POZNAN UNIVERSITY OF TECHNOLOGY
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DOCTORAL DISSERTATION

Application Research of Simulation and Evaluation Based on BIM Technology in Urban Design

AUTHOR OF DISSERTATION
M.Eng. arch. Xia WEI

DISSERTATION SUPERVISOR
Professor Wojciech Bonenberg D.Sc. Ph.D. in Architecture

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Abstract

Cities are developing rapidly, the drawbacks of urban design issues are increasingly show, sustainable urban design has become the most significant demand for urban development. However, traditional urban design methods have been brutal to meet this purpose. The development and mature application of BIM technology provide an opportunity to solve this problem. This dissertation introduces the application process of BIM-based technology in urban design projects and profoundly analyzes the application methods in urban design. Researches how the BIM technology applications will make urban design more rational and standardized.

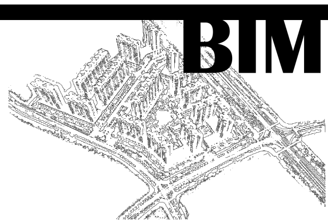
Building information model (BIM) is changing the entire building environment. Customers, professional designers, including contractors and manufacturers in the construction industry supply chain, want to seize the opportunities brought by BIM. Buildings and architectural environments are becoming more and more digitized, using computer data more and more. The use of BIM helped and facilitated this transformation, providing strong support for the digital industry, emphasizing the use of shareable building information to support better creation of the public domain. BIM can help achieve better results at all construction project life cycle stages and achieve sustainable building design. BIM is helping everyone move into the emerging urban planning and infrastructure industry, providing people and society with the value foundation they need. BIM data can quickly generate design options and better implement design options. Simulate and analysis evaluation early in the urban design phase to get better design results.

This dissertation focuses on exploring and researching the application, technology, and professional practice of BIM in urban design. Through theoretical analysis and case studies, the method of BIM technology to optimize urban design is discussed.

By studying the digital tools used in BIM projects, the dissertation emphasizes the “information” in building information models and the possibilities provided by data-rich models in urban design.

Utilizing questionnaire surveys, aiming at the influence of the current innovative design information system of BIM on traditional urban design methods, the research field and professional designers’ views on BIM in urban design are investigated. The conclusion of the questionnaire survey guides researchers in the future research direction of applying BIM to urban design.

Contents



1 Introduction

1.1 General overview

With increasing urbanization, the world is facing serious problems of energy shortage and environmental pollution, and cities need a lot of energy to support their construction. In such an environmental context, the development of new energy and technology fields is a priority and factor to be considered in urban construction[1]. At the same time, in order to solve the problems of urban environment and energy, it is necessary to develop and apply the implementation of sustainable buildings and cities. Sustainable cities require rational and effective urban design, which has a lasting impact on the urban environment for hundreds of years[2]. The sustainability of urban design is usually determined in the planning and design stages[3]. The most used technology in sustainable design in recent years is BIM application. The BIM (Building Information Modeling) information model contains rich and accurate digital information, including information such as dimensions, materials, and manufacturers of each building component[4]. Using its digital information model, BIM can carry out different types of analysis effectively in the architectural design process in the corresponding software. Most common CAD (Computer-aided design) design systems make it difficult to carry out sustainability analysis. This research explores the developmental history, current status, and application methods of BIM in the process of urban design.

The application of BIM in the design of independent buildings has been very prominent. However, there are still not many real cases and implementation projects in large-scale urban design projects. This dissertation assumes, that, through BIM technology in the

[1] Santamouris, M., 2013. Energy and climate in the urban built environment. Routledge.
[2] Haughton, G. and Hunter, C., 2004. Sustainable cities. Routledge.
[3] Moughtin, C., 2007. Urban design: street and square. Routledge.
[4] Sacks, R., Eastman, C., Lee, G. and Teicholz, P., 2018. BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers. John Wiley & Sons.

early planning and design process of urban design, urban design projects can achieve sustainable design more effectively.

1.2 The research problem and its genesis

Expanding urbanization is continuously consuming global natural resources and energy, causing environmental pollution and global climate change.
In 1900, only 13% of the earth's population was urban; in 1950, this proportion was 29%. Currently, more than half of the world's population lives in cities[5].
By 2050, the proportion of the world's population living in urban areas is projected to increase to 75%, increasing the urban population by 2.5 billion people. The greatest growth in urban population is occurring in Asia and Africa. This trend has been clearly visible since the year 2000. In the 21st century, the number of mega-cities has tripled. It is predicted that in 2030 the number of metropolises with more than 10 million inhabitants will have increased to forty-two[7]. It is worth realizing that, on a global scale, the total number of urban residents is increasing by 1.3 million every week[6].
The observed demographic trends in the world indicate that the center of urban activity is shifting from cities derived from Western culture, such as London, Paris, New York, towards new metropolises such as Shanghai, Beijing, Chongqing, Seoul, Dubai. This trend is presented by Daniel Brook in his book "A History of Future Cities"[7].
According to the research of Mckinsey Global Institute, 80% of economic growth is generated in urban areas[8]. According to a World Economic Forum report, capital associated with the construction industry in cities will increase to $7 billion by 2030[9].
Cities produce about 1.3 billion tons of waste per year, and it costs about $205 billion to dispose of it. As estimated by Hoornweg and Bhada-Tata, the amount of urban waste will increase to 2.2 billion tons in 2025[10]. According to the IPCC Working Group report, 70% of global energy is consumed by cities. The amount of carbon dioxide emissions is similarly configured[11]. It is estimated that cities consume 75% of the world's natural resources[12].

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[5] Floater, G., Rode, P., Robert, A., Kennedy, C., Hoornweg, D., Slavcheva, R. and Godfrey, N., 2014. Cities and the New Climate Economy: the transformative role of global urban growth.
[6] UNITED NATIONS, DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS, PD: World Urbanization Prospects, the 2014 Revision. Highlights 2014
[7] Brook, D., 2013. A history of future cities. WW Norton & Company.
[8] Dobbs, R., Smit, S., Remes, J., Manyika, J., Roxburgh, C. and Restrepo, A., 2011. Urban world: Mapping the economic power of cities. McKinsey Global Institute, 62.
[9] Alliance, G.G.A., 2013. The Green Investment Report: The ways and means to unlock private finance for green growth. In World Economic Forum.
[10]Hoornweg, D. and Bhada-Tata, P., 2012. What a waste: a global review of solid waste management.
[11] Change, C., 2015. Mitigation of Climate Change: Working Group III Contribution to the IPCC Fifth Assessment Report.
[12] United Nations Environment Programme: Global initiative for resource efficient cities, Engine to sustainability, 2014

It is also important to note the specific problems faced by cities in different parts of the world. In Western Europe, the main problems concern demographic collapse, migration and integration of immigrants. In Asia, there are problems with uncontrolled urban sprawl, weakness of planning at the regional and local levels, environmental pollution, and management of urban resources. The main problems of American cities are uncontrolled urban sprawl, social exclusion, and access to basic social and health services. In South America, they have to deal with urban overpopulation, uneven economic development leading to social tensions, political instability, lack of common access to education and social services, poor state of public safety, substandard housing. In Africa and the Middle East, the main problems are the lack of water, food shortages, safety and security of the population, armed conflicts, migration of residents, political instability.[13]

Cities around the world struggle with many common problems. These may include: disproportionate social and economic stratification, insecurity, water, food and housing shortages, access to health services, environmental pollution, and the negative impact of cities on climate change.

