Evaluating Urban Vitality through Place Quality in Knowledge Districts Using City Information Modeling (CIM)

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In the global contemporary economy, innovation-oriented cities increasingly rely on attracting and retaining intellectual capital — the so-called creative class — who choose where to live and work based on place quality and lifestyle. Urban vitality, by fostering encounters and exchanges among people, is essential for the success of knowledge ecosystems. This article is part of a broader project aimed at developing an analytical tool to quantify objective and subjective place quality indicators related to urban vitality in knowledge districts. In this stage, a parametric model is proposed to serve as the foundation for integrating the Visit Potential Model (VPM), which estimates pedestrian flows in public spaces through a graph-based structure. The VPM is used as a methodological framework, adapting its application to knowledge district contexts to simulate urban vitality scenarios at early design stages. The contribution lies in proposing a model capable of incorporating spatial and functional attributes of the built environment, enabling the assignment and calibration of weights on the graph edges according to their influence on walking impedance. Thus, this work establishes the foundations for a broader modeling approach. In later stages, pedestrian flow simulation and qualitative place attributes will be integrated into the model, which will be calibrated with empirical data.

Keywords: *Knowledge-based Urban Development, Urban Vitality, Place Quality, City Information Modeling (CIM), Parametric Modeling.*

INTRODUCTION

In the global contemporary economy, innovation-oriented cities have undergone significant transformation, shifting from mass industrial production to knowledge-based economies, establishing a new nexus between innovation and urban development through the Knowledge-Based Urban Development (KBUD) paradigm. KBUD emerged as a strategic approach for cities aiming for economic prosperity in the 21st century. This approach positions knowledge as the driving force of economic prosperity, social equity, environmental sustainability, and good governance (Yigitcanlar, 2008; Yigitcanlar and Inkinen, 2019). Spatially, KBUD manifests at multiple urban scales, with knowledge districts being the focus of this study.

These contemporary districts evolved from first- and second-generation science and technology parks — that is, isolated suburban campuses focused on research and development, primarily involving universities and industries —

to third- and fourth-generation districts, located in central urban areas or their peripheries, respectively. While third-generation districts have increasingly incorporated governance roles for government and society, fourth-generation districts, due to their location, must also incorporate environmental aspects. Thus, these third- and fourth-generation districts are implemented through urban regeneration processes or development in greenfield areas. They integrate into the urban fabric as neighborhoods shaped around knowledge-based activities, blurring traditional boundaries between work, learning, and living spaces, and creating environments where innovation flourishes through serendipitous encounters among highly qualified knowledge workers (Annerstedt, 2006; Gyurkovics and Lukovics, 2014; Noronha, Silva and Celani, 2023).

Urban vitality, therefore, becomes a central element in creating these ecosystems, where proximity and population density facilitate the exchange of innovative ideas and creative collaboration. Their success is intrinsically linked to their capacity to attract and retain intellectual capital represented by the creative class. Unlike traditional industrial workers tied to fixed production sites, knowledge professionals are highly mobile and choose their places of residence based on lifestyle preferences, urban quality, and service diversity (Florida, 2013; Yigitcanlar, Baum and Horton, 2007).

In this context, place quality emerges as a strategic asset in the global competition for talent and knowledge-intensive companies (Esmaeilpoorarabi et al., 2018). The circular relationship between urban vitality, talent attraction, and economic development highlights the importance of understanding and measuring the qualitative attributes of these territories.

Despite the recognition of these factors, there is still a methodological gap in the objective measurement of urban vitality indicators and place quality attributes, especially when applied to knowledge districts under planning. Most studies on urban vitality focus on consolidated urban areas, without advancing the development of parametric tools applicable to simulating future scenarios or integrating them with spatial simulation models, particularly in the context of knowledge districts (Jiang et al., 2023; Eloah, Noronha and Celani, 2024).

Some studies have proposed conceptual and operational frameworks that explore place quality attributes in these territories (Yigitcanlar, Pancholi and Esmaeilpoorrarabi, 2024; Adu-McVie et al., 2022). However, although they provide important reference structures, many of these models remain predominantly qualitative, descriptive, and with limited application in parametric design contexts.

The Visit Potential Model (VPM), proposed by Herthogs et al. (2018), represents an advance in the field by offering an integrated model to assess public space characteristics and predict visitation potential. It proposes a universal law of visit frequencies associated with a gravitational model to measure accessibility. In the model, the public space network is represented as a graph, estimating pedestrian flows based on interactions between population objects, attraction objects, and transport nodes. Although the VPM was not originally designed for knowledge districts, it considers the possibility of incorporating public space quality attributes as weights on graph edges, thereby reducing movement impedance and increasing visit potential.

