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# Urban Form and Digitalization of Urban Design

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**Abstract:** In the mid-19th Century, John Snow utilized spatial data analysis to trace the source of a cholera outbreak in London. His methods established the fundamental theory of using urban morphological approaches to solve practical urban issues. Accompanied by rapid innovation, technological improvements, and increasing computational power, the digitalization of urban design has seen advances made in urban morphology studies. Given this digitalization of urban design, this paper examines the development and impacts of urban morphology studies in education, design practice, and research using the urban form elements analytical framework proposed by Kevin Lynch. It presents a variety of international case studies and discusses the importance of urban morphological studies and digitalization of urban design at a global scale.

**Keywords:** Urban Form; Spatial Analysis; Digitalization of Urban Design; Urban Intensity

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## Introduction

A key question in urban morphology studies and the digitalization of urban design is how we can build sustainable, healthy cities. In 1855, John Snow from Britain utilized spatial analysis to research the outbreak of communicable diseases (cholera) in London, thereby laying the foundations of modern urban morphology studies as an approach in solving urban issues. This rudimentary form of data processing is the simplest application of spatial clustering analysis, where he compared and traced the water sources of households with a high concentration of the disease. With urban degradation, redevelopment, and expansion brought about by the Industrial Revolution, migration, and the two World Wars, urban morphology theory saw an expansion in the scale of analysis, from monocentric cities to megalopolises at the regional level under Jean Gottmann, a French Geographer. This posed a greater challenge to Kevin Lynch's pioneering research on urban form. With improvements in computational speeds and capacities, as well as the increasing use of data, the application of urban morphology studies in the digitalization of urban design saw further advancements. These included Michael Batty et al's urban development models. Given the new economic, political, and social environments, urban morphology studies will need to be integrated with the digitalization of urban design, and be applied in urban design education, research, and practice. This will allow it to offer recommendations and assistance at the level of urban planning and design policies for public health and the sustainable development of smart cities.

### 1. Urban Morphology Studies and Spatial Analysis Methods

The understanding of urban morphology can be traced back to Aristotle's density and specification. Density has become one of the most important concepts in understanding and measuring urban and rural settlements. However, density as a standalone measure increasingly proved to be inadequate in capturing the complexities in urban studies research, which saw the evolution of Rent Theory that was based on the monocentric city, to the development of the polycentric city, particularly with the emergence of the "megalopolis" concept in the 1960s. Given the increasingly complex urban spatial structure and socio-economic systems, a singular measure alone (such as density) will not be able to satisfactorily provide an understanding of the city's physicality as a whole and in terms of its parts, nor will it be able to achieve the objective of offering guidance in urban design. Under these circumstances, a range of spatial analysis measures which have been widely adopted in other disciplines, including density, compactness, diversity, and permeability, have been integrated to measure the urban systems we inhabit. The resultant modern Urban Morphology Studies offers an integrative analysis of the urban environment by researching the formation and evolution of the urban spatial structure and combining spatial features such as the urban infrastructure, road network, public amenities, and residential districts <sup>[1,2]</sup>. In addition, urban morphological also covers issues related to the urban environment, such as urban functions, social relations, as well as economic, cultural, and technological progress.

Using the example of London and its reconstruction after the great fire of 1666 to illustrate the impacts of land ownership on the new urban form of the city, Shlomo Angel emphasized the historic legacies of urban form on the future of urban development <sup>[3]</sup>. Wang Jianguo sought to understand the planning and organization of urban form using the urban grid. He argued for a bottom-up theory of urban inception that adheres to the conditions of nature <sup>[4]</sup>. In his book, *The Nature of Order*, Christopher Alexander called for a sustainable model of urban form and development by suggesting that life is the starting point of urban development and transformation; he stressed the importance of distinguishing between preserving transformation and destroying transformation. Yang Junyan incorporated an understanding of urban form into the urban design process, and his research focused on the emergence of digital spatial analysis

techniques and its role in shaping urban development at the policy-making level <sup>[5]</sup>, while Xu Gang applied the study of urban morphology in practice at a topographically complex site in the mountains where he stressed the hyperspatiality of urban form <sup>[6]</sup>.

## **2. Research & Developments in Urban Morphology Studies**

To better understand a city's past, present, and future using urban morphology studies, we will need to grasp the characteristics of a city's physicality to solve the issues encountered in urban design, urban planning, architecture, and landscape architecture. The characteristics of a city's physicality include the urban block, road network, and scale. Ewing and Cervero proposed the concept of the "5Ds" in 2010, which used density, diversity, design, distance to transit, as well as destination accessibility to measure the built environment <sup>[7]</sup>. This standard is more appropriate for research on the urban form and transportation features of American cities. By incorporating the unique qualities of Chinese cities, Guan and Rowe proposed the concept of "urban intensity" – a new angle integrating the observation of urban form and urban design <sup>[8]</sup>. This article first analyzes the urban intensity of abstract urban forms - monocentric, polycentric, and linear cities – to stipulate the basic evaluation standard. It will then apply Urban Morphology Studies in urban design education and research, before conducting urban morphological and digitalized urban design analysis using specific case studies. An outcome of this research is the integration of Urban Morphology Studies with digitalized urban design, another is to further advance the analysis of the urban morphology concept in Urban Morphology Studies and research that was first pioneered by Kevin Lynch in the 1960s.

