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Mathematics and/as Humanities–Linking Humanistic Historical to Quantitative Approaches

Tino Mager and Carola Hein

Abstract The article reflects the state of mathematics between the natural sciences and the humanities. By arguing that mathematics is a humanities subject, it suggests a close connection between mathematics and urban morphology studies. This also applies to the discrepancy between quantitative and qualitative methodological approaches. New types of research based on quantitative methods reveal previously unknown aspects of urban phenomena. They will play an increasingly important role in future research, and it is a challenge for the humanities to effectively integrate mathematical perspectives on the human habitat.

1 Mathematics as Humanities

There is something delightful in mathematics that the humanities are lacking and that has inspired other scientists: The beauty of truth emerging from itself. This dynamic is mostly abstract but serves as a basis for describing the world. Both the objectivity of mathematics and its ability to prove an infinite number of individual cases by a finite logical procedure are enviable. Unfortunately, this form of derivation of validity is virtually impossible in the humanities, where correlations can hardly be represented by elegant theories or formulas.

Mathematics and the humanities have a common starting point, largely hidden from view due to the contemporary relevance of applied mathematics and its intertwining with the natural sciences, technology, and engineering. The foundations of what we call mathematics today were present at the beginning of history. The fundamental importance of counting objects or forming numerical contexts has proven itself in everyday life over thousands of years. This knowledge was further developed and used by the ancient Egyptians and Babylonians to build the pyramids and create

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calendars. Eventually, knowledge about numbers and their calculation itself became the object of reflection in the heyday of Greek antiquity. The Pythagoreans began to develop a philosophical interest in mathematics and set up logical evidence as a means of finding an objective truth. The study of mathematics became a theoretical matter, a purely intellectual examination with no necessary reference to the application; the mathematician Helmut Hasse concluded that "mathematics of the classical Greek epoch is pure humanities in content and methods."[1]

Today, mathematical philosophies soften the distinction between pure and applied mathematics to the extent that they trace all humanities and natural sciences back to algorithmic roots.[2] The emergence of the so-called digital humanities exemplifies this reconnection of mathematics and humanities. It signals a shift from qualitative to quantitative approaches in the humanities. Thereby, the latter is often regarded as tools for data management only. This not only reduces their potential unnecessarily, but also largely ignores a whole range of possible contributions to the humanities. How can research in the humanities and natural sciences be integrated in a way that is equally challenging in and enriching to both fields?

2 Quantitative Approaches in Urban Morphology

Examining the history of architectural and urban design, we can see many moments when scholars integrated mathematics and humanities. Over many centuries, humans have tried to bring an understandable order to the diversity of urban and architectural forms, often using mathematical formulas not only to implement a reliable system of structure, but also to provide a supernatural meaning based on numerology. The use of particular numbers has played an important role in both Chinese architecture and in European design traditions. The designation of architectural styles and the countless setups of architectural order by various antiquarians, archeologists, and architectural historians were and are means of intellectual organization. From proportions of columns to counting window axes or applying the golden ratio, architectural historians have long worked with numerical and geometrical assessments. In some cases, their analysis became the starting point for new architectural and urban design theories, including the principles of the Leonardo da Vinci's Vitruvian man, and Leon Baptista Alberti's theories on the esthetics of proportionality.[3] The German architect Ernst Neufert's standardization of interior objects and architectural elements, a much reprinted standard handbook for architects, is a more recent example of both the power of numbers in architectural design and the role such sys-

[1]Hasse, Helmut. "Mathematik als Geisteswissenschaft und Denkmittel der exakten Naturwissenschaften". Newly edited by Gabriele Dörflinger. Heidelberg: Universitätsbibliothek, 2008, p 3. URL: http://archiv.ub.uni-heidelberg.de/volltextserver/12976/1/StudGen.pdf [access: 13 March 2018].

[2]Kanitschneider, Bernulf. *Kleine Philosophie der Mathematik*. Stuttgart: Hirzel, 2017.

[3]Leon Battista Alberti, Sebastiano Serlio, Andrea Palladio, Leonhard Christoph Sturm and Claude Perrault are but a few famous writers that refined and established the classical order.

tematization as played in shaping design. The analytical mapping of urban spaces and their usage is yet another example of mathematical formulas that humanities scholars use in writing the history of the built environment.