It can be seen that the urban planning methods used to-date have not kept pace with the emerging environmental, social, transport and infrastructure challenges. As Dorling (University of Oxford) notes[14], a large part of these problems is due to weaknesses in urban planning and urban design at the local and regional level.

There is a noticeable technology gap between urban design methods and design methods in architecture and industrial design.

In architecture and industrial design, a significant development of design methods can be observed, taking account of contemporary consumer demands and competitive challenges. Architecture and industrial design have begun to implement methods based on the requirements of engineering, product life cycle planning methods, and advanced methods of project effectiveness control.

Examples include: Building Information Modeling (BIM), Building Life Cycle Modeling (BLCM), Building Performance Evaluation (BPE), Integrated Project Delivery (IPD). To these increasingly used methods can be added new methods that are being dynamically developed:

- Experience Management (XM) [15],
- Competitor Analysis (CA) [16],
- Customer Relationship Management (CRM) [17],

[13] Bonenberg W. Miasto przyszłości. Builder 05/2018, pp.42-45

[14] Dorling D. Population 10 Billion: The coming demographic crisis and how to survive it. Constable and Robinson, London 2013

[15] Tynan, C., McKechnie, S. and Hartley, S., 2014. Interpreting value in the customer service experience using customer-dominant logic. Journal of marketing management, 30(9-10), pp.1058-1081.

[16] Fleisher C.S., Bensoussan B.E.: Business and Competitive Analysis: Effective Application of New and Classic Methods, FT Press, Upper Saddle River, New Jork 2007.

[17] Greenberg, P., 2001. CRM at the speed of light: Capturing and keeping customers in Internet real time. Berkeley, CA: Osborne/McGraw-Hill.

- Customer Journey Planning (CJP) [18],
- Kaizen method [19],
- Integrated environmental management systems (ISO 14000),
- Neuro-Design [20],
- Intelligence-Based Design [21],
- Precedence Diagram Method (PDM) [22].

From this collection of new design technologies, the author saw the greatest opportunity to implement Building Information Modeling (BIM) technology in urban design. In the author's opinion, BIM technology can contribute to improving environmental, social, transportation and infrastructure difficulties faced by modern cities. The author believes that creative implementation of BIM in urban design will contribute to more sustainable development of settlement structures.

The research problem outlined in this way reflects cognitive gaps in the current state of knowledge regarding the possibility of applying BIM in urban design. The problem addresses important cognitive issues, investigating the relationship between digital spatial modeling tools and urban design. The problem is directly related to applied research into specific design issues in urban design.

It is important to keep in mind that BIM is a relatively new and dynamically developing tool for which there are not yet clearly defined application boundaries. These boundaries are constantly being expanded to include more and more relationships between the built environment and the technical, social, natural, and organizational environments of contemporary urban structures. The conducted research is in line with the scientific interpretative direction, which can be illustrated as a dynamic network of spatial, social and natural connections with a variable configuration.[23]

1.3 Research questions (Research postulate)

The presented research problem has an autogenous character, resulting from planning and design experience, case studies analysis, readings, scientific discussions and independent thoughts and observations. This problem formed the inspiration to undertake research in the field of application of BIM in urban design. On this basis, the

[18] Brown T.: Change by design, Harper Collins Publishers, New York 2009.
[19] Maurer R.: The Spirit of Kaizen: Creating Lasting Excellence One Small Step at a Time (1 ed.), McGraw-Hill, Columbus 2012.
[20] Hevner A.R., Davis C., Collins R.W., Gill T.G.: A neurodesign model for IS research. Informing Science: the International Journal of an Emerging Transdiscipline, volume 17, 2014, pp. 103-132
[21] Salingaros N.A., Masden K. G.: Intelligence-Based Design: A Sustainable Foundation for Architectural Education World Wide, International Journal of Architectural Research, MIT, Vol. 2, Issue 1, 2008, pp. 129–188
[22] Nicholas J.M., Steyn H.: Zarządzanie projektami: Zastosowanie w biznesie, inżynierii i nowoczesnych technologiach, Oficyna Wolters Kluwer Business, Warszawa 2012
[23] Gibson B., Gareth M. Sociological paradigms and organisational analysis. Ashgate Publishing Company, 2008

objectives of the work and research questions were formulated, which have the character of research postulates.[24]

These questions can be formulated as follows:

- **What are the research trends in the use of BIM in urban design?**
- **Can BIM technology be as useful in urban design as in architecture design?**
- **In which elements of urban design can BIM find effective application?**
- **Will this BIM-based design technology completely replace traditional urban design methods?**

Methodologically, the above-mentioned research questions arise directly from the research problem and they have two directions:

(1) Cause-effect direction, which determines the dependencies and connections between BIM and urban design;

(2) Utilitarian direction, related to the application of BIM in urban design practice. It can be noted that the questions formulated in this way are both explanatory and previsual (prospective-design).[25]

Such an approach to the research problem and research questions allowed distinguishing the descriptive layer (observation of the studied phenomena), the interpretive layer (interpretation of the studied phenomena) and the argumentative layer (justifying) of the scientific argument.

1.4 State of research

The state of the research will be presented in chronological order, covering the development of BIM from early conceptual ideas to today's advanced applications. Attention has been paid to the need, advocated in numerous studies, to incorporate graphical multidimensional analysis into urban design, analogous to the way in which architectural structures are designed using BIM.

At the outset, it should be noted that the conceptual basis of the BIM system dates back to the second half of the 20th century. In 1962, Englebart in his paper "Augmenting Human Intellect" presented a futuristic vision of architectural design based on parameterization and a relational database of building characteristics[26].

Alexander's 1964 paper "Notes on the Synthesis of Form" had a significant impact on object-oriented building information modeling. Alexander described design as "the process of inventing things which display new physical order, organization, form, in response to function."[27] The concepts in this work could not be realized in practice without a graphical interface through which to interact with a digital model of a building.

[24] Apanowicz J., Metodologiczne elementy procesu poznania naukowego w teorii organizacji i zarządzania, Wyższa Szkoła Administracji i Biznesu, Gdynia 2000

[25] Niezabitowska E. Research Methods and Techniques in Architecture. Taylor & Francis, New York, London. 2018

[26] Engelbart, D., 1962. Augmenting human intellect: A conceptual framework. Summary report. Stanford Research Institute, on Contract AF, 49(638), p.1024.