Based on this logic, the VPM is adopted as a methodological framework, adapting its application to the context of knowledge districts without altering its original structure. Therefore, this study proposes the development of a generic parametric urban model, incorporating urban vitality indicators selected according to common place quality attributes found in knowledge districts. The model allows simulation of urban morphology scenarios, such as block typologies, land use, density, sidewalk widths, and the presence of parks and green spaces, among others. Additionally, in future stages, it will integrate with the VPM, enabling the calibration of impedance weights based on spatial and functional place attributes. As an empirical reference for the initial parametrization, spatial strategies implemented in the Moulon district of the

Etablissement Public d'Aménagement Paris-Saclay (EPAPS), a recently implemented knowledge district in France, were adopted. The future validation of the model through multiple case studies and its calibration with empirical data from various case studies are also discussed. The goal is to quantify and compare qualitative information and subjective characteristics of urban space.

METHODOLOGY

This study is based on the Constructive Research Approach (Lukka, 2003), as part of an ongoing project aimed at developing an analytical tool capable of quantifying objective and subjective place quality indicators associated with urban vitality in knowledge districts. The City Information Modeling (CIM) approach (Gil, 2020) is adopted, using algorithmic-parametric tools to simulate urban vitality scenarios in knowledge districts still under planning.

The initial morphological and functional structure of the parametric model is based on the urban strategies implemented in the Moulon district, Paris-Saclay (EPAPS), used as an empirical reference for computational parametrization (germe&JAM, 2017). The methodological development was structured into three main stages: cross-referencing urban vitality and place quality indicators in knowledge districts (Eloah, Noronha and Celani, 2024); identification of the morphological characteristics of Moulon (germe&JAM, 2017); and initial computational parametrization of the urban model, including the selected variables.

Framework Development

The construction of the indicator framework combined two stages. The first corresponds to the systematic literature review previously conducted (Eloah, Noronha and Celani, 2024), which reviewed the main indicators applied in assessing urban vitality, with emphasis on the objective measurement of built environment attributes. This review revealed the predominance of the 5D framework (Ewing and Cervero, 2010): density, diversity, design, destination accessibility, and distance to public transit, often operationalized using Big Data sources and spatial analysis techniques such as Space Syntax.

In the second stage, four frameworks specifically addressing place quality and urban morphology in knowledge districts were analyzed. Yigitcanlar, Pancholi and Esmaeilpoorrarabi, (2024) propose five qualitative dimensions organized into 17 indicators that encompass both tangible and intangible aspects of urban experience. Adu-McVie et al. (2022) present a multidimensional framework structured into four dimensions comprising 16 indicators and 48 measures, among which seven are physical-spatial and directly applicable to parametrization. Finally, Kim (2020), analyzing Canadian urban innovation districts through the lens of urban morphology (British School), organizes the evaluation into three dimensions operationalized through 11 measurable indicators, eight of which directly address built environment attributes.

Despite the distinct approaches, these studies, although essential for understanding the specificities of these territories, did not directly provide the metrics and measurement methods required for parametric modeling. On the other hand, a strong convergence was observed between the indicators proposed in these studies and those identified in the general literature for assessing urban vitality in consolidated urban contexts.

This cross-referencing resulted in the identification of 33 indicators related to place quality in knowledge districts, which can be parametrized and applied in the simulation of prospective urban scenarios. Based on this integrated framework, the indicators were organized into five operational categories: Urban Amenities (12 variables), Green and Blue Infrastructure (4 variables), Urban Morphology (11 indicators), Transportation (3 indicators), and Land Use (3 indicators). Each indicator was also classified according to the 5D framework, allowing multiple spatial measurement approaches and their future integration into the geometric-parametric model. In this initial development stage, only the indicators already parametrized in the model are presented, covering morphology, green areas, transportation, and land use, as systematized in Table 1.

Moulon District (Paris-Saclay)

The Moulon District, located on the Saclay Plateau, is part of the urban development project led by EPAPS. Covering approximately 300 hectares and developed by the Germe & JAM office since 2017, the area represents a paradigmatic transformation of formerly rural land into a "university city," integrating research, education, and housing with surrounding green spaces and landscape structures. The project constitutes an emblematic example of KBUD, grounded in the transition from monofunctional campuses to university cities, promoting high urban vitality within a compact environment that combines controlled urban density with preserved natural and agricultural areas (Eloah, Galdina and Celani, 2025; germe&JAM, 2017).