### **2.1 Urban Morphology from the Perspective of Urban Density**

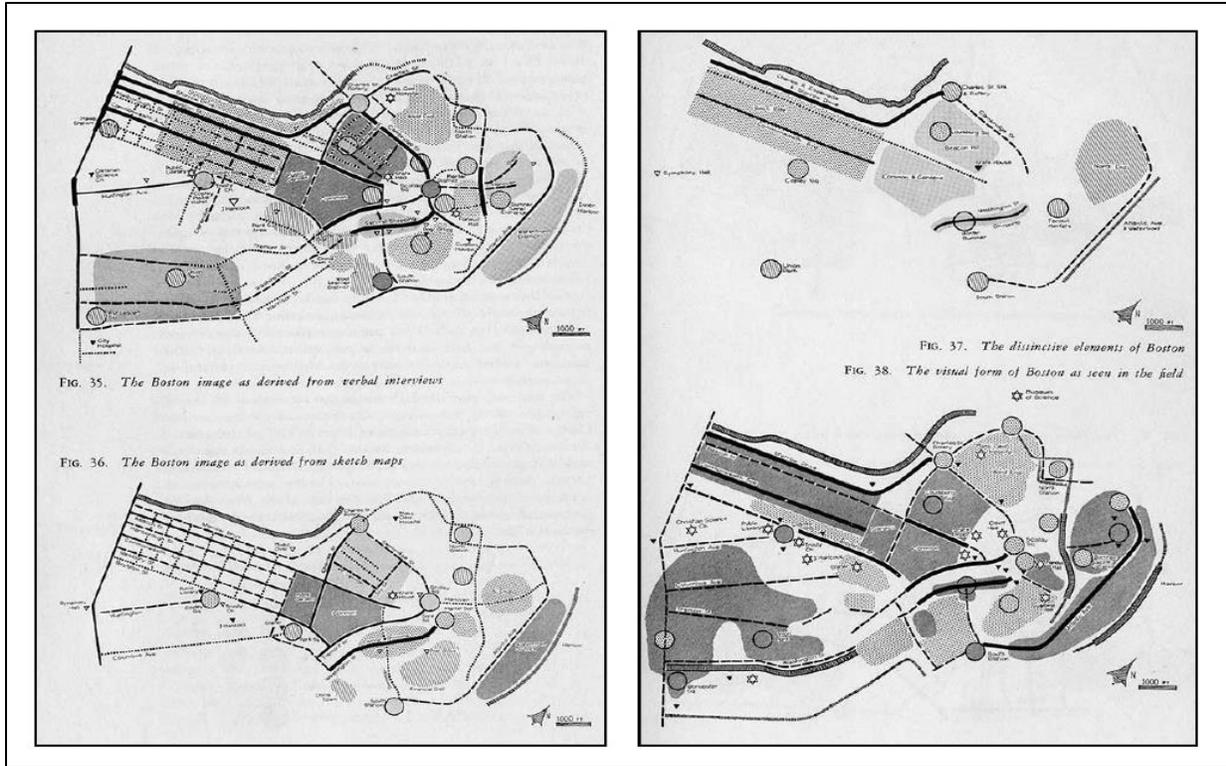
Density is a concept with a long history. Since its scientific beginnings with the definition of mass ( $m$ ) and volume ( $v$ ), the concept of density ( $\rho=m/v$ ) has occupied an important position in the development of society, science, and nature. By analyzing the systematic nature of organisms and the natural world, Aristotle explored a type of density distribution in the life sciences known as organized scientific understanding. Emile Durkheim expounded on labor specialization using the concept of dynamic density in his book, *Modernization Theory*, using Aristotle's perspectives on speed and density<sup>[9]</sup>. Building on Adam Smith's suggestion that there is a societal necessity for the division of labor, Durkheim argued that population density has become one of the most important factors in promoting the division of labor. Nevertheless, should population growth be maintained with some relative isolation, then population growth would not necessarily promote the social division of labor<sup>[10]</sup>. Only when there is continual increase in the person-to-person or group-to-group interaction, will there be the promotion of the social division of labor and the transformation of social solidarity. Clearly, this also raises various questions such as spatial distribution and connectivity.

