Chapter 2 – Data Augmented Design (DAD): Definitions, Dimensions, Performance, and Applications

Abstract: The emerging new data environment formed by big and open data provides a lens for a more detailed understanding and description of the entangling physical and social urban space. Since 2010, more than a dozen new labs, departments and schools have been applying this new data in urban planning and design in various ways. In this context, this chapter reflects on a new urban design methodology - Data Augmented Design (DAD), first proposed in 2015, to highlight the use of data in design. This chapter introduces the profile of DAD by comparing its definition with related concepts such as Planning Support Systems (PSSs) and Geo-design, depicting its framework and applications, and reviewing progresses regarding to the research network and annual conference, the DAD manual, courses and workshops, and the feedback from academics and practitioners. Its academic contributions and potential applications, as well as potential biases and future research avenues are also discussed.

2.1 Foundations and Prerequisites

2.1.1 Planning Support System as an Information Framework for Urban Planning

Planning Support Systems (PSSs) as sets of geo-information technologies are developed to embrace the available methods, techniques, and models developed in research laboratories to analyze spatial problems and to evaluate future options or project alternative scenarios (Geertman 2006). They were first described by Harris (1960) as a means of utilizing computer-based modeling and analysis instruments to support planners. Inspired by Harris, there was a growing effort to develop and optimize the frameworks and tools of PSSs. "SimLand," "What if," "UrbanSim," and "BUDEM" are typical types of PSSs (Wu 1998; Klosterman 1999; Waddell 2002; Long et al. 2009). According to different combinations of activities (e.g., observing, measuring, analyzing, modeling, simulating, predicting, prescribing or designing, optimizing, evaluating, managing, and negotiating) (Batty 2007), PSSs can be classified into different packages – GIS; land use transportation models (LUTMs); multicriteria analysis (MCA); plan-generation techniques such as What if? TM, CAD, and 3D GIS; and public participation/multimedia community-visioning methods (Shiffer 2001). In a sense, PSSs can be regarded as use-driven approaches to large-scale urban modeling and planning support and are thus distinguished from theory-driven methods (Geertman and Stillwell 2009).

However, PSSs have encountered bottlenecks in supporting planning and design for various reasons, including limited interest from planners, difficulties with understanding systems, and their constrained functions (Liu et al. 2014). First, barriers related to resistance to change and working habits that have been in place for years have allowed few planners to apply PSS in practice (Timmermans 2008; Vonk et al. 2005). Furthermore, consideration to the specific demands of planners and to characteristics of the PSS planning process is insufficient (Geerman 2006). Some scholars such as Van Kouwen et al (2009) even argue that "PSSs do not bridge the gap between knowledge and policy making, but are rather part of the problem."

2.1.2 Geo-design as a Design and Planning Tool

With the evolution of Geographic Information Systems (GIS) in environment design, geo-design has also become a hot topic in academia, design institutes and geospatial industries. Generally, any design activities informed by geographic knowledge, experience, information and data could be called geo-design (Li and Milburn 2016). According to Li and Milburn (2016), geo-design in landscape architecture has been involved in four main eras. The first one is the analogue era (mid-19th century to mid-20th century), which was characterized by the use of analogue media and techniques for data storage and information representation for scientific investigation and rational decision making. The second era ran from 1950 to the mid-1970s. Driven by decades of the introduction of scientific knowledge, usage of survey data, and the initiation of analytical approaches, the classic "survey-analysis-design" process became standard practice and a central design approach (Sasaki 2002; Swaffield 2002). With the rapid development of electronic engineering and computer science, environmental data became available, resulting in the third era of geo-design called the small data era. In this era, GIS-based analysis developed rapidly and became widely used for advanced research (White and Mayo 2004), regional design, planning and policy making (Hanna 1999; Lyle 1985). From 2000 to the present, revolutions in information technologies and spatial data have formed a lens for fine-scale geo-design practice. This era can be called the big data era, in which the creation of new definitions, principles, theories, applications, and organizations have continually emerged.

According to the definition of geo-design, the whole framework related to design activities in geographic space is a reflection of its function (Miller 2012). Some scholars have defined the function more strictly and focused on alternative design evaluation and impact assessment (Dangermond 2009; Ervin 2012; McElvaney 2012). Recently, Steinitz (2012) revised his landscape framework to provide a theoretical foundation and structure for geo-design. In his view, "geo-design applies systems thinking to the creation of proposals for change and impact simulations" (Canfield and Steinitz 2014) and can help one "understand the study area," "specify methods," and "perform studies" (Steinitz 2012). The core tenet of geo-design is spatial thinking, which involves understanding, defining and analyzing the locations, distances, directions, shapes, scales, patterns, and trends of features and processes observed in living environments (Kastens and Ishikawa 2006) in the context of geographic information science (GIScience). In environmental design, geo-design is regarded as a methodology which facilitates the generation and impact assessment of design proposals with geospatial information and technologies. In the field of planning practice, geospatial analysis and modeling generated from geo-design serve as a planning support tool in searching for solutions of better urban form by ascertaining the patterns of activities in urban space (Neutens et al. 2010; Yuan et al. 2012; Long and Shen 2015). From the perspective of planning support, geo-design can be regarded as part of a PSS. However, compared to the PSS, geo-design is a GIS-based analysis tool for capturing, storing, manipulating, analyzing and displaying and is applicable to many different spatially related problems. Even though in many cases a PSS also contains GIS tools, it is involved in undertaking specific planning tasks.