Over centuries, such standardizations have provided an overview of existing forms, but they have also distorted the understanding of the built environment of the past. These systematizations and typologies are often only a partial representation of the diversity of the built environment. Vernacular architecture and urban morphologies that are beyond scientific focus—including workers' housing, slums, suburban urbanization, and settlement forms resulting from flight and migration—are often excluded from architectural histories that largely stick to the canon of "capital A" architecture.[4]

The desire to construct an architectural or urban history that is comprehensive (not selective or based on temporal and spatial preferences), is an attractive starting point for humanists turning to quantitative approaches. In a recent paper, for example, the urban planner Geoffrey Boeing extended several quantitative methods to the analysis of the complexity of urban form; for example, he used network-based spatial clustering to identify agglomerations of jobs or amenities.[5] The result is a multilayered typology of temporal, spatial, visual, fractal, and network measures that advance our understanding of urban complexity. Mathematical approaches, algorithms, and artificial intelligence can help us analyze and compare forms and structures that are virtually unmanageable for human brains in terms of quantity and complexity. The following two examples illustrate some novel possibilities: Vahid Moosavi, a researcher in Machine Learning, a field applying data to train computers for specific tasks without explicit programming, demonstrated that deep learning can allow a scholar to compare the complexity and shape of more than one million urban patterns worldwide.[6] Using publicly available data from Open Street Map and a specially tuned artificial neural network, he analyzes the shape of patterns in a broad variety of urban settlements across the planet, comparing them for similarities and grouping them into a large number of types based on rectangularity and complexity. The network focuses on geometric similarities without looking for man-made concepts or order structures, circumventing linguistic and conceptual conditions which bias our thinking about built forms. It "sees" no linear or dispersed settlements, no medieval town centers, no sprawl or suburbs. Rather, it discovers formal similarities that can be expressed mathematically, for example by assigning closely related structures a specific color. The result is a visualization of the current worldwide distribution of the similarities and differences of human settlements, revealing novel insights on global correlations and developments without referring to canonical categories. Quantitative methods can further deepen these insights, for example by generating

[4]E.g.,: *The Political Meaning of Informal Urbanisation* (Roberto Rocco, Jan van Ballegooijen| TU Delft), *Eine Architekturgeschichte der Armut* (Britta Hentschel| ETH Zürich).

[5]Boeing, Geoff. "Measuring the Complexity of Urban Form and Design", 2017, http://geoffboeing.com/publications/measuring-complexity-urban-form/ [access: 19 March 2018].

[6]Moosavi, Vahid. "Urban morphology meets deep learning: Exploring urban forms in one million cities, town and villages across the planet", 2017, https://arxiv.org/abs/1709.02939 [access: 20 March 2018].

connections to aspects of economy, politics, social conditions, or culture—as far as they are available digitally.

Computer vision—methods enabling computers to recognize and understand image content—can also be used for classic basic research. COMPOSITO, a research project at the University of Heidelberg, investigates the automatic recognition of architectural elements in early modern architecture.[7] The goal is to identify a structure's architectural elements—for example, column capitals, window lintels, rustic masonry—and to find other buildings with similar features. This approach aims to simplify the comparative study of buildings and to help scholars investigate the spread of architectural styles much more comprehensively than before. Furthermore, COMPOSITO experiments with the search for similarities through unsupervised learning. This means that it examines and classifies objects for similarities that do not correspond to any architectural categories, but are found by the algorithm itself. The results, which are purely formal in nature and not influenced by implicit knowledge, may, conversely, catalyze qualitative analyses of individual objects.

Another program that integrates quantitative methods into other research on the built form is the ArchiMediaL project, carried out by researchers of the Delft University of Technology and the Vrije Universiteit Amsterdam.[8] It uses publicly available data and the capabilities of a neural network to facilitate a deeper investigation of built form. In a first step, Mapillary street view images of today's Amsterdam provide a basis for image content matching, helping identify the buildings captured in more than 3,60,000 historical photographs of the city.[9] This enables the creation of a street view of Amsterdam's past. It will also allow for adding a historical layer to the neural network's training set, to make it more sensitive for recognizing the architectural content of more visual representations of the city's past. The ultimate goal is for the project to analyze imagery beyond photography—paintings, drawings, sketches—and to automatically detect buildings in these images. The outcome will be a complete set, across space and time, of the visual representations of Amsterdam's architecture. In combination with nonarchitectural data (e.g. cadastral information, election results, local income, etc.), this data set allows for automated analyses correlating architecture with urban planning and other societal conditions. The sheer amount of cases may lead to insights beyond the scope of traditional humanistic methods that are restricted by the amount of scholars working on the project.