In urban studies, scholars have already begun to integrate urban density with urban design, urban planning, and landscape architecture since the second half of the 20<sup>th</sup> century. Ebenezer Howard proposed the evolution from a monocentric to a polycentric city, and in Howard's Garden City concept plans, he suggested a scheme combining a 58,000-person, 12,000-acre central city (equivalent to a density of 1,190 people per square kilometer) and a 32,000-person, 9,000-acre satellite city (equivalent to a density of 880 people per square kilometer), separated by urban green belts to relieve the overly high population densities and deleterious effects on the residential environment in the cities. Although these densities are no longer comparable to the actual population densities in the large metropolises of today, what Howard

proposed in the form of a planning intervention to regulate the population densities has become a precedent for zoning ordinances in modern urban planning. The floor area ratio (FAR) concept familiar in the planning world emerged based on the 1916 zoning regulations in New York and was officially adopted by the city's planning department in 1961. The emergence of the FAR concept effectively regulated overly high densities and construction of high-rise buildings and curtailed their impacts on urban light and air. In large, high-density cities, population density is a crucial factor in determining a project's development and its land value <sup>[11-14]</sup>. And the key to effectively regulating the urban scale and density distribution is each land parcel's FAR. Before 1961, some of the FAR in Manhattan's land parcels exceeded 10, reaching as high as 25 in the Empire State Building. At present, many of the high-rise development projects in Manhattan have FARs ranging between 5 and 6. In China, it would be worth considering whether having FARs around 2 for parcels slated for new development would encourage issues such as urban sprawl, even if its lower densities might resolve the problem of population growth <sup>[14]</sup>.

## 2.2 Multi-Dimensionality of Urban Morphology

Kevin Lynch made a landmark contribution to the beginnings of Urban Morphology Studies since the 1960s. His publications, including *The Image of the City* (1960), *A Theory of Good City Form* (1981), *The Form of Cities* (1954), and *The Pattern of the Metropolis* (1961), formed the theoretical basis of modern urban morphology studies. Lynch elaborated on the five key elements of the "mental map" in *The Image of the City*: nodes – these can be the focal point of a center or street intersections; paths – roads, paths, and other channels by which people travel; districts – areas that are not just based on administrative boundaries and their cultural and economic populations; edges – undefined and defined edges, which serve as a definitional boundary for the analysis of urban expansion and can also be contiguous with edge cities; landmarks – which have been used in public cognition research, such as Wang Jianguo's research on the building heights in Nanjing's Old City which analyzed the popularity of key terms <sup>[4]</sup>. As shown in **Figure 1**, Lynch illustrated the image of the city and the concept of wayfinding in urban areas by analyzing Boston, Jersey City, and Los Angeles.



**Figure 1:** Analysis of Cambridge, Massachusetts, Using the Five Elements in The Image of the City

Source: See Reference Article [15]

After Lynch, advancements in computational techniques have had a significant impact on the development of Urban Morphology Studies, like every new technological revolution in human history, whether it is the shift toward vertical cities brought about by steel construction and elevators, or the suburbanization spurred by access to home loans and the impacts of Ford's automobile industry after the Second World War. In the case of New York City's Manhattan, the urban population quadrupled in the first half of the 20<sup>th</sup> century. Faced with increasing housing demands and the desire for better public environments, a series of interventions emerged. These interventions were both complementary and contradictory, including: (1) the creation of Central Park, a 700-acre land set aside by legislature in 1853 and designed by Olmsted Senior from 1857. More than 150 years later today, Central Park has fundamentally altered Manhattan's urban form and spatial structure; (2) the emergence of tenement housing; (3) the beginnings of suburbanization; (4) the occupation of high-rise buildings on the city's core.

From freestanding, single-dwelling units to the popularity of multi-family housing and high-rise buildings, these have all had profound social impacts. Lewis Mumford integrated the concept of density, with those of population, urban expansion, and urban development, and expressed his enthusiasm for regulating population density and seeing the city evolve from a monocentric to a polycentric form [15]. Mumford was of the view that the urban agglomeration effect of population density resulted in a type of social norm. Findings by several economists showed that the productivity per capita is considerably enhanced in high density cities as compared to lower density ones. Glaeser referred to this phenomenon as productivity premium, where crime rates, educational backgrounds, and employment income are all interrelated [18]. High density urban forms can also have repercussions on the residential environment. From Chicago's tenement model, New York's dumbbell housing, Berlin's rental barracks/ *Mietskaserne*,

Buenos Aires' *conventillos*, to Mumbai's *chawls*, these are all high-density communities that emerged after industrialization. Neil Brenner proposed his urban theory of partial incision to comprehensive vision [19], where the re-design of capitalist space adheres to particular transformations in various stages. As shown in **Figure 2**, the construction workers perched on a steel beam suspended above the Manhattan skyline symbolizing the labor force is contrasted with the ever-increasing heights of the urban space below, and serves as a classic example of the capitalist forces shaping the urban form.



