et al.* (2018).

The incorporation of new technologies, such as virtual reality and artificial intelligence (Figure 8), has expanded the possibilities for visualizing and analyzing the dynamics of urban infrastructure (Ma *et al.*, 2020). Digital tools, such as collaborative platforms and integrated frameworks, have been developed to reconcile built elements and natural processes and facilitate decision-making in landscape projects (Sandre; Pellegrino, 2021). Furthermore, the advancement of interoperability between SIG and BIM systems has enabled greater precision in modeling information applied to the landscape. They promote the integration of ecological, urban, and architectural data in a single digital environment (Borkowski; Wyszomirski, 2021).

Figure 8: The frequency of use of technologies in the 123 selected articles.



Source: Authors (2025).

The future of landscape modeling is moving toward and increases sophisticated use of spatial data when it combines SIG layers, satellite imagery, and artificial intelligence to analyze ecological and urban patterns (Guo *et al.*, 2021). Methodologies are expected to become more dynamic and interactive, enabling accurate simulations (Figure 9) and the adaptation of planning strategies to climate change and social demands. With the evolution of technologies and the integration of different disciplines, information modeling applied to landscapes is beginning to establish itself as a promising tool for the development of more resilient and sustainable cities.

Figure 9: Example of digital twin creation for the city of Zurich.

Source: Sharifi *et al.* (2024).

Some relevant characteristics to Landscape Information Modeling were identified. First, a methodology that uses LIM tools:

a) It must work with different scales, based on a SIG approach, but also using 3D modeling at different scales;
b) It requires the use of updated data and, preferably, fed in real time to ensure a real and positive impact on projects;
c) It will be linked to intercommunication between different programs, this interaction being non-linear and particular to each case;
d) Parametric modeling and/or modeling using artificial intelligence are fundamental factors for understanding and, consequently, designing complex and constantly changing landscapes.

When it comes to integrating different landscape design scales, MI requires complementary modeling stages depending on the level of complexity that it is desired. MI programs have primarily focused on the building itself as an object. However, when it comes to landscape integration, at least two distinct levels of planning and modeling are required. These can be categorized as city/neighborhood scale and building scale, and they require an interface between parallel computational procedures and different programs. SIG is a typical application for larger scales, and BIM programs for object design (Jusuf *et al.*, 2017).

This complementary approach indicates that the demands of landscape planning and design are not yet adequately met by a single program or process when they are relative to the imperative multi-scale approach. Complementarity is essential when we are dealing with multiple scales and highly complex and multi-scalar landscapes from a modeling perspective (Lange, 2001). A two-level approach is the minimum requirement for applying MI to the landscape.

Thus, it's safe to assume that manually modeling the virtual environment, which is the traditional CAD approach, isn't the most appropriate for landscapes, and a SIG-based approach should be combined with a 3D-based approach for landscape objects. Furthermore, integration between landscape planning and design, or across different scales, requires a potentially non-linear interface between various programs and/or plugins.

Secondly, MI must be data-driven and utilize constantly updated information, when relevant. Current technologies, such as the use of annually updated satellite imagery, highlight the importance of leveraging these resources to propose more appropriate and efficient landscape designs. Furthermore, it is crucial using this data before, during, and after design creation, based on indicators customized for each situation. This is essential for developing more resilient projects that, as mentioned previously, require constant adaptation, including considering the exponential changes in the landscape resulting from climate change. Parameterization and artificial intelligence have the potential to become allies in intelligent and reactive landscape planning, as opposed to traditional models.

Thirdly, MI incorporates dynamic processes into design and allows the visualization of multiple possibilities before arriving at the ideal result. This dynamic arises from parametric modeling, based on the principle that each model is built with entities whose attributes can be fixed or variable. Fixed attributes are controlled and correspond to shape, materials, performance, and costs (Eastman et al., 2008), while variable attributes or parameters are the rules that define the geometric behavior (lines, surfaces, volumes, and their associations) and the non-geometric behavior (materials, quantities, performance, etc.) of the fixed attributes, allowing objects to automatically adjust according to changes in control and context. Digital landscape models, whether for visual inference, simulation, and understanding of behavior or other invisible aspects of the landscape, require abstractions and simplifications (Ervin, 2001).