2.1.3 New Opportunities for Integrating Big Data into Urban Planning and Design

With the advent of the fourth generation of the industrial revolution, artificial intelligence, virtual reality, augmented reality, the Internet of Things (IoTs), and various other kinds of intelligent technologies are now constantly reshaping housing, work, transportation and recreation. Simultaneously, the information and communication technology (ICT) boom has created both 'big data' through, for instance, mobile phone signaling and public transportation smart card records, and 'open data' through, for instance, commercial and government websites, together giving rise to a 'new data environment' (see Appendix 1 for more information) that has allowed geo-design users to take advantage of new methodologies and to transition from PSSs to data-driven planning and design.

There are three reasons why a new data-driven methodology should be proposed. First, as we described in Chapter 1, our cities are in transition. To meet this new wave of information technology, there is a concern that much more powerful theories and methods are needed to generate a requisite understanding of cities (Batty 2013). Models and methods relying on traditional PSS framework will face challenges. Second, with the boom of new data environments, there are many types of urban data, which serve as important sources for planners in identifying planning issues and solutions in urban areas using geospatial analysis technologies (Long and Shen 2015). Although geo-design is also starting to use big data for analysis, it pays more attention to the attributes of physical space and less attention to the social attributes of the city and especially activities in the virtual environment. Finally, fine-scale data provide us with a new perspective on understanding the city at the human scale. Compared to PSSs and traditional geo-design, microscale urban planning and design require the use of a series of new methods and tools.

Since 2005 (mostly since 2010), labs, departments and schools have increasingly pursued deeply quantitative and computational approaches to understanding and creating cities. The MIT Media Lab, MIT Senseable City Lab and ETH Future City Lab, to name but a few, are presenting data and design driven research. Similar initiatives are also underway in China (see Appendix 2 for more information). The use of new data to identify new urban life and urban physical environments is also occurring at an increasing rate. For instance, bike lanes are planned based on the trajectories of share-bikes (Bao et al. 2017) and intelligent transportation systems of the future can be improved through visual analysis (Andrienko et al. 2017).

Against this background, it was previously recognized by Long and Shen (2015) that the data themselves are not platforms or software but reflect the physical and social environment, which can in turn reflect the future space and life of our cities. To better describe this data transformation in planning and design, the authors jointly proposed a new methodology termed Data Augmented Design (DAD) in 2015 (Long and Shen 2015) to highlight the use of data in design. Since then, in China many scholars have conducted research in response to the concept of DAD. This paper will discuss DAD by offering a definition and introducing the specific processes, features and tools used to realize the scope of future-oriented design. Following from this, three typical applications to DAD are presented with several practice cases. Then, the progress of DAD is reviewed with regard to the its research network and annual conference, the DAD manual, courses and workshops, and feedback from academics and practitioners. A concluding section outlines main points related to DAD and discusses its potential applications in smart cities.

2.2 Data Augmented Design (DAD)

2.2.1 The definition of DAD

Empowered by the emerging big and open urban data together with quantitative spatial analysis, statistical approaches, and cutting-edge techniques, Data Augmented Design (DAD) provides a supporting platform for the whole planning and design process, including field investigation, existing condition analysis, future forecasting, scheme design, and operation evaluation and feedback. The application of DAD in planning and design practice is expected to improve the science of planning and design and to inspire the creativity of planners and designers (Long and Shen 2015). Based on an understanding of the supporting tools for planning and design, the proposed DAD system belongs to a new planning and design support format following CAD (Computer Aided Design), GISs (Geographical Information Systems), DSSs (Decision Support Systems) and PSSs (Planning Support Systems) (Table 2.1). It should be understood that DAD is not equivalent to quantitative analysis, CAD and geo-design. As a new planning and design methodology, DAD emphasizes a future-oriented method of design. DAD focuses on applying various data to technical methods and obtaining experience from designers to quickly generate and evaluate schemes whereas CAD focuses on providing planners with a mapping environment to improve the efficiency of generating planning and design results. Compared to geo-design, DAD concentrates more on people and their activities. In contrast to the "nonlinearity" of parametric design, DAD also does not advocate the use of mathematical analysis to completely replace design thinking, but instead provides quantitative methodologies and reliable evidence for design creation with solid quantitative analysis. Although DAD is similar to a PSS in terms of the whole process supporting urban planning, there are still some differences. First, DAD is a data-driven framework and thus diverges from model-driven PSSs. Second, DAD focuses on fine-scale urban planning and design while a PSS operates in the context of macro-scale urban planning. Third, DAD fully embraces cutting-edge technology in planning and design and studies the impact of new technologies on urban space and urban life.

Table 2.1 Comparison of DAD to other planning and design support formats

Concepts	Core Function	Period	Driving force	Process	Scale
ES (Expert System)	A process based on knowledge and expert experience for finding solutions to problems	Long-term	Experience- and knowledge-driven	Classification, diagnosis, monitoring, design, scheduling, and planning for specialized endeavors	Whole scale
CAD (Computer	Planning and design support	Short-term	Data-driven	Design generation	Whole scale

Concepts	Core Function	Period	Driving force	Process	Scale
Aided Design)	software tools				
GIS (Geographic Information System)	Planning and design support software tools	Short-term	Data-driven	Existing condition analysis, design generation, and visualization	Whole scale
DSS (Decision Support System)	A collection of tools for the decision-making process	Short-term	Model-driven	Decision making	Macroscale
SDSS (Spatial Decision Support System)	A collection of tools for the spatial decision-making process	Short-term	Model-driven	Decision making	Macroscale
PSS (Planning Support System)	A collection of tools and a framework for the planning process	Long-term	Model-driven	Whole process of planning	Macroscale
DAD (Data Augmented Design)	A collection of tools and a framework for the planning and design process	Long-term	Data-driven	Whole process of planning and design	Mesoscale and microscale