The morphological analysis of the district enabled the identification of four structural systems that define its spatial and functional organization. The first is the system of functional structural axes, in which the project is organized through an orthogonal grid structured around three main axes. The scientific axis (Le Deck) functions as a linear public space connecting academic and research facilities, incorporating leisure areas, plazas, gardens, and multimodal infrastructure such as metro and bus corridors. The economic axis concentrates research centers and companies along the most connected streets and in proximity to the multimodal transportation system. In turn, the commercial-pedestrian axis crosses transversely through the others, organizing local commerce and daily services, and is surrounded by family residences, student housing, and public facilities (germe&JAM, 2017).

In addition, the morphological development of the district reflects a sequence described as the "Three Ages": the first stage characterized by free-standing blocks representing the modernist legacy; the second stage marked by closed courtyard block reflecting large-scale urbanism; and the third stage characterized by fragmented urban blocks forming a mixed and permeable urban fabric (germe&JAM, 2017) (Figure 1).

Figure 1
Distribution of functional axes and block typologies in the Moulon territory. Source: germe&JAM, 2017, adapted.

These stages materialize into seven specific morphological typologies: the “Îlot Bloc à Cour Jardin”, a block with an open courtyard garden; the “Îlot Bloc à Patio”, blocks with partially enclosed internal courtyards; the “Espace Ouvert Modulique”, open and modular urban blocks; the “Îlot Sur Socle”, mixed-use blocks with commercial ground floors and residential or office uses on upper floors; the “Îlot Lanière”, narrow and deep plots (linear typology); the “Îlot Ouvert”, open blocks with free transitions between built

Category	Indicator	5D's	Description	Metric Type	References
Greenery	Public Green Spaces	Density; Destination Accessibility	Parks; Squares and public gardens; Institutional open green areas	area/area; number of accessible destinations/radius; Access time; Area per inhabitant; Area/time of access	Adu-McVie et al. (2022) ; Esmaeilpoorarabi et al. (2018)
Greenery	Soil Permeability	Design	Ratio of permeable area over paved area	ratio	Adu-McVie et al. (2022)
Morphology	Sidewalks	Design	Sidewalk quality	Width per land use	Adu-McVie et al. (2022); Esmaeilpoorarabi et al. (2018)
Morphology	Street Connectivity	Design	Connected street network (streets and intersections)	Number of intersections per area	Kim (2020); Adu-McVie et al. (2022)
Morphology	Public-Private Space Ratio	Design	Ratio of public to private space	ratio	Esmaeilpoorarabi et al. (2018)
Morphology	Street Network Permeability	Destination Accessibility	Connected street network (streets and intersections)	Number of street segments / Number of nodes	Kim (2020); Adu-McVie et al. (2022)
Morphology	Block Size	Design; Destination Accessibility	Urban blocks	Average block area (m^2)	Kim (2020); Adu-McVie et al. (2022)
Morphology	Block Typology	Design	Block morphology (e.g., internal courtyard, open block)	Typological classification; Number of distinct typologies	Kim (2020)

Table 1
Place quality indicators of knowledge districts related to urban vitality selected for this stage of the parametric model. Source: Authors, 2025

Transporta-tion	Cycling Infrastructur e	Distance to Transit	Bike lanes and cycle tracks	Percentage of road network with cycle paths	Adu-McVie et al. (2022); Esmaeilpoorara bi et al. (2018)
Transporta-tion	Mobility and Transportati on Modes	Distance to Transit	Modes of travel (walking, cycling, public transport, car)	Number of distinct modes	Adu-McVie et al. (2022)
Transporta-tion	Public Transportati on	Distance to Transit	Train stations, metro, LRT, bus stops	Average distance; Quantity/area	Adu-McVie et al. (2022) ; Esmaeilpoorara bi et al. (2018)
Greenery	Soil Permeability	Design	Ratio of permeable area over paved area	ratio	Adu-McVie et al. (2022)
Land Use	Mixed Land Use	Diversity	Areas with multiple functions (residential, work, education, leisure)	Entropy index; Number of distinct uses	Adu-McVie et al. (2022); Esmaeilpoorara bi et al. (2018); Kim (2020)

volumes; and the “Îlot Pavillonnaire”, low-density blocks (germe&JAM, 2017).