Finally, considering the ever-changing nature of the landscape, parametric modeling and artificial intelligence are promising tools for incorporating dynamism into landscape planning and design processes, and also for achieving dynamic models in which the interactions between landscape, society, and the environment can be more accurately represented through functions and algorithms.

Such characteristics are not original, as each was inferred from previous research and practices. However, bringing them together as a set of integrated strategies is relevant for applying LIM in a case study and for reflections aimed at replicating them in other situations. To achieve one of the objectives of this work, those characteristics aim to reinforce that computing offers more opportunities and new ways of thinking to expand design tools, workflows, and methodologies for landscape planning and design.

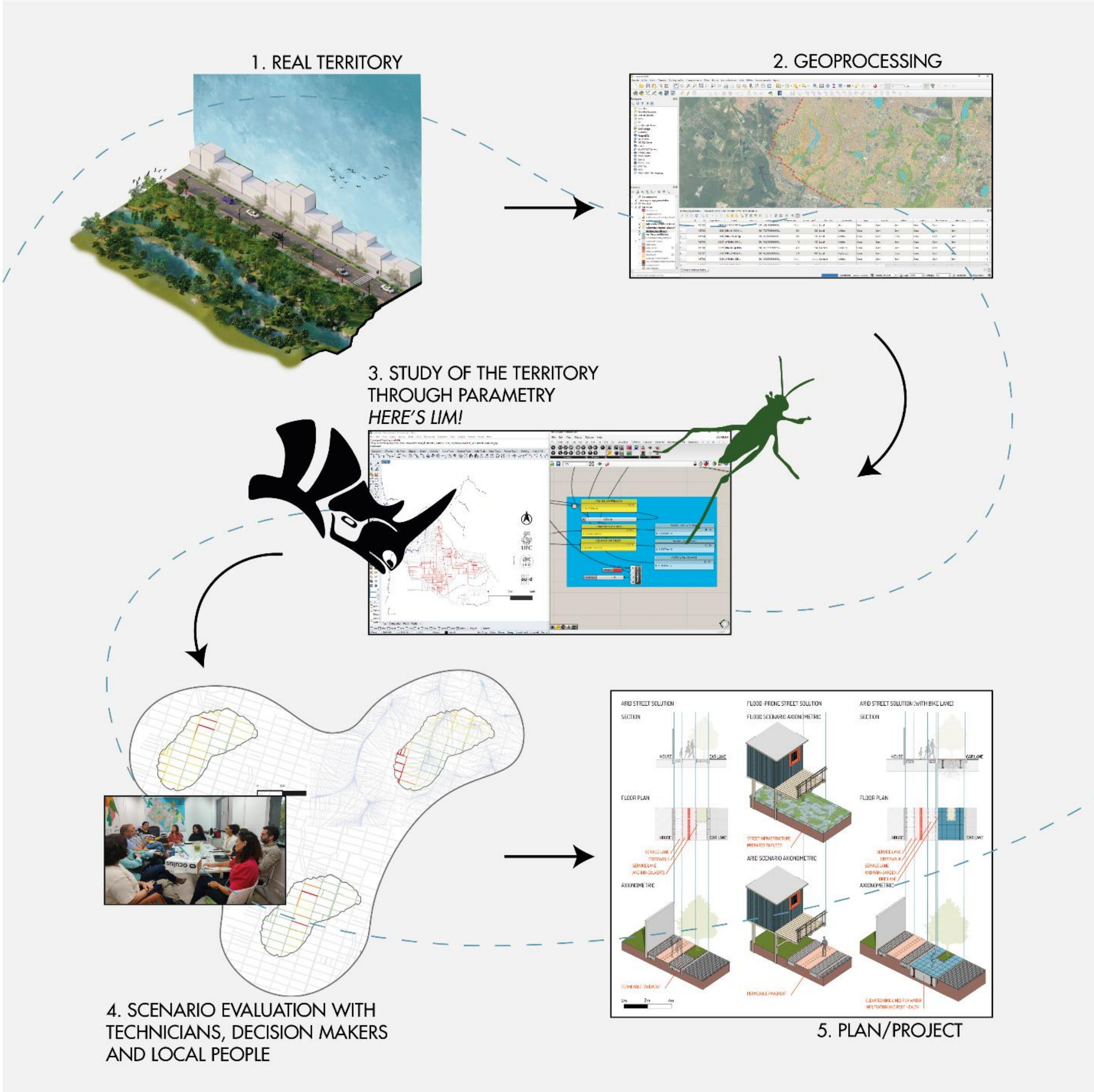
According to Cantrell, Martin e Ellis (2017), solutions to future landscape demands and challenges must move away from current professions amazed with the representation of design and aesthetics. Instead of that they must take advantage of the potential and collaborative nature of design with a connection between virtual and physical realities. LIM, therefore, is an opportunity for visualization, but not limited to it, as it incorporates information into modeling that relates to natural processes and implies a comprehensive approach aimed at achieving balance between the structures of the artificial and natural systems that sustain us.