2.2.2 Process of DAD

DAD, as a new quantitative planning and design methodology, can support each phase in the process of urban planning and design by employing modeling toolsets to extract, analyze, and predict on the basis of various data sources, and eventually, it can also increase the rationality, creativity and resilience of planning in a new data environment. The typical application of DAD in supporting planning and design can be divided into five steps (Fig. 2.1). First, using a quantitative analysis based on the DAD framework in an existing condition analysis can inspire the extraction of design elements and the generation of concepts. Data with large coverage and fine spatial granularity can integrate different spatial factors and effects onto the same scale, overcoming difficulties with traditional planning design in matching and connecting across different scales. Meanwhile, urban data analysis methods and models are used to extract the most appropriate urban design elements using the requirements of planning regulations and master planning as control factors. This rational analysis method helps one avoid the limitations of research dimensions and personal knowledge and experience. Second, the introduction of DAD augments the optimization of planning and design via a real-time process of simulation and evaluation. Third, the quantitative results of DAD can support the output expressions of planning and design. Personal judgment serves as a final filter before generating the design scheme. Then, a report of spatial data and its visualization will help reduce communication costs while ensuring t effectiveness and the implementation of participatory decision-making. Finally, the use of increasingly diverse and sophisticated urban data will lead to a more transparent urban management atmosphere and especially in aspects related to public participation, planning, and management. After these processes are complete, the design scheme is constantly optimized, thus eventually meeting scientific, feasibility, timeliness and aesthetic requirements.

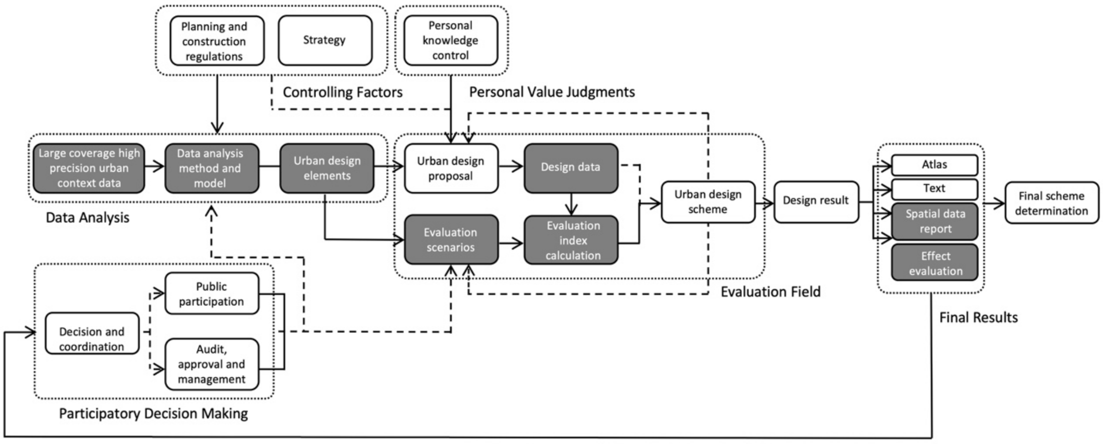

Fig. 2.1 The specific planning and design support format of DAD (Long and Shen, 2015) (revised by the authors)

Within the framework of DAD, the interpretation of complex urban orders and their sustainability can be considered as decision-making process in which different phases are included and the most appropriate and effective spatial intervention plan is generated and proposed (Shen and Long, 2015). Fig. 2.2 shows the process of connecting and implementing different spatial designs and their sustainability contributions within a dynamic, quantitative framework of urban sustainability using the DAD system. From this perspective, the DAD research framework is a specific, future-oriented epistemology system, which conducts archaeological studies on the contemporary urban situation. Such a framework not only contributes to rational planning proposals but is also helpful for understanding the sustainable functionality that underlies planned and unplanned orders.

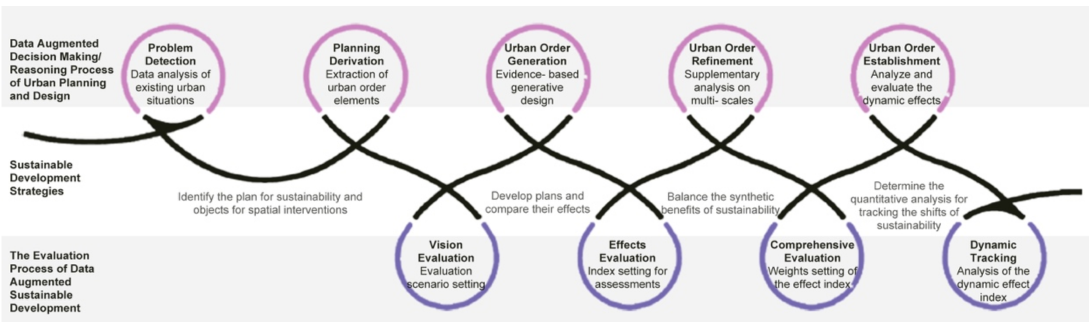

Fig. 2.2 Decision making / reasoning process of urban planning and design towards sustainability (Shen and Long, 2015) (revised by the authors)

2.2.3 Features of DAD

The data used in DAD are not limited to big data but also include open and traditional data. These various sources and types of data interact with each other to react and support the application of quantitative analysis in urban planning and design. Specifically, the principal features of DAD are as follows. 1) Applicable: directly responding to planning and design practice. 2) Multidimensional: a model that combines spatial attributes with socioeconomic data. 3) People-centered: studying people's activities through social networks, POIs (points of interest), mobile phone data, etc. 4) Perceptible: corresponding to the "spatial spirit" of the design with the help of new data and methods. 5) Fine-scale: emphasizing an accurate understanding of the context of the given environment and people, analyzing existing laws, and establishing different combinations of models to provide support for special planning and design. 6) Adaptable: focusing on a quantitative understanding of the relationship between people's activities and the environment to create better ones. 7) Applying a binary world: combining the virtual world with the real world. 8) Integration: integrating multisource data and encouraging public participation. 9) Using multiple tools: reflecting design methods in a series of tools. 10) Effect-based: aiming at better social, economic and ecological benefits of design. 11) Traceable and assessable: continuously evaluating and cycling through the design process until the best results are available.