[27] Alexander, C., 1964. Notes on the Synthesis of Form (Vol. 5). Harvard University Press.

The first attempts at spatial imaging appeared in 1963 with the SAGE graphical interface and the Sketchpad program. The creator of this tool was Ivan Sutherland, whose invention influenced the development of methods of human-computer interaction.[28]

In the 1970s and 1980s, two main methods for visualizing digital models of geometric forms emerged. These were Constructive Solid Geometry (CSG) and Boundary Representation (BREP). CSG is a technique for defining new solids by combining other solids using Boolean operators: sum, common part and difference. This method is particularly useful in geometric modeling of architectural objects.

Boundary representation (BREP) is a way to interpret a shape using constraints. A solid is described as a set of connected surface elements that define a boundary between interior and exterior points. The boundary representation of a model includes elements such as surfaces, edges, and vertices. It also describes the geometric relationships between these elements. Compared to the CSG method, the boundary representation is more efficient and has a richer set of tools for shape modeling.

The history of the development of CAD and BIM methods is presented in De Monchaux's book "Spacesuit: Fashioning Apollo"[29].

Looking at architecture through the lens of a digital database helped to break down a building into its elemental components. A milestone in this regard was the Building Description System (BDS). It allowed for the creation of independent libraries describing building components that could be downloaded and attached to the overall model.

This program, written in 1974 by Charles Eastman, had a built-in graphical user interface, orthogonal and perspective views, and a database that allowed the user to search for information by material type, physical properties, price, and supplier. The Building Description System (BDS) was written before the era of personal computers and therefore very few architects used it in design practice[30].

Eastman's next project, GLIDE (Graphical Language for Interactive Design), created in 1977, was similar to contemporary BIM platforms.

During the 1970s, several systems were developed in the UK that found practical application in built projects. These include programs such as Cedar, Sonata, EdCAAD, and GDS. The first computer aided design system was RUCAPS (Riyadh University Computer Aided Production System). The system was developed by John Davison and John Watts (Liverpool University), who, together with the architectural firm GMW Architects, applied it to the design of Riyadh University. The system consisted of 38 different modules. It included time-based construction schedules, modules for generating building geometry, and modules for defining individual building elements

[28] Bonenberg, W., Giedrowicz, M. and Radziszewski, K., 2019. Współczesne projekowanie parametryczne w architekturze (pp. 1-365). Politechnika Poznańska.

[29] De Monchaux, N., 2011. Spacesuit: Fashioning Apollo. MIT press.

[30] Quirk, Vanessa. A Brief History of BIM. ArchDaily 12,07,2012. https://www.archdaily.com/302490/a-brief-history-of-bim (Accessed on 22 oct. 2019)

and putting them together. Over time, it became Really Universal Computer Aided Production System (RUCAPS) and was commercially available from 1977. RUCAPS was used in the design of London Heathrow Airport's Terminal 3[31].

The term "digital building model" (in the sense of BIM as it is used today) was first used in a 1985 article by Simon Ruffle [32].

During this time, we can see the development of specialized design support tools for many engineering disciplines. Certainly, this progress was driven by competition between the Western bloc of countries and the Eastern bloc. The Soviet bloc formed two prominent programmers, Leonid Raiz and Gábor Bojár, who in later years were the creators of the Revit and ArchiCAD design platforms. Bojár began his professional career at the state geophysical institute in the late 1970s. In 1980, he developed software to help solve a major problem related to the installation of a Soviet nuclear power plant. After this work was completed, the geophysics institute stopped funding Bojár for his work and, consequently, he continued his research abroad. In 1982, Bojár founded Graphisoft, of which he was president until 2007. In the 1980s, Bojár formed a partnership with Steve Jobs. In 1984 he used Building Description System technology to write Radar CH software dedicated to Apple's Lisa operating system. Radar CH in later years was renamed ArchiCAD, which became the first BIM software to be made available on Apple personal computers. Today ArchiCAD is the world's leading BIM software using a GDM (Geometric Description Language) environment.

A later but significant example of a simulation tool that provides feedback and variant spatial solutions was Building Design Advisor, developed at Lawrence Berkeley National Lab in 1993. This software used an object model of a building to make multivariant virtual models [33]. A significant example of a BIM tool was a software called "Revit" written in 2000 in C++. Revit revolutionized the world of building information modeling by creating a platform that used a visual programming environment to create parametric models, allowing for the addition of the time attribute as the "fourth dimension" of building modeling. This made it possible to generate construction schedules using BIM technology. In 2002, Autodesk purchased the company and began to heavily promote Revit, independent of the "Architectural Desktop" platform. In parallel, a number of specialized programs were developed to import BIM models into branch projects. These included Navisworks, Green Building Studio, Energy Plus, IES, Ecotect.

At this point it should be noted that the variety of programs used by architects and engineers made cooperation difficult, which was caused by different file formats. In order to standardize the digital recording of multi-discipline design studies, the International Foundation Class (IFC) file format was developed in 1995 to allow data

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[31] Port, S., 2012. The management of CAD for construction. Springer Science & Business Media.

[32] Ruffle, S., 1986. Architectural design exposed: from computer-aided drawing to computer-aided design. Environment and Planning B: Planning and Design, 13(4), pp.385-389.

[33] Papamichael, K., LaPorta, J., Chauvet, H., Collins, D., Trzcinski, T., Thorpe, J. and Selkowitz, S., 1996. The building design advisor (No. LBL-38584; CONF-9610271-1). Lawrence Berkeley National Lab., CA (United States).

exchange between different BIM platforms. IFC is an open independent file format specification that is not controlled by a single vendor. The IFC model has been recognized as an international standard by ISO 16739-1:2018.

The Danish government was the first to make the IFC format mandatory for publicly funded construction projects. This was followed by the governments of other Scandinavian countries.

The General Services Administration (GSA) in the United States has developed and promoted a national 3D-4D-BIM project. As early as 2003, established project policy stipulated that all building services projects for public utilities should use BIM. GSA also actively works with BIM vendors, federal agencies, professional associations, open standards organizations, and academic research institutions. Today, 72% of construction firms in the United States believe that using BIM technology can significantly reduce project costs.

The UK has developed a clear national strategy with government support, making it the undisputed global leader of BIM.

In Poland, more and more construction projects are starting to use BIM technology.

As the most sought-after application technology in the field of engineering construction in China, BIM is getting more and more attention, but the research on BIM in China started late. In recent years, China has tried to popularize this technology in the construction industry. Many professionals have intensified research on the widespread implementation of BIM under the policy of supporting innovation in construction. Some achievements have been made, but obstacles still exist in the current research and application of BIM. The China Construction Industry Association, in a 2012 survey, estimated that less than 15% of 388 companies were using BIM.