The experiences gained from this kind of research on Amsterdam will help scholars understand how to investigate images that have less data available. That is, millions of images with architectural content lack titles, meta tags, or annotations. This matters especially if the content belongs to vernacular architecture and urban form, still underrepresented in research and not part of historical architectural and urban

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[7] *COMPOSITO - Arthistorical Analysis of Architecture via Computer Vision* is a project conducted by Björn Ommer, Peter Bell and Michael Arnold at the Heidelberg Collaboratory for Image Processing.

[8] *ArchiMediaL* is a cooperation between historians of architecture and urban form (Carola Hein, Beate Loeffler, Tino Mager, Dirk Schubert) and computer scientists (Victor de Boer, Jan van Gemert, Seyran Khademi, Ronald Siebes). URL: http://archimedial.eu.

[9] The historical images are from the collection of Stadsarchief Amsterdam and available at Beeldbank Amsterdam. URL: http://beeldbank.amsterdam.nl.

canons. Primarily, these shortcomings apply to data of non-Western architecture. Overcoming them will enhance the further investigation and understanding of global networks of architectural ideas and techniques that lie behind the migration and evolution of form.[10]

Quantitative methods—in this case, the automatized analysis of form by computer vision—are particularly helpful in tracing developments and distributions of architectural and urban form beyond the main recognized architectural highlights. Moreover, they allow scholars to do this without having to precisely name specific features linguistically in the metadata, as they can refer to purely visual aspects. Eventually, image content matching, powered by computer vision, will help us navigate and search in visual sources as easily as we conduct research in text sources today. Then it won't matter if the object of interest is referred to as, e.g., windmill, tuulimylly, ανεμόμυλος, or 風車, as the search will concentrate on the visual representation of the linguistic term.

Linked data approaches, in this case that means the semantic interlinking of visual content and attributes, will further help to open up visual sources that are currently difficult to access due to foreign language, or deviating or even incorrect labeling.[11] Ideally, such approaches will work across public and private archives, libraries, and collections, providing scholar access to all existing sources for a specific object—or to millions of objects. The restriction is less technical than political—the willingness of archives, institutions, and private parties to allow open access to the source material—complicated by legal questions that are rather blurry for nonexperts. In the short term, however, it is clear that technology and mathematics will change the character of studies of urban morphology.

3 Imminent Changes

But quantitative methods and automatic data processing cannot replace human experience or qualitative information processing: It will hardly be possible to carry out individual studies—which rely on the deep knowledge of regional historical developments and on interdisciplinary knowledge—by using approaches that are essentially based on algorithmic approximation or even nonhuman intelligence. What these approaches can do, however, is overcome the previous focus on comparatively few objects and the reliance on types, which is only of limited validity to reality. The possibility of examining hundreds of thousands of objects, in conjunction with worldwide data acquisition, will give us a more global perspective beyond the types and

[10] E.g. Hein, Carola: *Port Cities: Dynamic Landscapes and Global Networks*. London: Routledge 2011.

[11] Löffler, Beate; Carola Hein; Tino Mager. "Searching for Meiji-Tōkyō. Heterogeneous visual media in times of global urban history, digitalization, and deep learning". In: *Global Urban History*, 20 March 2018. URL: https://globalurbanhistory.com/2018/03/20/searching-for-meiji-tokyo-heterogeneous-visual-media-and-the-turn-to-global-urban-history-digitalization-and-deep-learning/ [access: 21 March 2018].

canons limiting much of today's scientific thinking. This will also have an effect on classification, which is useful as an aid to thinking, but hitherto applies only to parts of reality. Novel classes will result from factors that have not yet been taken into account and are of greater complexity, which will make them more applicable.

Quantitative approaches can thus help us better explore urban forms and morphologies. To win this broader perspective, humanists will be obliged to deal more intensively with quantitative methods and their possibilities, as well as the possibilities of integrating them with qualitative methods. The main step, however, lies in the challenge of developing research questions in cooperation with computer scientists that enrich both fields. In this way, the potential of new technologies can be meaningfully exploited and at the same time a mutual interest can be generated. Since the human sciences are known to be difficult to monetize, they must be particularly creative in order to attract computer scientists (competing with more profitable areas such as, e.g. bioengineering). Incentives will include groundbreaking research in areas such as deep learning and computer vision. Ultimately, classical approaches in architectural and urban history will also benefit: new insights will contribute to stimulating new qualitative research, based on unprecedented results made possible only by cutting edge quantitative methods.