2.2.4 Commonly Used Methods and Tools of DAD

There is a tendency for methods and tools used in DAD to be increasingly more closely linked to new data and new technologies. The main methods of DAD include the following (Table 2.2): 1) applying spatial abstraction models for identifying and abstracting design and analysis of spatial units such as spatial syntax, the grid division method, and node analysis; 2) using spatial analysis and statistics to identify statistical characteristics of space such as spatial statistical methods, density analysis methods, and interpolation analysis methods; 3) using data mining and visualization tools such as machine learning and spatial visualization; 4) applying natural language processing to discover information in social network data such as stop words, word clouds and semantic analysis; 5) employing urban development models to predict urban development boundaries and short- and long-term effects of planning design such as cellular automata, multiagent models, and urban procedural modeling; and 6) adopting parametric design tools to generate design schemes automatically such as Grasshopper and City Engine.

Table 2.2 Commonly used methods and tools of DAD and their key functions

Commonly used methods and tools	Key functions	Samples
Spatial abstraction models	Identify and extract spatial units for design and analysis	Spatial syntax, the grid division method, and node analysis
Spatial analysis and statistics	Identify statistical characteristics of space	Spatial statistical methods, density analysis methods, and interpolation analysis methods
Data mining and visualization	Mine and visualize data information	Machine learning and spatial visualization
Natural language processing	Discover information included in social network data	Stop words, word clouds and semantic analysis
Urban development models	Predict urban development	Cellular automata, multiagent

	boundaries and short- and long-term effects of planning design	models, and urban procedural modeling
Parametric design tools	Generate design schemes automatically	Grasshopper and City Engine

2.3 Three Typical Applications of DAD

The design of DAD is based on the in-depth observation and understanding of a current city including its physical environment and individuals' activities. According to different types of design, we can divide our applications into three categories (Fig. 2.3). For redevelopment-oriented planning and design, we emphasize better understanding elements by using multisource data. For expansion-oriented planning and design, we encourage learning from excellent city cases by comparing their quantified attributes on the same scale. For future cities, we observe transitions in current cities influenced by advanced technologies and fully embrace cutting-edge technologies to imagine future urban life and create future urban forms.

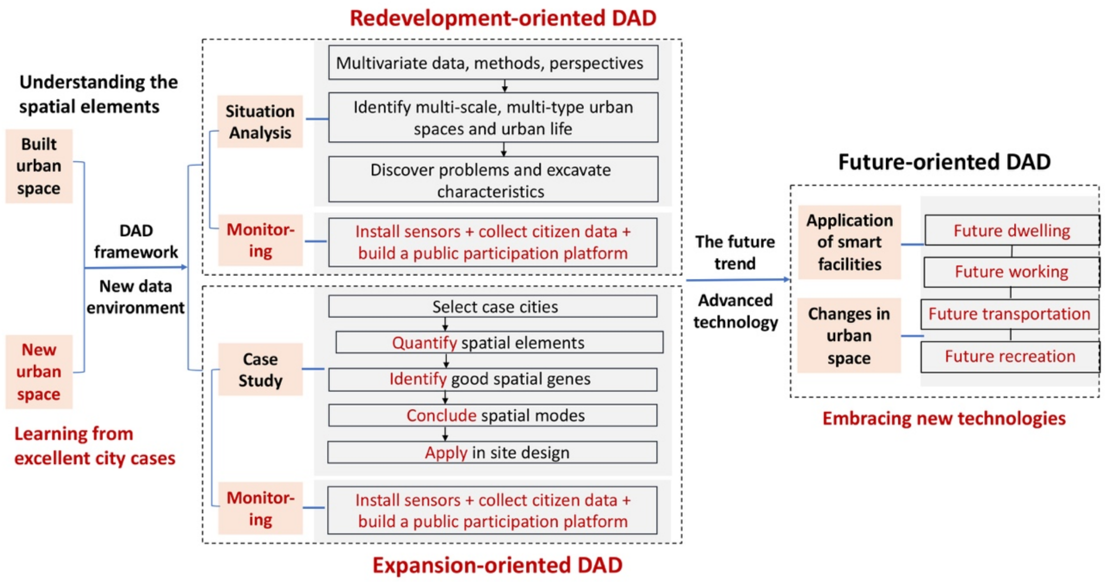

Fig. 2.3 Three typical applications of DAD for different design types

2.3.1 Understanding the Elements of a Site to Better Design Sites

DAD can be applied to redevelopment-oriented planning and design, which helps identify problems via an existing condition analysis based on multidimensional data, and to quantitatively evaluate the implementation of designs after reconstruction (Cao and Long 2017). First, under the guidance of the TSP model (Long and Shen 2016), the framework supports an understanding of physical and social space via analysis of upper planning, physical environmental elements, social networks, and economic performance. This way, existing problems in different dimensions such as functional positioning and service facilities distribution are recognized. This process prioritizes the "people-centered" approach by dealing with existing problems and responding to the demands of citizens. Based on this framework, two teams using DAD in both the 2016 and 2018 Shanghai Urban Design Challenges have been supervised and received very good outcomes. In these two works, DAD as a methodology for urban design provided different means of analyzing big and open data in different dimensions (for an example, see Fig. 2.4). In redevelopment-oriented planning and design, shrinking cities are also an important issue. Although some international strategies have been designed to cope with the shrinkage of cities, few of such designs have been developed in China. In 2019, the China Shrinking City Research Network launched a workshop on shrinking cities in the city of Hegang, China. Another team guided by the DAD framework also achieved good outcomes.