In parallel with the development of digital tools for managing building information, there has been a trend in urban design in China to criticize approaches that reduce complex urban problems to two-dimensional drawings. A number of studies have emerged, indicating the need for drawings representing urbanism in the form of three-dimensional views and complex graphical analyses depicting the relationships between factors affecting the quality of life in urban space.

Such an approach is expressed in the scientific works of Gzell. As the author writes: "However, if we treat the human environment as a three-dimensional work of art which is bringing us peace, happiness and the development of human intellect, this must be changed, mostly through urban design. It is one of the most attractive tools of creativity, exerting an important influence on all relevant parties (inhabitants, authorities, developers, planners, architects) involved in city development" [34]. In a similar manner, Andrzej Gawlikowski claims that, when organizing space in small towns, much more

[34] Gzell, S., 2016. Urban design and the sense of the city. Czasopismo Techniczne, 2016(Architektura Zeszyt 2-A (8) 2016), pp.15-19.

precision is needed in depicting spatial dependencies because each investment, each object, and each change of space affects the city and its character [35].

Solarek postulates the necessity of introducing the third dimension in spatial planning [36].

Guyrkovich analyzes the role of spatial three-dimensional elements of urban composition in building the image of the city center. His research indicates that selected elements of urban composition, which have been shaped in European culture over the millennia, are still necessary to create an efficiently functioning European metropolis [37].

The issue of the multidimensional approach to urban revitalization design of historic cities is discussed by Wrana [38].

Ossowicz compares urban creation to the work of gardeners in a real multidimensional space. "The conception of the city as a multidimensional living, developing biological organism has a tradition in urbanist thought. One need only cite Patrick Geddes (1854-1932), who treated the city as a product of nature undergoing an endless process of evolution."[39]

The cultural dimension of the city, closely related to the perception of space, is the subject of Zuziak's research. The author focuses his attention on the problems of the cultural urban construction of contemporary cities and on the improvement of cultural analyses. He postulates that cultural values should be included as a separate dimension of urban planning [40].

The aforementioned examples highlight the need to treat urbanism as a multidimensional phenomenon. Therefore, the use of BIM as a planning and design tool for depicting and analyzing complex urban relationships seems to be an urgent necessity. Currently, BIM is not widely used in urban design outside of some specific areas related to architectural forms. However, the building-related information provided by the BIM system can greatly guide the decision-making of urban planners.

With the deepening of the concepts of green buildings, smart buildings and sustainable urban development, traditional urban design is becoming less and less responsive to people's needs, and defects are becoming more and more evident, such as light pollution of buildings, spatial layout of buildings, lack of ventilation of urban neighborhoods and other problems. This confirms the urgent need to supplement existing research with BIM applications in urban design.

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[35] Gawlikowski Andrzej., 1988. Czy planowanie miejscowe może być skuteczne, Państwowe Wydawnictwo Naukowe, Instytut Urbanistyki i Planowania Przestrzennego Politechniki Warszawskiej. Łódź. pp. 134, 136.

[36] Solarek, Krystyna., 2019. Urban Design in Town Planning. Oficyna Wydawnicza Politechniki Warszawskiej. Warszawa.

[37] Gyurkovich, M., 2012. In search of the urban composition of sub-centres in polycentric european metropolises. ACE: architecture, city and environment, 6(18), pp.231-244.

[38] Wrana, J., 2017. Synergia w nieidealnym mieście „idealnym"–próby integrowania Zamościa. Budownictwo i Architektura, 16(1), pp.5-17.

[39] Ossowicz, T., 2019. Urbanistyka operacyjna. In Zarys Torii (Operational City Planning–the Outline of a Theory). Oficyna Wydawnicza Politechniki Wrocławskiej Wrocław.

[40] Zuziak, Z.K., 2020. Wstęp do nowej filozofii urbanistyki. Teka Komisji Urbanistyki i Architektury Oddział PAN w Krakowie, 48, pp.181-206.

1.5 Purpose of the research.

To ensure the city gradually moves towards sustainable urban ecological development, this dissertation studies the necessity of applying sustainable development based on BIM-based technology in urban design in view of the current shortage of resources, pollution, deterioration of air quality, and population density. It is important to combine the urban design with environmental development to meet the precise requirements of sustainable urban development. Urban design projects, whether sustainable conditions are in the design process, are also the key to achieving the best overall project benefits. In design engineering, technical designers can combine BIM technology to accomplish the overall design direction and design it as a city model with data. In this design, it is necessary to choose a scientific method to describe the architectural and environmental processes in the city and to balance them. It applies BIM's 3D digital model in the design phase, full consideration of social benefits, and economic and environmental sustainability. Given the broad application prospects of BIM technology, it can also reflect in the application of urban design.[41]

1.6 The research goals.

This dissertation aims to study the application of BIM as new information technology in urban design projects.

Urban design requires the integration of complex information about the city's traffic, location, surroundings, layout, and so on. Without an intuitive display and representation method when doing urban design, it is impossible to develop a detailed and effective urban design, and the 3D information model can intuitively reflect just this necessary information about the city.

First, it will examine the research theories and methods of BIM technology in the field of urban design. The scale, cycle, and complexity of modern urban design and construction projects have been entirely different. The theories and methods used in traditional urban design can no longer meet the problems encountered in current projects, such as life cycle management and multi-party collaboration. This dissertation will analyze the current research situation and provide strong theoretical support for subsequent research.

The limitations of traditional urban design methods have led to the timely, accurate, and efficient interaction of information on urban design projects. By combining urban design, this dissertation puts forward the specific methods and procedures of BIM application in urban design. It provides new ideas for urban construction projects.

It will study the evaluation methods of existing urban design projects, compare the application of BIM in architectural design, sort out the beneficial elements and methods

[41] Saad, M.M., Ibrahim, M.A. and El Sayad, Z.M., 2017. Eco-city as approach for sustainable development. American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS), 28(1), pp.54-74.