In addition, the district features an Integrated Green Infrastructure System: public spaces act as both social and environmental catalysts, organized around Le Deck as the central activating axis. The green network is complemented by the Parc de Moulon, Carré des Sciences, Jardin Argenté, and the metro square, each playing a specific role in urban activation. Beyond serving as spaces for social interaction, this system provides environmental functions such as urban drainage, microclimate regulation, biodiversity corridors, and continuous connections between public and private spaces, consolidating a comprehensive system of environmental quality and urban vitality.

Parametric Model Development

The developed parametric urban model uses as its foundation the strategies identified in the Moulon district, implementing a completely flexible and adaptable structure for other urban contexts. Developed in Rhinoceros 3D/Grasshopper, the model enables the execution of multiple design alternatives through the manipulation of controllable urban parameters.

The system is structured in three hierarchical stages of land parceling: first, the division into superblocks that defines the main streets; second, the subdivision of superblocks that determines block size and local neighborhood streets; and third, the parceling of blocks into lots that defines the typology, morphology, and permeability of blocks.

The model is based on a logical hierarchy of eight sequential stages, in which each parametric decision automatically influences the subsequent ones. The process begins with the division of superblocks through a fully parametric street grid. For this model, a reference dimension of 804x804 meters was chosen, corresponding to four superblocks of 402x402 meters each. This radius is equivalent to approximately a 10-minute walk, based on the "15-minute city" concept widely used in contemporary urban analyses — although the system allows these dimensions to be adjusted according to the specific context.

The second stage consists of choosing functional axes, implementing three configurable axes: the economic axis intended for innovation activities and multimodal hub location; the scientific axis aimed at academic institutions and parks; and the pedestrian commercial axis dedicated to commerce and services. The multimodal hub is positioned parametrically along the scientific axis through a continuous parameter from 0.0 to 1.0, its location automatically repositions the commercial axis to maintain proximity, reflecting urban accessibility principles.

Superblock parceling constitutes the third stage, offering two distinct algorithms: System A uses regular orthogonal grid, while System B employs the EqualAreaGreedy (Decoding Spaces plugin) algorithm for greater morphological diversity, both controlled by block area varying between 0.6 to 2 hectares.

The street hierarchy is established in the fourth stage through three parametrizable levels: the Economic/Mobility Street with public transport corridor and bike lanes; the Neighborhood Street including bike lanes; and the Local Street prioritizing pedestrian scale, all with completely controllable widths for sidewalks, bike lanes, streets, and transport axis. Parallel to the street system, the model integrates parametric green spaces: the parametric linear park controlled by its total area, allowing adjustment of extension and configuration of linear green spaces; and parametric linear squares controlled by the width of the front setback of the chosen block.

The fifth stage implements spatial centrality analysis using two network analysis algorithms: Closeness Centrality, which measures global accessibility, and Betweenness Centrality, which identifies critical passage points along shortest paths. Both are executed via the Decoding Spaces plugin and operate with fully adjustable weights assigned to commercial, economic, and other streets (reference values: 2.0, 1.0, and 0.1, respectively), generating a classification into four spatial intensities: very high, high, moderate, and low (Figure 2).

Parceling typologies are applied in the sixth stage, incorporating four Moulon-based typologies parametrized for permeability, morphology, and public-private relationship. The seventh stage allows for the application of architectural morphological typologies with parameters that can control density, height, and built area. The process culminates in the eighth stage with manual designer control, allowing complete override of automatic analyses according to specific project criteria.

Parametric interdependency generates cascading effects: changes in functional axis weights instantly recalculate the closeness centrality analysis, redistributing spatial intensities and providing a new analytical basis for the designer to choose typologies according to their professional analysis. The Grasshopper interface allows real-time manipulation with instant visual feedback, enabling iterative exploration while maintaining systemic coherence.

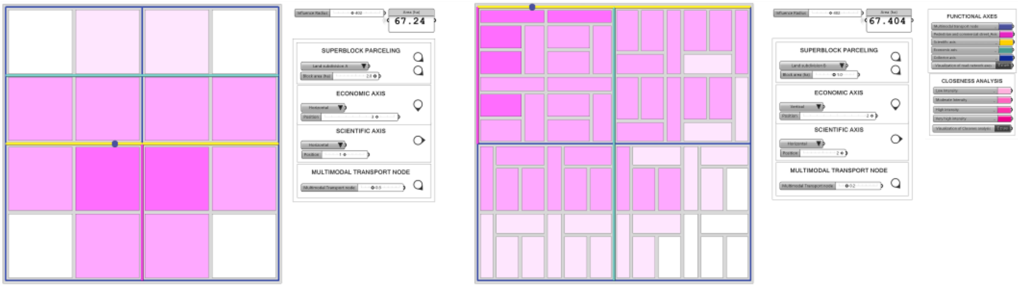

Figure 2
The figure presents parceling systems A (orthogonal grid) and B (varied typologies), functional axes, multimodal transport node, parametric interface, and centrality analysis represented by color tones. Source: Authors, 2025.