Fig. 2.4 Walkability evaluation derived from the 2016 Shanghai Urban Design Challenges

2.3.2 Learning from Other Cases to Better Design Sites

DAD can also be applied to the planning and design of urban expansion, which helps extract spatial indexes from existing cases to form a classified "gene pool" for quantification and a reference index system for new designs (Gan and Long 2017). The specific framework is constructed over three steps (Fig. 2.5): first, there is an analysis of the built environment of the selected case cities based on the new data environment and DAD method where the extracted and quantized index from the spatial dimension is added to each gene pool; next, each suitable gene pool is used for planning and is adjusted according to its specific conditions; finally, a quantitative evaluation is made for the postconstruction city space, including a comprehensive comparison of the status of the planned city and the corresponding index of the case city. Based on this method, DAD was successfully applied in the Tongzhou Sub-Centre of Beijing and Xiong'an New District projects, proving the applicability of DAD concepts to Chinese planning and design.

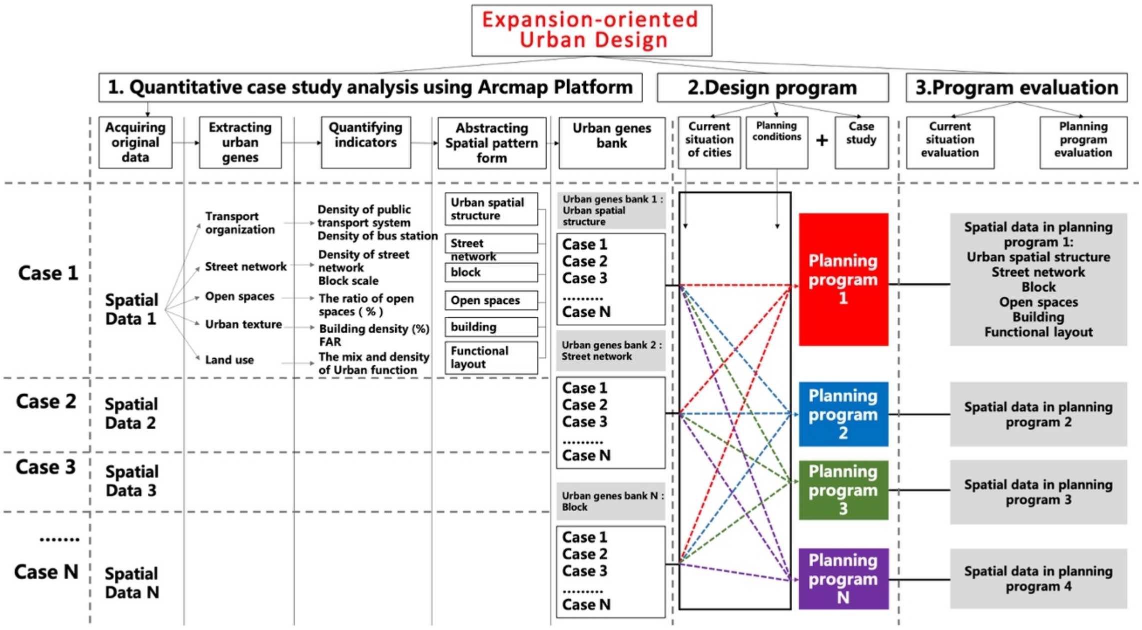

Fig. 2.5 The quantitative case study framework

2.3.3 Embracing Advanced Technologies and Transitioning of Cities into Better Designed Sites

The third type of DAD application is future oriented. As we introduced in Chapter 1, we live in a time of very rapid development and change that is driven by various forms of science and technology, which have the potential to change the way we live, work, spend free time and travel. Only by embracing the most advanced technologies and transitions in cities can a better future be created. First, we should conform to the reconstruction of urban space by science and technology and imagine a future urban form under the influence of new technologies such as autonomous vehicles, smart logistics, VR, UAVs, artificial intelligence, and sharing technologies (Fig. 2.6). This concept is reflected in the work *The Next Form of Human Settlement* submitted to the Yilong Futuristic City International Design Competition. This work focuses on living spaces of the city and proposes an assumption of future living form. This scenario is illustrated in Chapter 9. Then, we should also fully integrate certain existing technologies into our design. In combining design with technology, our design is not limited to physical space but is also expanded into virtual space. Through the development of Huangguan Island, we connect design with nature and technology and augment nature with science and technology, which is interpreted in Chapter 10.