**Figure 2:** Rockefeller Center Construction Site on September 20, 1932 (Not shot on scene)

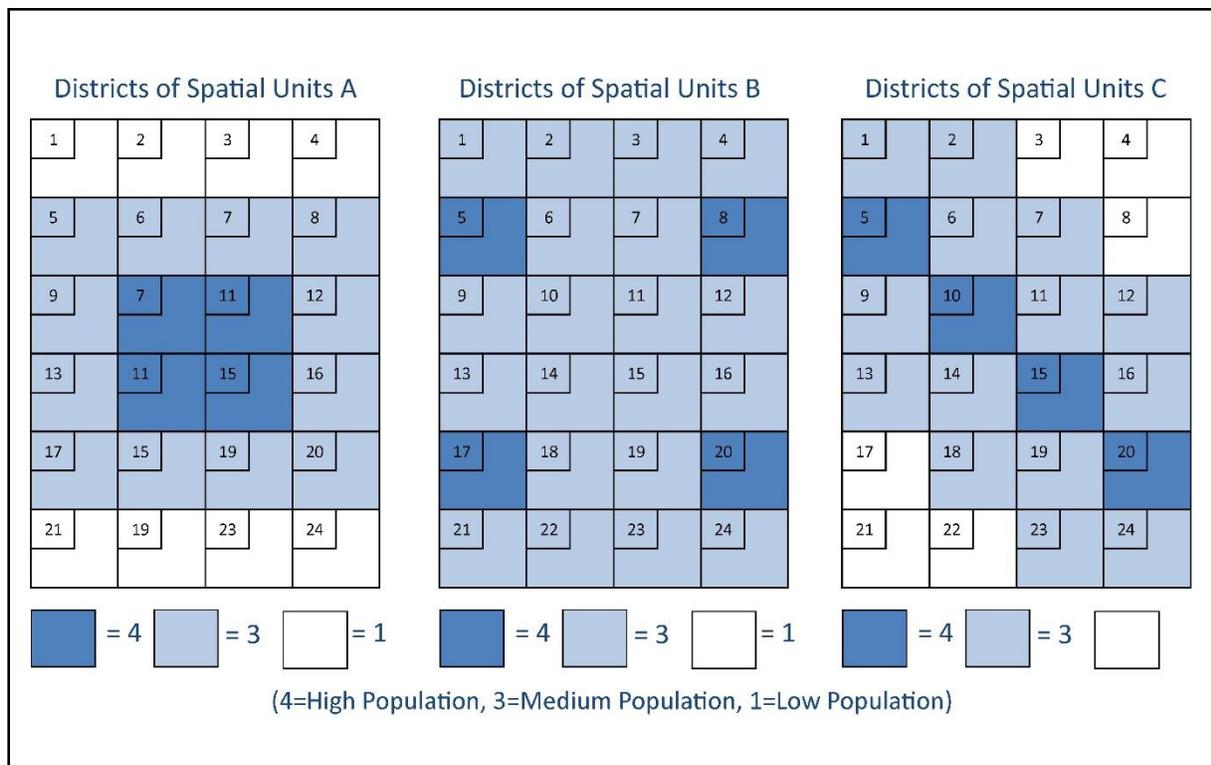
Source: The New York Herald Tribune, First published in October 1932

### 2.3 Urban Morphology Studies & Digitalized Urban Development Models

After this initial exploration of Kevin Lynch's concept of the urban form and its role in understanding the city's physicality, it is also apparent that there are limits to this theory. While urban designers have broadly applied the image of the city in practice, their limited understanding of the urban space as a whole often resulted in a fragmented urban fabric or sequence [25]. In one of Lynch's other books, *A Theory of Good City Form*, he responded to the criticisms about the limitations of objective understanding and the core of what constituted urban form; he argued that a static understanding of the city neglected the spatial complexities during the process of urban development and transformation. Building on this observation, Michael Batty, a leading scholar in urban modeling, was able to create a simulation of urban and regional developments using urban modeling [20]. This represented a breakthrough in the research methods used in Urban Morphology Studies, both in terms of technique and theory.

With the introduction of digitalized spatial models in urban studies, certain concepts had to be more nuanced and precisely defined. For instance, urban density would have to include land cover density,

building density, as well as the more widely adopted measure of population density. A Canadian Health Census Index further used different population densities as an important indicator of neighborhood and residential health. In the CAGE framework proposed by Pankaj Ghemawat, “connectivity” included cultural distance, administrative distance, geographical distance, and economic distance<sup>[21]</sup>. Due to the continual flux in these different types of connectivity, what we have is an even more complex network of spatial relations. “Compactness” reflects the degree to which urban expansion increases the occupation and hence loss of surrounding environments, protected regions, and other areas such as arable and forested lands. “Diversity”, drawing on the definition in biology, measures the types, extent, and impacts of the urban functions as they are distributed in space. Together, “Composite Density”, “Connectivity”, “Compactness”, and “Diversity” are the components of “Urban Intensity”. This concept has been used to propose hypothetical scenarios of various urban forms and have provided the basis for urban modeling. As shown in **Figure 3**, these hypothetical scenarios can be classified as monocentric, polycentric, or linear urban forms, and are not affected by geographical, climatic, and natural factors.



**Figure 3:** Hypothetical Scenarios in the Various Urban Forms

Source: Drawn by the author.