of using the BIM information model to evaluate urban design projects. It will find the best design method in the design stage for the purpose of sustainable urban design.
BIM and sustainable design did not have many intersections at first. Sustainability design did not receive much attention in the early days. Sustainable design is beginning to gain notice because the consumption of non-renewable energy decreases, greenhouse gas emissions increase significantly, and the consequences of global warming are growing. In practice, designers often overlook the link between urban and sustainable development environments because of the high cost of energy savings. With the advent of BIM technology, there is an opportunity for improvement in this state of affairs. By using versatile and straightforward building information models with the appropriate BIM software, architects can quickly assess the performance of physical building environments at any time or any stage of the design. Architects perform a series of reasonable adjustments to the program through the analysis results obtained. They compare and analyze the advantages and disadvantages of different solutions from an environmental perspective to determine the choices that meet the building sustainability requirements. In the early stages of design, architects can obtain accurate and intuitive feedback on building energy performance and BIM-based applications to achieve the most outstanding sustainability in computer-aided building design.[42]
BIM technology has had a profound impact on the sustainable design of cities. Designers can fully quantify sustainable urban design through BIM's information model, providing a useful tool for urban energy-efficient design. BIM technology can analyze the characteristics of the whole city in detail, and it virtualizes the objective conditions such as economic conditions and human conditions into the information model to analyze and develop better plans for the city. Therefore, BIM can comprehensively and uniformly arrange the city's land use, spatial layout, and infrastructure. BIM creates conditions for transportation, landscaping, environmental protection, other facilities and planned implementation.
Design is the most critical stage that affects the life cycle of an entire project. It will directly affect other steps. With the increasingly scientific and technological content of planning and design and the increasingly complex process, the traditional CAD two-dimensional design technology cannot meet the current design requirements. Including BIM technology in architectural planning and design can improve efficiency, control quality, reduce error rate, and facilitate modification and adjustment. BIM has seen significant improvements in cost and time savings, especially in estimating, reworking, changing, and avoiding errors caused by lost information. However, the use of BIM for future planning and design projects involves more than just altering the software currently in use, but requires a set of upgrades from theory to practice. To benefit from everything BIM offers, everyone in the planning, engineering, and construction industries needs to understand how to work in new ways. The construction industry is

[42] Reizgevičius, M., Reizgevičiūtė, L. and Ustinovičius, L., 2015. The need of BIM technologies implementation to design companies. Ekonomia i Zarządzanie, 7.

one of the most wasteful industries in the world. It consumes many raw materials and energy supplies. It generates a large amount of global solid waste and produces half of greenhouse gas emissions. Through BIM technology, it can effectively cut costs. Therefore, this dissertation hopes that, through the study of theory and case-history, it can offer appropriate guidance and promotion, of value for BIM technology development in urban design.

1.7 Description and scheme of the research methodology

This dissertation conducts research based on the basic ideas of asking questions, analyzing problems, solving problems, case studies, questionnaires, and research conclusions. The research methods used mainly include:

- Scientometric Analysis
- Empirical Research
- Questionnaire

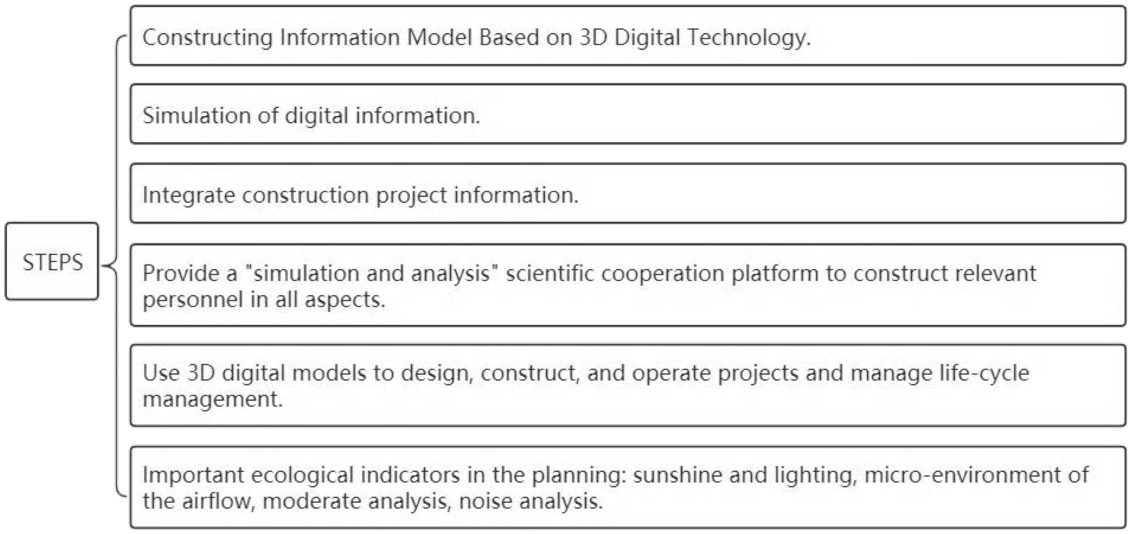
1.7.1 Scientometric Analysis

The research used innovative tools - Scientometric Analysis for identifying the research trends in the use of BIM in urban design from 2010 to 2020.
Scopus and **Web of Science (WOS)** bibliographic and abstract databases were used for the analysis.
The research results provide valuable information for researchers, practitioners, and decision-makers through visual analysis results. They allow researchers, practitioners, and decision-makers to understand the latest developments in the field of BIM research in urban design and to know future research needs.

1.7.2 Empirical Research

To analyze the application method and principle of BIM in the urban design project more clearly, this dissertation takes the actual project as an example, to study how to use the BIM model's digital information to design the conceptual design of the project. In the design phase, the BIM information model is used to construct an information platform. Through the simulation of digital information, various elements of project-related information are integrated to simulate and analyze various aspects of the project and obtain the results. The research BIM application steps:

Table 1. The research BIM application steps.



1.7.3 Questionnaire

In the era before CAD, architectural engineering designers used rulers and pens to outline architectural designs bit by bit. The advent of CAD greatly improved the working conditions of designers, and at the same time, completely changed the form of engineering design drawings. The emergence of BIM was another major change, as drawings became three-dimensional and four-dimensional from the original two-dimensional. Will CAD be replaced by BIM in the future, and will BIM become as indispensable as CAD? This dissertation research will invite urban design experts from various countries to make a questionnaire survey on this issue, so as to fully understand the current problems of BIM in urban design, and explore the solution to the issues, and thus find the direction of future research development.

1.8 The research objectives

The definitions and scope of the main research objects covered in this dissertation are as follows:

- **Object 1: Cities for sustainable development**. The urban design focuses not only on the combination of individual building groups but also on the city's harmonious unity. From the perspectives of finding problems, analyzing problems, and solving problems, this dissertation expounds on the lack of sustainable development factors in urban design. It gives the design principles and design methods of sustainable urban development.
- **Object 2: BIM information modeling.** The BIM model is the core of BIM technology and is a digital model for the design, construction, and operation of a construction project's entire life cycle. It contains all the building's geometric information and contains non-geometric information such as the physical properties

of the building materials, component prices, construction process, and maintenance management. BIM models can be used in architectural design, building analysis, construction drawings, maintenance management, and other aspects of the project. The BIM models commonly used in a project mainly include the following types: design model, construction drawing model, design coordination model, analysis model of specific system, cost and planning model, construction coordination model, processing detail of the system, and pre-stab model, completion model, etc. The BIM model targeted in this dissertation is a robust three-dimensional model of the architectural design stage. In addition to the building's geometric shape information, it also covers the relevant functional information of the building. Through the simulation analysis of the BIM model, find the application method in urban design.