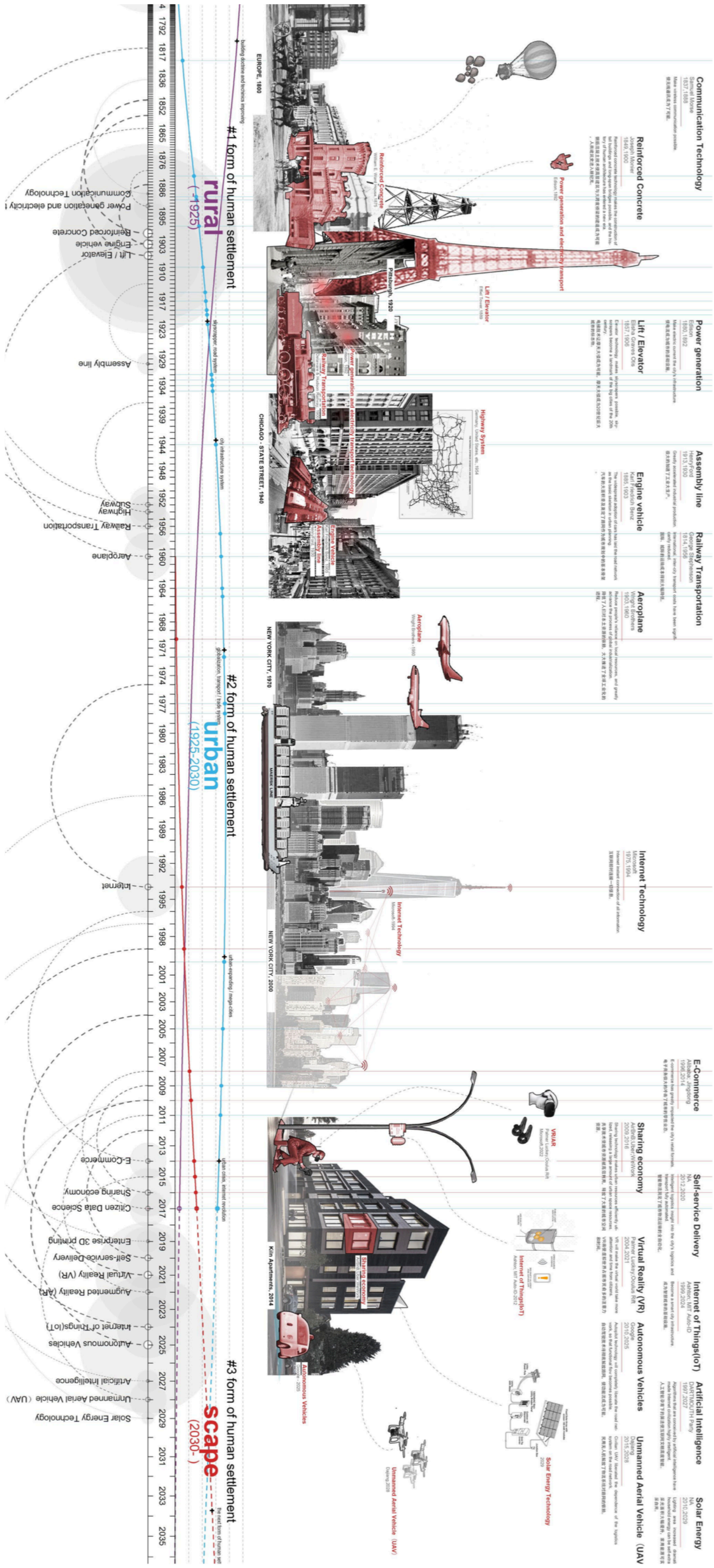

Fig. 2.6 The transformation of human settlements through emerging technologies

These practice cases reflect the applicability of redevelopment- and expansion-oriented urban planning and design using DAD and its future-oriented attributes and form. This book will also focus on the design practices of these three types of application methods and specifically introduce the application of DAD methodologies across different design situations to provide new ideas and methodological support for design.

2.4 Recent Progress and Achievements

The DAD methodology has attracted widespread attention from academia and industry since it was first proposed and has achieved some progress so far, which is mainly reflected in the following aspects. The first concerns the formation of a research network based on DAD. At the annual academic symposium on DAD, endless studies are presented on the combination of data and design from academics and industry, promoting the development of data-driven design research. Second, a DAD guideline guided by methodology further refines the DAD method and its research content. Third, a trend of combining data with design has also been applied and promoted in college courses. The first author of this book launched a course named *Big Data and Urban Planning* at Tsinghua University, which attracted the attention of academics and achieved good outcomes. After a series of efforts, we received ample feedback from academia and industry. Therefore, we also hope to summarize the staged achievements of DAD in this chapter as an exploratory reference for planning and design methods in the new era.

2.4.1 Research Network and Annual Conferences

The DAD research network, established in 2015 as a community for DAD and led principally by a team from Tsinghua University, has been dedicated to the research and application of DAD. The DAD symposium, an annual conference for the DAD research network, was launched to facilitate the dissemination of up-to-date DAD research and applications from members of the research network. Five annual conferences have been held (Table 2.3), in which a large number of research institutions and individuals have participated, sharing and discussing pioneering research and design practices. The organization of these conferences can be regarded as a sign of broad acceptance of DAD in China. Readers seeking more detailed and slightly more technical information are referred to the BCL website, which lists the program of the third DAD symposium. (https://www.beijingcitylab.com/projects-1/17-data-augmented-design/symposiums/)

Table 2.3 Information on the five previous annual conferences on DAD

Order	Time	Place	Themes	Number of Reports
1	2015.12.05	Beijing Jiaotong University	Analysis and design in the data age	39
2	2016.12.10	Tsinghua University	Data augmented design	22
3	2017.12.23	South East University	New ideas and methods for DAD; Application of multisource big data to urban planning and design; DAD at the	11

			human scale	
4	2018.12.27	Tsinghua University	Data, design and the city	13
5	2019.12.23	China Architecture Design & Research Group	Data augmented design	9

2.4.2 Data Augmented Design Manual

Inspired by the DAD methodology proposed by Long and Shen (2015), Mao et al. (2016) developed a DAD manual for better supporting urban planning and design practices in China. The manual (Fig. 2.7) was put forward to support urban renewal. In this manual, for different levels of planning, tools, methods, indicators and other aspects of planning and design were proposed with respect to the analysis of the current status, program design, and evaluation and operation phases, rendering this a holistic solution for planning and design in the new data environment. Specifically, based on multisource data, the manual selects various elements (e.g., land use, location, spatial structure, population, employment, residence, functional quality, industry, transportation, etc.) as objects for analysis and research to guide users through the planning and design process and through the three phases of analysis, design and evaluation.