RESULTS AND DISCUSSION

This research developed a parametric model of place quality aimed at future integration with the Visit Potential Model (VPM). While the VPM calculates the visitation potential of public spaces based on attractors, population, and transportation infrastructure, it does not yet consider the quality of urban spaces along pedestrian routes. The proposed parametric model specifically addresses this gap, functioning as a layer for urban morphological qualification.

The structure offers full control over more than twenty parameters organized into six functional groups, derived from indicators identified through a systematic literature review on urban vitality. These parameters were cross-referenced with key place quality indicators for innovation districts, as detailed in Table 1. The system allows the application of four block typologies inspired by Moulon, each parametrized for different levels of permeability, morphology, and public-private relationships, ensuring broad adaptability to project demands.

From a technical perspective, the model integrates closeness and betweenness centrality analyses with the functional classification of urban axes, providing designers with a consistent quantitative basis for typological decisions. The automated analysis of spatial intensity enables the identification of areas with different levels of urban use, guiding the allocation of typologies according to their proximity to economic, commercial, or scientific axes (Figure 2).

The versatility of the system also demonstrates operational capacity to quantify specific urban indicators, such as street connectivity, green area density, land use diversity, cycling infrastructure, public transport accessibility, and morphological characteristics of blocks (Figure 3).

Figure 3
Parametric interface showing block typologies, street types, and adjustable urban parameters for real-time scenario modeling. Source: Authors, 2025.

The integration of the VPM with the model will occur through the parametrization of morphological characteristics, allowing the generation of different urban scenarios by changing input values, directly impacting urban vitality. In this way, its weighted qualitative calibration can be assigned to the edges of the VPM network, functioning as a modifier of pedestrian travel costs. Consequently, areas with higher place quality scores will have lower impedance in the graph, encouraging pedestrian flow. The full parametrization of the urban grid and typologies confirms the applicability of the model to different territorial contexts while maintaining methodological consistency. Finally, the system is configured as an open and extensible tool, capable of incorporating new sustainability indicators, adapting to local regulations, and expanding the typological database.

qualitative information and subjective characteristics quantifiable and comparable.

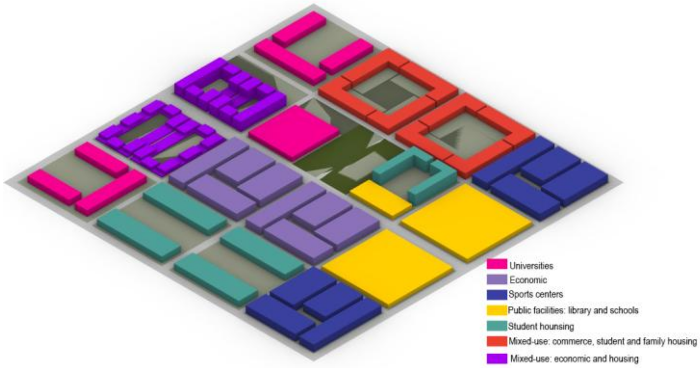

Figure 4
3D model of land use distribution showing functional zones, including universities, economic and mixed-use areas, student housing, public facilities, and sports centers. Source: Authors, 2025.

CONCLUSION

This contribution aims to offer a more comprehensive modeling approach that accounts for both quantitative flow prediction and qualitative place attributes in evaluating urban vitality in knowledge districts. Furthermore, it discusses the full integration with the VPM in future work and provides valuable insights into how place quality can be quantified and visualized using City Information Modeling.

Models are purposefully incomplete representations of reality, as its complexity would make it impossible to comprehend and analyze every aspect and internal relationships. Thus, this research focuses on the aspects of quality of place and their direct influence on urban vitality. This type of model can be used to represent an existing reality in order to assess it, or to generate ideal scenarios for maximum vitality. We can then try to convert these ideal scenarios into retrofitted or new spaces through urban planning and design. To this end, the model will have to be calibrated in future work using experimental data from multiple case studies. As a result, we hope to be able to increase the model's precision, making

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