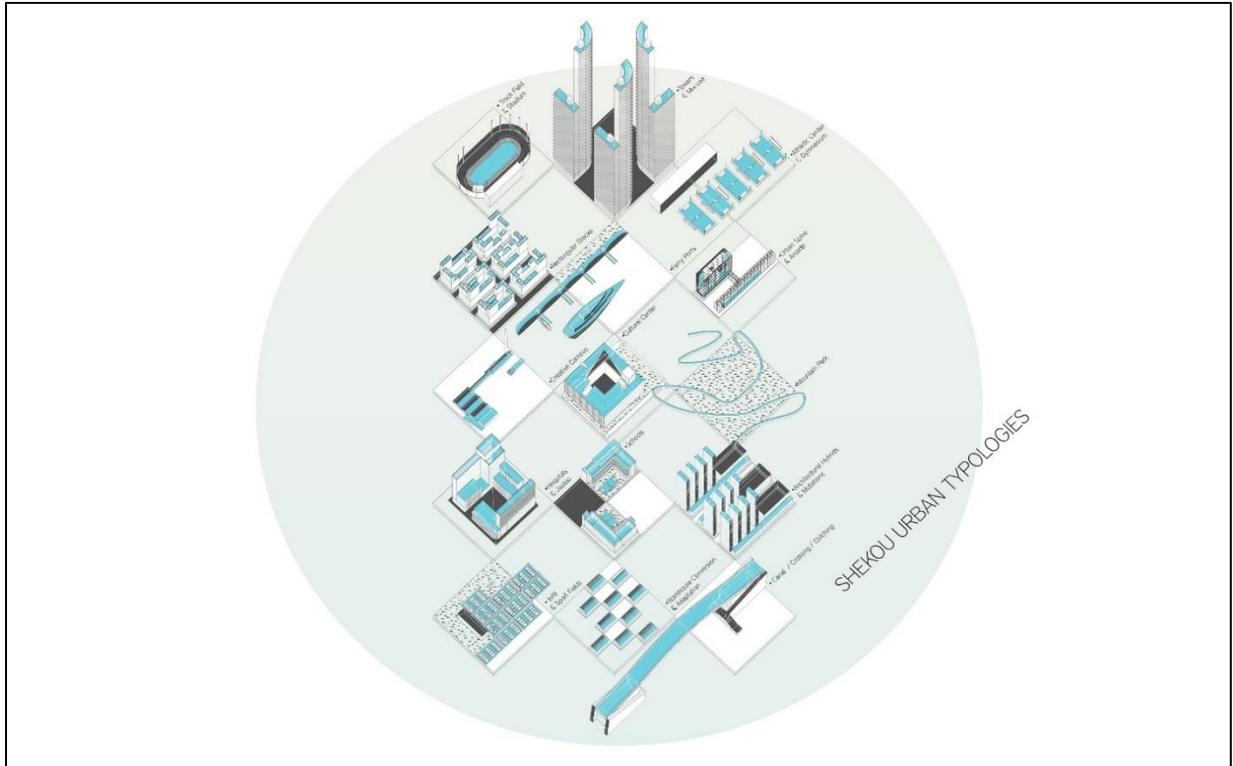
The concept of “urban intensity” has already been applied to a research on the distinctive towns of Zhejiang province. It should be noted that a persistent issue in urban morphological spatial analysis is that of scale, including those of the specific spatial standards and the research parameters to be adopted. This is like the “Modifiable Area Unit Problem” that surfaced in the earlier phase of research when the Geographic Information Systems was created at Harvard’s Graduate School of Design, and the digitalization of Urban Morphology Studies will likewise continually redefine the understanding of various issues, such as ecological fallacy and gerrymandering<sup>[24]</sup>. Subsequently, there are several research questions that Urban Morphology Studies will need to consider: First, which urban form is the most

efficient? Second, should cities of various sizes, whether they are large or small, adhere to the same kinds of spatial distribution rules?

### **3. Policy Role & Application of Urban Morphology Studies with the Digitalization of Urban Design**

#### **3.1 Application of Urban Morphology Studies and Urban Intensity with the Digitalization of Urban Design Education**