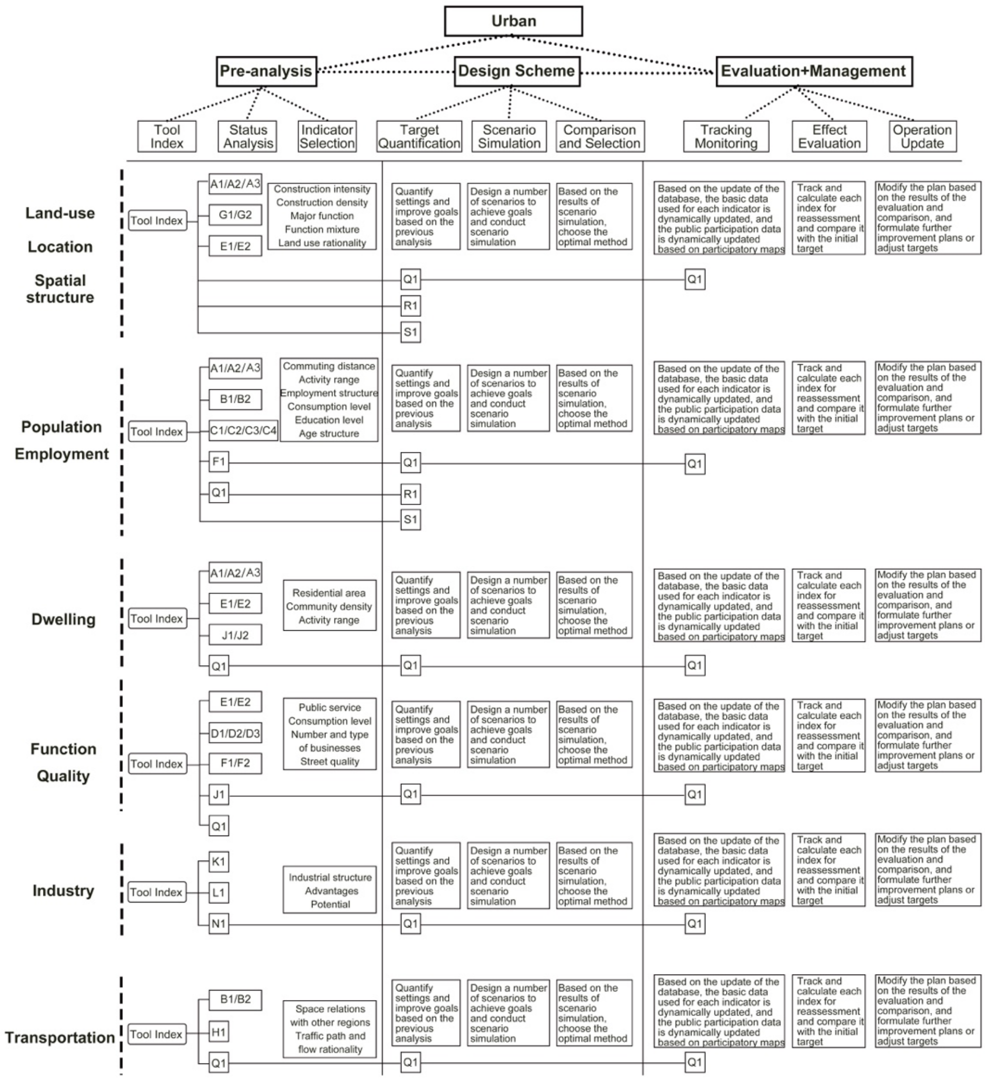

Fig. 2.7 The Data Augmented Design Manual for supporting urban renewal projects (Mao et al., 2016)

2.4.3 Education and Workshop

Educating urban planning graduate and undergraduate students, most of whom will become urban planners, with knowledge of DAD is important in advancing its further application. DAD has only been introduced into several courses under the Department of Urban Planning at Tsinghua University (Long, 2016). Such courses are titled *Big Data and Urban Planning*, *Structural Urban Design*, *Urban and Rural Comprehensive Surveying*, *An Introduction to Urban Modeling*, and *A New Science of Cities*. The spirit of DAD in these courses has been informational, allowing students to focus more on data analysis and quantitative studies in design. The courses can be divided into theoretical and practical courses.

1. Theoretical courses expand students' perspectives and promote acceptance of new data and cutting-edge technologies

Theoretical courses, such as *An Introduction to Urban Modelling* and *A New Science of Cities*, as cross-disciplinary courses fully combine new data and cutting-edge technologies in various professional fields. They provide important opportunities for better understanding the urban system and its development rules and outline important theories and technical support for urban research, planning and management. *An Introduction to Urban Modelling* illustrates both recent progress in urban modeling and the foundations of the Chinese urban system, providing students with a basis for applying urban modeling such as analytical methods and data visualization tools as well as various mainstream urban models (e.g., spatial interaction, cellular automata, multiagent systems, system dynamics, network analysis and artificial intelligence models). *A New Science of Cities* combines the recent progress of the new science of cities with its urban applications, including the contents of IoTs and citizen sensors, virtual and augmented reality, intelligent construction, artificial intelligence, computer vision, advanced urban modeling, and smart cities. It aims to enhance students' knowledge bases and to expand their perspectives on new data and cutting-edge technologies, the most important component of DAD. Such courses constitute early attempts to deliver theoretical courses related to urban science and urban modeling in China.