- **Object 3: BIM simulation and evaluation application.** In the 3D platform of urban design, BIM can fully realize the multi-dimensional application that cannot be recognized by the current 3D simulation system. In particular, the performance analysis of urban design schemes can solve problems that cannot be quantified by traditional methods, such as comfort and noise cloud maps. The performance analysis of BIM will have a positive impact on the quantification of multiple indicators, scientific development and sustainable development of urban design. The urban design micro-environment simulation is based on 3D information model, through the micro-environment simulation platform, the micro-environment indicators are simulated and evaluated to control and adjust the detailed design; and the building space layout is effectively adjusted.
- **Object 4: Smart city design approach based on BIM technology.** Extend the superiority of BIM technology in the optimization and coordination of above-ground buildings and pipelines to the underground pipes and municipalities. A group-level urban information model with full coverage above and below the ground is synthesized by combining the three-dimensional information model of the above-ground structures. This information model is a comprehensive collection in form and carries a more analyzable value on data information and thus becomes a model for planning management of emerging cities. The urban information model covered by big data can be applied to various planning management units, from single to residential areas, from individual public buildings to entire commercial streets or public buildings. Through the application of BIM technology, a smart city is being realized.

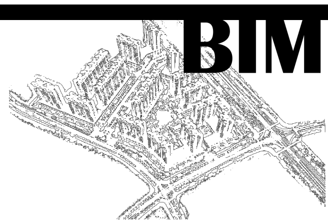
1.9 Structure of the thesis

This dissertation is organized through the following sections:

- **Chapter 1. Introduction.**

Introduction to the whole research content, the background of the research, and the significance of the study.

- **Chapter 2. Scientometric analysis and visualization of BIM research in urban design.**
  Use Scientometric methods to analyze and study the development trend of BIM in urban design.
- **Chapter 3. Definition of Building Information Modeling (BIM) and Urban Design.**
  Introduce the development history of BIM and the definition of BIM.
- **Chapter 4. BIM in urban design.**
  Information based on BIM technology simulation in urban design methods and processes. Study how BIM applications evaluate urban design.
- **Chapter 5. Application of BIM in urban design.**
  Analyze the current application of BIM in urban design. By studying actual cases, find the process and method of applying BIM to urban design.
- **Chapter 6. The impact of BIM technology on traditional urban design methods.**
  Use questionnaires to study the influence of BIM on traditional urban design methods.
- **Chapter 7. Synthesis of Research material.**
  A synthesis of the research material is organized with reference to the main objectives in the dissertation title.
- **Chapter 8. Summary and Conclusions.**



2 Scientometric Analysis and Visualization of BIM Research in Urban Design

2.1 Scientometric analysis

Building Information Modeling (BIM) technology has developed rapidly and has attracted extensive attention from the construction industries of various countries. A comprehensive understanding of the research progress in BIM has essential reference value for scientific researchers and corporate departments to carry out related work. This dissertation uses the Scopus database as its data source, uses a combination of qualitative and quantitative research methods, and uses the visualization tool- CiteSpace software in order to sort out the relevant literature on BIM and urban design published between 2010 and 2020. It will draw a map of scientific knowledge and compare and analyze the three aspects of architectural design, urban design, and BIM. According to the results of this quantitative analysis, it will be clear what are the research trends in the use of BIM in urban design.[43]

2.1.1 Introduction of scientometric analysis

Since its inception in the 1960s, scientometrics has been widely used in many ways, such as the strength inspection of scientific research subjects, the quality evaluation of

[43] Li, X., Wu, P., Shen, G.Q., Wang, X. and Teng, Y., 2017. Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. Automation in Construction, 84, pp.195-206.

academic journals, the formulation of scientific and technological development plans, and scientific management funds projects.[44]

Scientometrics is a theory that uses measurement methods to study overall scientific and technological development and the law of quantity and contribution of related components and to explore the trend in scientific and technical activities.

Scientometrics is a discipline that takes science itself as the research object and conducts quantitative research. With scientometric indicators, this discipline uses mathematical methods to measure the results of scientific research, describe the structure of the scientific system, analyze the internal operating mechanism of the scientific approach, reveal the temporal and spatial characteristics of scientific development, and explore scientific activities in the context of the entire society quantitative regularity.[45]

2.1.2 The scientometric toolkits CiteSpace

As an excellent bibliometrics software, CiteSpace can visualize the relationship between documents in front of the operator in the form of a scientific knowledge map, which can help us sort out the trajectory of past research and enable us to study the future, giving a general understanding of future prospects.

CiteSpace is also translated as "citation space". CiteSpace is a visual analysis software that focuses on analyzing potential citations in scientific knowledge. It is a scientific measurement and data visualization of scientific knowledge.[46]

CiteSpace is a software used in scientific literature to identify and display new trends and developments in scientific development.

Using the analysis results of this software, we can know:

- In which years did research in this field begin to appear.
- In which years did the research results in this field began to increase.
- In which years did the attention to this field began to decrease.
- In the research and development process of the entire research field, which years have marked documents, and how these documents affect the trend of the whole research field.
- Co-author analysis can show who the researchers in this field are.
- The analysis of cooperating countries can discover which countries pay more attention to and develop better in this research field.
- From the analysis of the knowledge map in the scientific field, we can see the research field's situation.

[44] Geisler, E. and Abdallah, W., 2000. The metrics of science and technology. Greenwood Publishing Group.
[45] Bastide, F., Courtial, J. and Callon, M., 1989. The use of review articles in the analysis of a research area. Scientometrics, 15(5-6), pp.535-562.
[46] Chen, C., 2017. Science mapping: a systematic review of the literature. Journal of data and information science, 2(2).

Moreover, with this CiteSpace software, all analyses can be visualized, allowing researchers to understand the research field's development and trend more clearly.

2.2 The research searches.

2.2.1 Search framework

The scientometric research framework and steps (Figure 1) are:

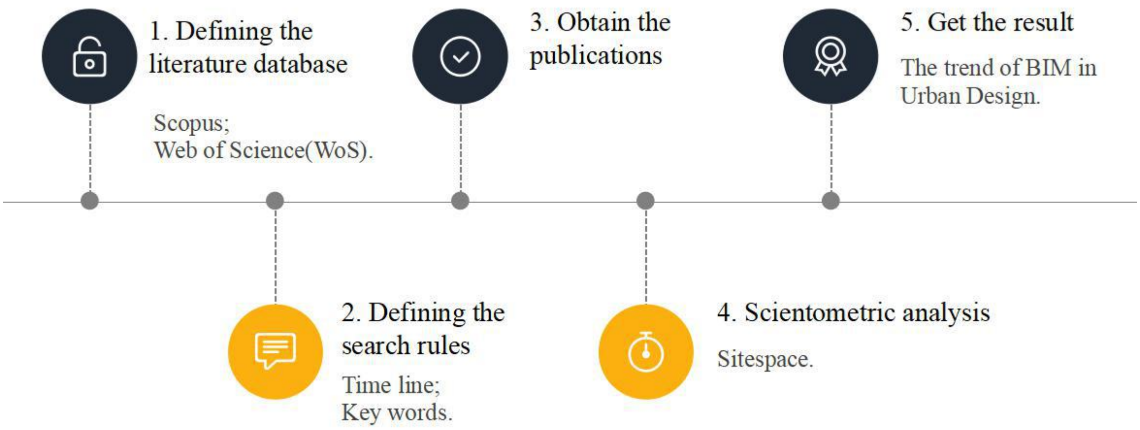


Figure 1. The scientometric research framework and steps. (Author research)

(1) **Defining the literature database:**
Scopus will be used as the main literature search database in this research.