The concept of urban intensity is suitable for use with the digitalization of urban design education. Spatial analysis methods offer a prompt reflection of the inherent spatial relations in the design schemes. This teaching method builds upon the foundation established by traditional design education; it not only enhances opportunities for students' self-exploration when the proposals are implemented, it also reinforces the utilization of Geographic Information Systems (GIS) and digitalization techniques in the design process. The concept of urban intensity has been used in the curriculum at Harvard's Graduate School of Design. In a design studio entitled "Obsolescence and Pathways to Redevelopment", 12 master's program students from urban planning and design, architecture, and landscape architecture participated in the field survey and site analysis. Thereafter, they were divided into four teams to explore the concept of urban intensity and its impacts on their urban design proposals from different angles. For instance, the first proposal focused on environmental hazards, utilizing a green space system and its various layers to enhance the city's resilience in the face of rising sea levels. Specifically, the green space system was composed of urban green spaces, land for forestry, as well as coastal wetlands. The combinations of various schemes produced differences in the urban intensity, especially the changes in the urban compactness when building density was maintained as a fixed variable. These differences in the urban intensity scores served as a useful design index to evaluate both a greenspace system in landscape architecture and developable land use. The second proposal emphasized an understanding of shipping routes and land reclamation, and utilized Amsterdam, Venice, and Suzhou as precedents in measuring urban intensity. The third proposal was designed using the neighborhood typology approach and researched the relationship between bottom-up urban block design and urban intensity (**Figure 4**). The final scheme focused on the relationship between the generic grid, organic grid, and urban intensity. The application of the urban intensity concept in urban design education offers a preliminary attempt at integrating digitalization techniques and the urban design curriculum. If urban development models and spatial analyses in Urban Morphology Studies can be effectively integrated in future teaching, this will significantly improve the education standards with the digitalization of urban design.



**Figure 4:** The urban block typologies presented in the third proposal.

Source: Harvard University Graduate School of Design, 2014 Spring Semester Urban Design Studio.  
Designed by: Thien Nguyen and Orcun Tonyali.

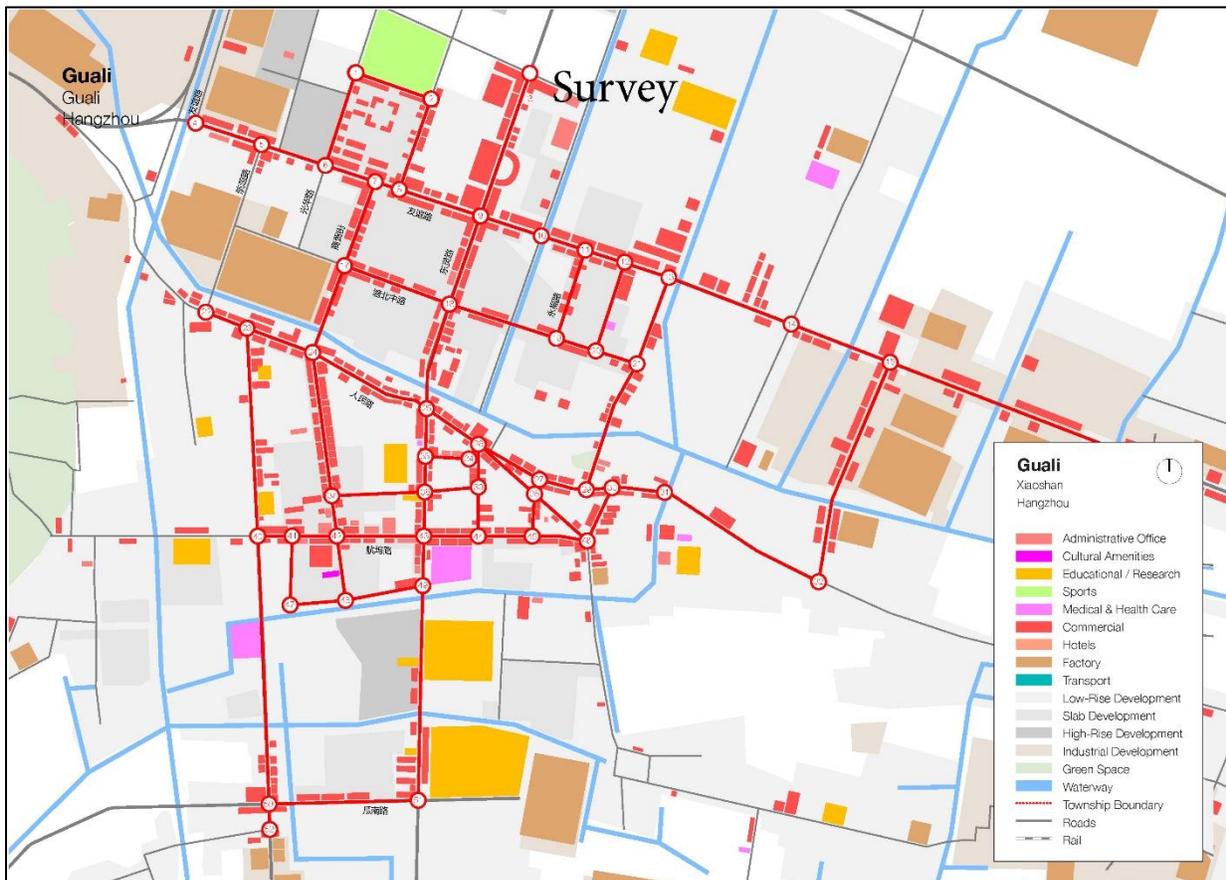
### 3.2 Application of Quantifiable Urban Morphology Analyses in Digitalized Urban Design Practice and Research

Urban Morphology Studies have been applied in urban planning and design practice. Prior to the government’s active promotion of the small township development policy, Zhejiang Province undertook an analysis of the development potential in 40 small towns within its jurisdiction. With the support of the Changjiang Delta Township Data Development Research Institute (TDDR), the research strategy focused on analyzing 4 dimensions: (1) provision of linkage and network; (2) agglomeration and economies of scale; (3) place identity; and (4) environmental amenity.