It is worth noting that, in this research, LIM is understood as a tool with great potential for improving the effectiveness of landscape projects and landscape studies. However, it is important to understand the difference between the concept of a tool and the one of a design methodology. A design methodology consists of a structured set of principles, guidelines, and steps that guides the development of a proposal. It involves procedural reasoning, grounded in theories, conceptual approaches, and strategies applicable to the specific project context (Lawson, 2005).

On the other hand, a tool, such as LIM, refers to a way or resource used within a methodology to facilitate certain stages of the design process (Lawson, 2005). LIM offers advanced computational support for modeling and managing spatial and environmental information. However, it does not define by itself the decision paths and criteria within the project, but rather provides data and resources that can be used in many methodologies. Thus, although LIM has great potential for application in landscape projects, its effectiveness depends on integration with an appropriate methodology.

Figure 10 illustrates this complementary relationship between LIM and methodological design approaches. From this perspective, landscape design is understood as a procedural sequence consisting of five main stages: (1) data collection from the actual territory, including physical, social, and environmental aspects; (2) geoprocessing and spatial analysis of this data; (3) application of LIM tools for structuring and integrating information; (4) creation and discussion of design scenarios based on the simulation of alternatives; and (5) definition of the final intervention proposal. This model aims to integrate different design methodologies, reinforcing the importance of the participation of technicians, decision-makers, and local people in the processes of formulating and choosing solutions, recognizing the collaborative and situated nature of landscape planning.

Figure 10: Illustration of the planning and decision-making process using LIM. From top to bottom: territory, georeferenced data, algorithm, possible scenarios, chosen scenario.



Source: Authors (2025).

4 Final remarks

This article presents the LIM based on a systematic literature review, which resulted in Table 1, bringing together the most relevant references on the topic and supporting the definition of the four LIM characteristics identified in the results. Based on this analysis, the LIM began to be framed as a tool — in other words, a resource capable of modifying and improving traditional methodologies, but which does not constitute a design methodology in itself. This distinction is illustrated in Picture 7, which presents a standard sequence of actions for a simplified landscape design methodology, showing LIM as a tool within this process.

In this context, LIM emerges as a promising approach to addressing urban challenges in landscape design, contributing to the development of more responsive cities. As an intelligent tool, its ability to work with constantly updated data allows greater adaptability to contemporary urban dynamics, expanding its potential to promote more efficient and resilient solutions.

The objective of this research was to explore the theoretical dimension of Landscape Information Modeling through a narrative review of established frameworks and recent scientific literature. This theoretical approach, supported by academic references, demonstrates that Landscape Information Modeling has significant potential to make cities more responsive and prepared to deal with urban changes and challenges.

Finally, considering the evolution of technologies and urban demands, this research can expand and specialize when new researchers bring different perspectives and challenges. LIM has the potential to address a wide range of issues related to the urban landscape, especially with advances in machine learning, which may make it even more autonomous and efficient in the future.

Acknowledgments

We would like to thank the Federal University of Ceará (UFC), especially the Graduate Program in Architecture, Urbanism, and Design (PPGAU+D), for providing the academic environment and resources necessary for the development of this research. We express our gratitude to the professors and researchers associated with Line 3 – Information Modeling and Design, whose theoretical and methodological work was fundamental to the construction of the conceptual and operational bases of this study.

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