(2) Defining the search rules:

- Time: Year 2010-2020
- Topic: BIM Urban design
- The basis for identifying research trends:
  - Article title
  - Abstract
  - Keywords
  - Authors

2.2.2 Search results

Obtain the publications:
When the search concerns "BIM", "Urban" and "Design", 397 document results come out. It is shown in Figure 2.

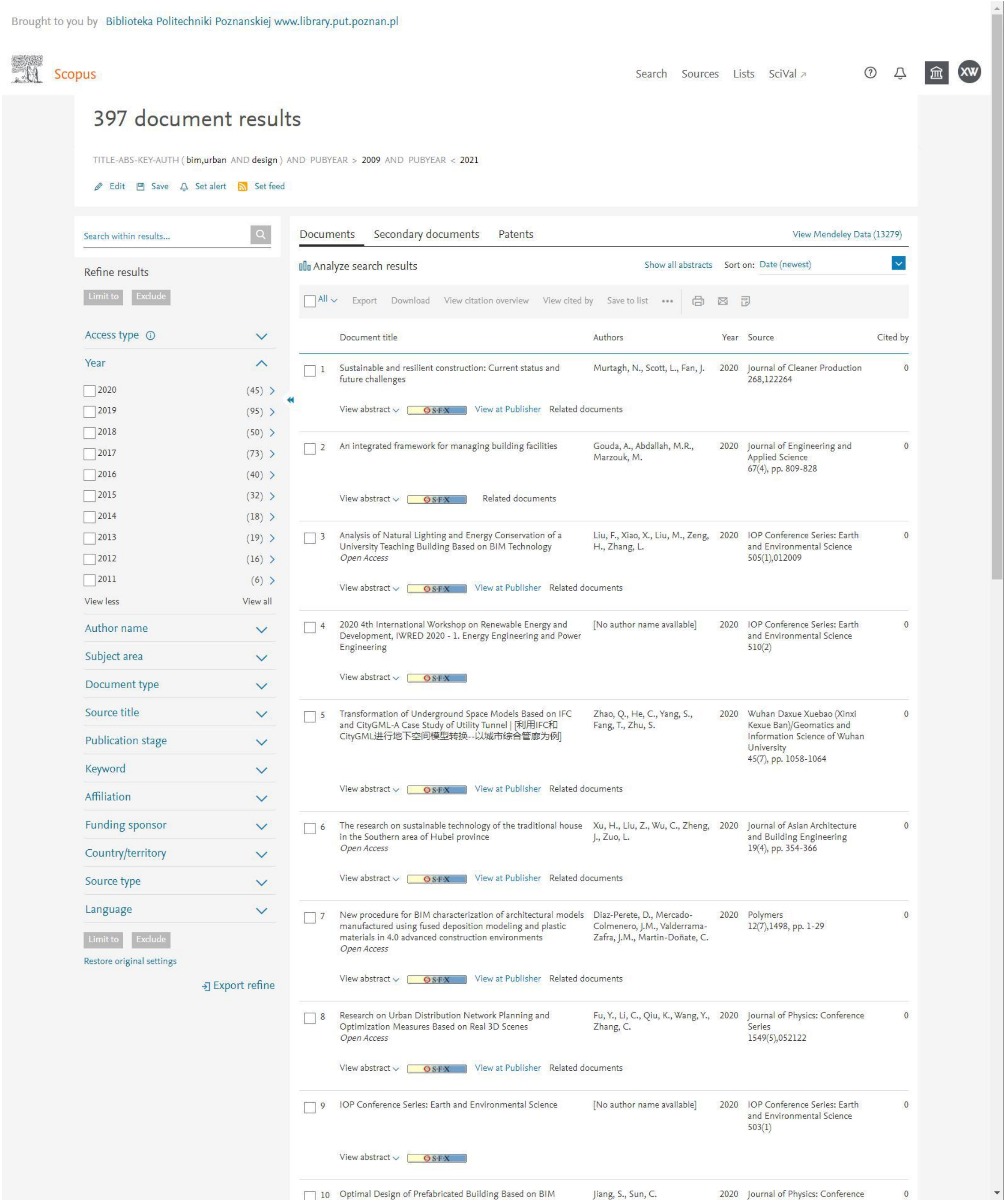


Figure 2. “BIM Urban Design” Document results in Scopus 2010-2020. (Author research)

When the search concerns only “Urban Design”, the results are 57218 documents in Figure 3.