The selected townships were primarily located in the more economically developed areas in the northern part of Zhejiang Province. The objective was to more effectively and efficiently promote urban planning and design, such that the less economically developed areas would benefit from the multiplier effects. At present, one of the greatest challenges in the digitalization of urban design in China is the data collection and ensuring data consistency<sup>[22]</sup>. Using publicly available information from Baidu Maps and other sources as a basis, an average of some 500 business entities were mapped for each town, and their locations were entered into GIS using a coordinate system, along with various other layers such as the road network and topographical features. Through subsequent site surveys, the number of business entities increased from an average of 500 to over 1,000. This is common in countries where there is a lack of publicly available data and statistics on the internet, and similar issues are encountered in other areas

such as the Mumbai metropolitan region in India and Bogota in Colombia. Such an issue is a reflection that: (1) there is a lag in the top-down data collection system, and this will require a more comprehensive online spatial and statistical registration system; and (2) that there are bottom-up, temporary vendors, subcontracted entities, family-style businesses, as well as non-commercial and non-profit organizations operating. This multi-dimensional business system may present some administrative challenges, but also offer solutions to the diversity of land uses and the stagnation of businesses in residential districts – a phenomenon often observed in the United States [23]. If a suitable data collection platform combining both top-down and bottom-up methods can be established, then such a continually accumulated database combining spatial and temporal data will provide an invaluable source of information, and could potentially address the persistent problem in China where there is a lack of longitudinal data [22,23].

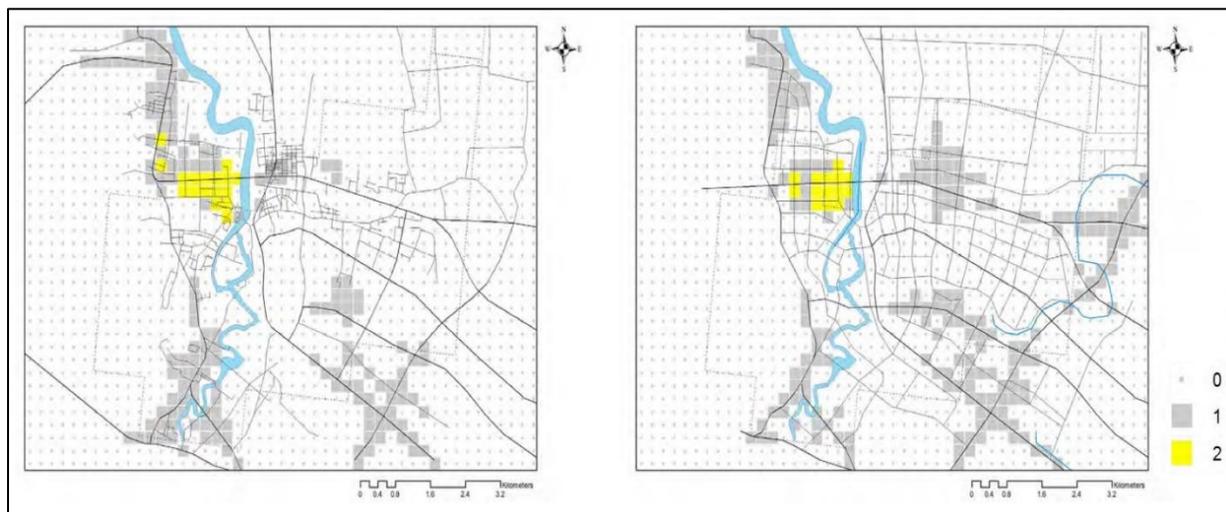
As shown in **Figure 5**, this data could also be further classified into 15 different types based on their land use. To enable a more seamless combination of the information obtained through site surveys and the GIS, the road network was used as a base map, where every intersection was represented by a number. Visually, the land uses were represented by the building footprint and different colors. The legend to this map refers to the transportation accessibility of the various places.