2. Practical courses encourage students to apply the DAD framework and philosophy in design studios and workshops

Practical courses, including *Big Data and Urban Planning*, *Structural Urban Design* and *Urban and Rural Comprehensive Survey,* serve as good opportunities for students to apply DAD to interdisciplinary urban studies and design practices. In these courses, students are encouraged to combine quantitative analysis with existing condition surveys and analysis for a more comprehensive study of sites. GIS tools, the GeoHey online visualization (www.geohey.com) platform, and new approaches to data mining and analysis are introduced to support the generation of design schemes, providing a stronger application of DAD to the design process. The course titled *Big Data and Urban Planning* also encourages the use of the online MOOC platform, which combines both recent progress in big data analysis and its applications to urban planning and design. Content focuses on big data acquisition, analysis, visualization and applications of planning tools from urban modeling methods to typical models as well as the emerging trends and potential revolution of big data in urban planning. Readers seeking more detailed information on this course are referred to https://courses.edx.org/courses/course-v1:TsinghuaX+70000662+1T2020/course/.

2.4.4 Feedback from Academics and Practitioners

With progress in DAD, the approach has received more attention from researchers involved in planning and design. 1) It has led to several special issues on the topic published in leading Chinese academic journals such as *Urban Planning International*, *Planners* and *Ideal Space*. 2) The lead researcher behind DAD has been invited by different planning and design institutes such as the Chengdu Planning and Design Institute, Qingdao Urban Planning and Design Institute, Shandong Urban and Rural Planning and Design Institute to report on DAD, and the journal *Chengdu Urban and Rural Plan* published a special issue on these reports. 3) The Human-scale Urban Form theory proposed by Long and Ye (2016) based on DAD has been well recognized by multiple experts, including the editor in chief of the journal *Landscape and Urban Planning*, in which he writes, "This is my favourite proposal, in the sense that the topic area is an exciting emerging area… I believe this to be a highly original and important theme for the special issue 'Measuring Human-scale Urban Form and Its Performance' in a rapidly developing field of science with increasing potential for applications in practice." This theory and its relationship to DAD will be introduced in next chapter.

2.5 Concluding Remarks and Discussion

2.5.1 Concluding Remarks

In reviewing the foundations and prerequisites of data and design, this chapter highlights tendencies of data-driven research and design, which have led to the introduction of a new planning and design support system termed Data Augmented Design (DAD) first proposed in 2015. In drawing on all kinds of data, including big, open, and conventional data, and embracing cutting-edge technologies, DAD can be regarded as a future-oriented design framework in terms of its focus on multidata, multimethod, multistage and multiscale approaches and use of a new planning and design support format following CAD, DSSs, GIS and PSSs. To better describe DAD, this chapter demonstrates the applicability of DAD within contemporary urban planning by introducing its three types of applications. Its progress in terms of the DAD research network and annual conference, the DAD manual, courses and workshops are also illustrated. Planners, officers and students as well as citizens can benefit from the research and design practices of DAD.

2.5.2 Potential Applications

Potential applications of DAD fall under two categories. First, as a new planning and design methodology, DAD has great potential to support multiscale urban planning and design practices, including redevelopment- and expansion-oriented urban planning and design. The other category of applications is future-oriented, under which DAD is most recognized for being committed to understanding new cities and combining new technologies to change new spaces, which can be used in the construction of smart cities. The data generated by advanced technologies in smart cities could provide support for DAD research, and DAD-based designs will combine the development of smart cities, comprehension of future urban forms, and the promotion of smart infrastructure construction and sensor application (Fig. 2.8).

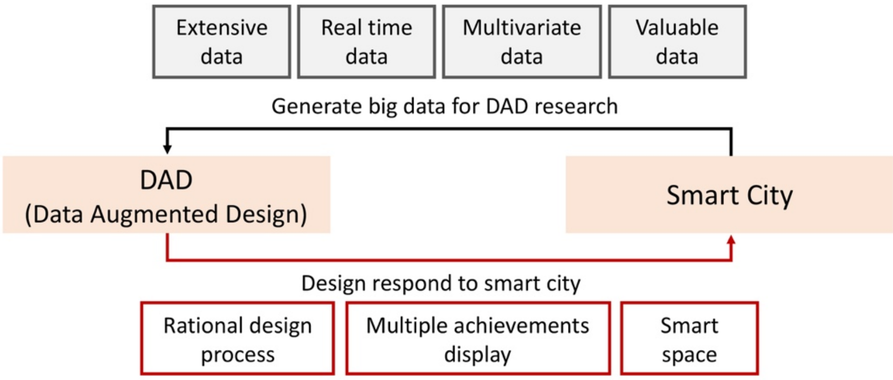

Fig. 2.8 Relationships between DAD and smart cities

2.5.3 Future Trends

As mentioned in Chapter 1, urban life and urban space are in transition as a result of technological developments. "Design" in DAD should also respond to and reflect this trend. Traditional design pays more attention to means of spatial intervention. However, with the application of sensors and the development of Internet of Things technology, future design will also embrace advanced technologies. Digital innovation will play an important role in design. Spatial design elements, including spatial interfaces of different functions and all kinds of urban furniture will be digitized, rendering space more intelligent, convenient, and flexible. In addition, digital means that do not rely on spatial elements such as mobile phone applications, AR (Augmented Reality), and VR (Virtual reality) will also change the use of space. The combination of Spatial Intervention and Digital Innovation (SIDI) is at the root of the future development of DAD and will guide the spatial projection of smart cities.

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