**Figure 5:** Site Survey and Spatial Distribution in a Township – Guali Township

Source: Studio for Urban Analysis

After collecting and organizing the data, the next step was to analyze it. This process included the use of urban morphological quantification and spatial analysis methods. For instance, the concept of urban intensity included compactness, diversity, density, and connectivity [8]. Here, compactness refers to the extent to which the population is spread out in space. It is measured using Euclidean Distance, where the population in each spatial unit and those around it are used as parameters to quantify the compactness. Here, diversity is a composite analysis of the land uses and building functions. This method of using the building itself as the smallest unit of calculation as compared to using planned districts allows for more accurate results. In the calculation process, the margin of error was reduced by conducting an automatic sort and a visual inspection. Density was calculated using the conventional population density. However, the population estimates were based on the actual resident population and not the registered population. Connectivity considered the physical and social distances and was calculated using the ratio of the population to the square of the distance in the gravity model. Lastly, these four parameters were integrated into a composite measurement of the urban intensity. This method of urban morphological analysis can be applied to both the existing conditions and future plans and can be used for comparative research. **Figure 6**, for instance, shows the accessibility comparison between the existing condition (2015) and the 10-year plan, for Shaoxing County's Qianqing Township, where the accessibility in the township's center remains almost the same even with the new plan. Given the policies to conserve and develop the original townships center, such an accessibility outcome is reasonable. The difference between the existing conditions and the future plan lies in the significant increase in the more accessible areas to the east of the township center.



**Figure 6:** Digitalized Urban Planning and Design Analysis: Existing and Future Conditions of Qianqing Township Based on Its Accessibility

Source: Drawn by the author.

Quantifying urban morphology not only offers policy recommendations at the macro-level with the digitalization of urban design, it can also be applied at the micro-level. Location analysis has been a longer, more commonly researched issue in urbanization. The economic geography model proposed by Von Thünen, Christaller, and Losch from the German School has become a focal point yet again in urban research with the rapid advancements in digital techniques. Paul Krugman, the 2008 Nobel Prize Winner for Economics, represents this new school of urban economic geography, where he has carried out new explorations in the logic and mathematical underpinnings of such spatial models. Using this new urban

economics as a theoretical basis, the top 20 townships with the highest urban intensities were selected out of the 40 analyzed in Zhejiang Province, and the locations for new commercial centers were identified using urban morphological methods. The quantification of urban morphological analysis in this project included the following key attributes: (1) population structure within the trade area and the daytime population; (2) time-distance accessibility; (3) physical and socioeconomic barriers within the trade area; (4) consumer psychology and lifestyle choices as exhibited in the income and expenditure patterns; and (5) the competition and cooperation between trade areas. These five dimensions include some relatively more abstract concepts and indicate the need for more nuanced and complex demand-supply models when translated into digitalized analyses.

The practice of digitalized urban design can also involve the compact city – a concept and form that has drawn considerable attention worldwide. Can the compact city offer a solution to sustainable urbanization? Firstly, there needs to be a holistic, comprehensive evaluation of the understanding of urban morphology. Second, there needs to be an examination of the regional disparities underlying the composite evaluation. For instance, the same population density in the United States has been classified as high density, pedestrian-friendly city where the same would be classified as a low-density city in China. In such research, besides analyzing the urban built environment, there would also be a need to understand the urban landscape and future developable space. Incorporating Richard Forman’s urban ecology and its key concepts including edge density, patch type, and parcel density, in addition to the above mentioned urban intensity index, would be critical to understanding the compact city.

#### **4. Conclusion & Discussion**

Urban Morphology Studies will be broadly applied with the digitalization of urban design. The use of urban morphology and urban intensity to classify and compare digitalized urban design from different cultural backgrounds and historic traditions span across several subdisciplines. (1) Urban morphology and open space: The At’Tuaraf Urban Redevelopment project, a UNESCO World Heritage site at Saudi Arabia’s first capital, is an example where spatial analysis in Urban Morphology Studies was conducted to determine the use and conservation of the open space. With the support of the Riyadh City Development Authority, this project has transformed the urban block and grid model in the desert, and instead utilized the traditional spatial model combining local oases and markets to promote urban redevelopment. In the long-term plan, the project also utilizes cultural centrality to complement the city’s ring road system. (2) Urban morphology and social equity: Since Olmsted’s design in the 1880s, Boston’s Emerald Necklace has yet formed a fully complete, unbroken loop even after more than a century. Under the initiative of Alex Krieger and several other urban designers, the Emerald Necklace Conservancy organized multiple public discussions in Boston. In these discussions, two areas of contention were whether the residents near Columbia Avenue would directly benefit from the completion of the design, or whether the project would result in gentrification. Spatial analysis methods in Urban Morphology Studies could perhaps find some consensus to support the different perspectives of the two parties. (3) Urban morphology and social media and networks: Whether it is Twitter in the U.S. or Weibo in China, the information obtained by social media and network users are collected in real time and time-stamped at specific points. During this process of using large amounts of data to carry out spatial analyses, the different spatial uses exhibited by visitors and residents in the urban morphology will enable a reconsideration of Kevin Lynch’s “image of the city” based on different population groups. Looking ahead, there is an optimistic outlook for the application of Urban Morphology Studies with the digitalization of urban design research and teaching. If Urban Morphology Studies is to be better incorporated into the foundations of urban design education, it can serve as a curriculum link between

urban design theory and practice. In conclusion, both urban morphology and digitalized urban design will continually be advanced with the introduction of new techniques and ideas. They will play an instrumental role in building healthy, harmonious, and smart cities and towns in China, and will continue to break new grounds in urban spatial analysis globally.

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