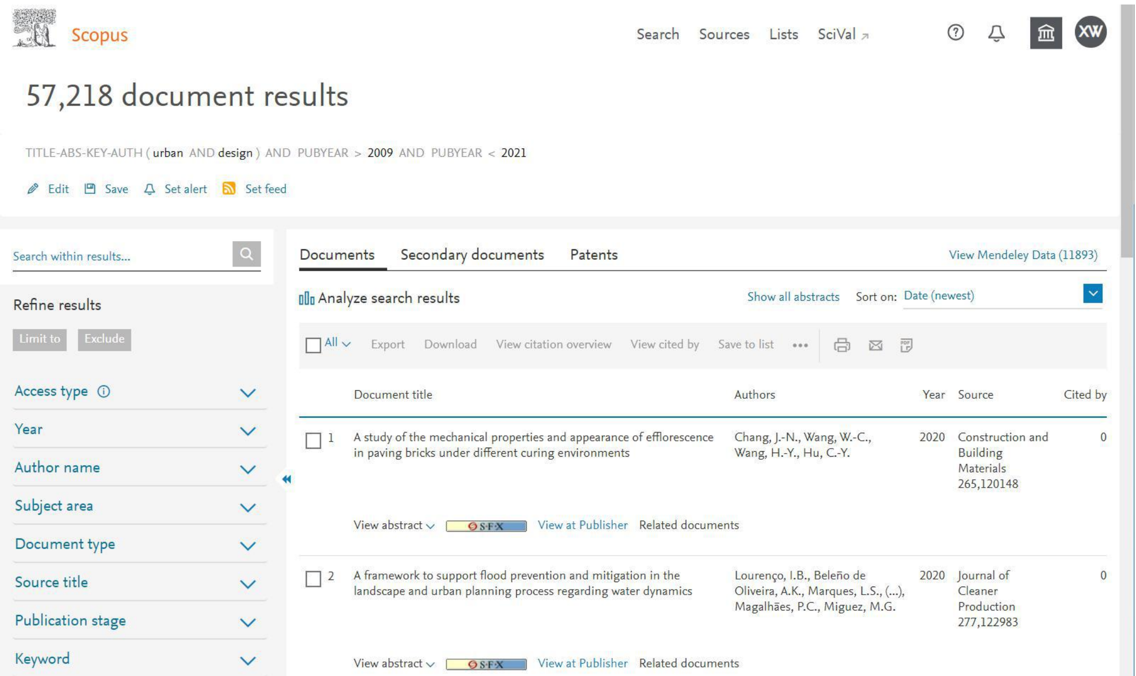


Figure 3. “BIM” Document results in Scopus 2010-2020. (Author research)

When the search concerns “Architecture Design|”, the results are 140051 documents in Figure 4.

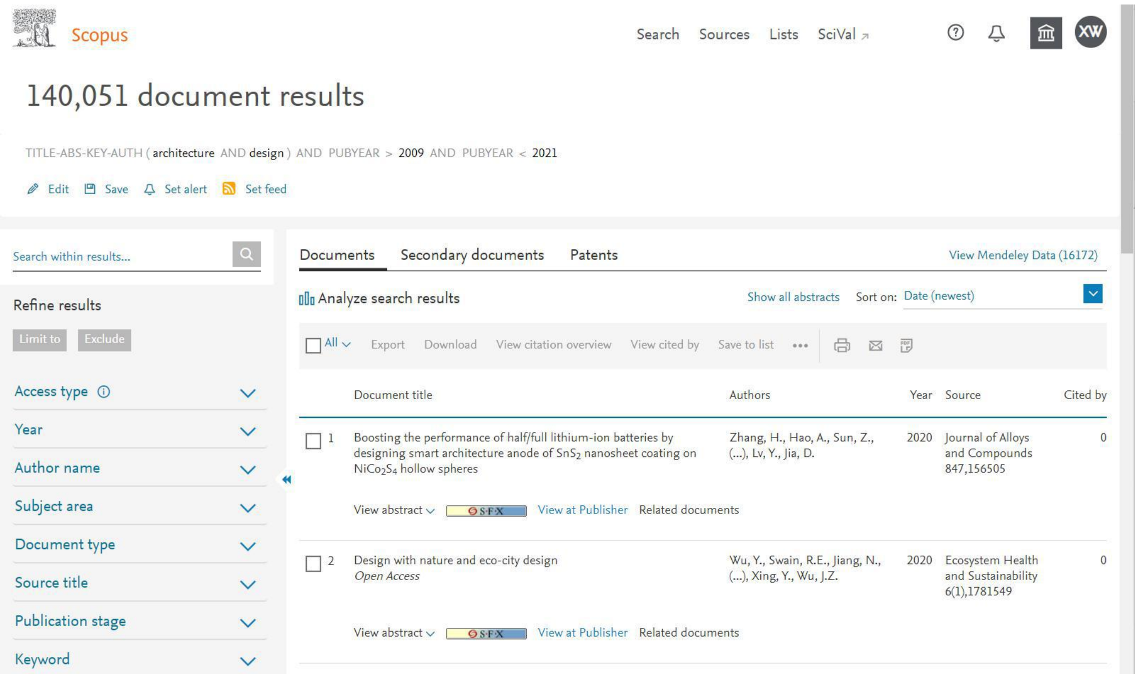


Figure 4. “Architecture Design” Document results in Scopus 2010-2020. (Author research)

Comparisons were made:

- To document counts for countries/territories
- To authors
- To subject area
- By the year of publication

Analyze search results in "BIM urban design". It contains different results:

- **Document counts for countries/territories** (Figure 5)**.**

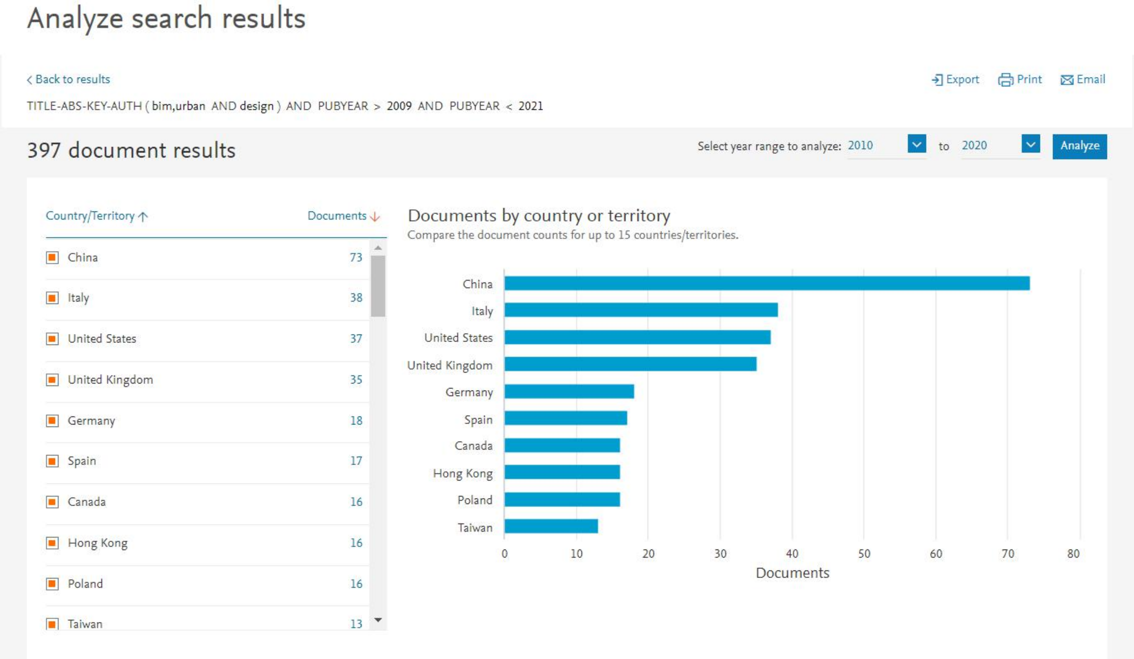


Figure 5. Analyze "BIM urban design" Document counts for countries/territories. (Author research)

The analysis of "BIM urban design" document counts for countries shows China has most researches in this field, then Italy, USA, UK. Poland has 16 publications about BIM in urban design.

- **Documents by author** (Figure 6)**.**

Figure 6. Analyze "BIM urban design" Documents by author. (Author research)

This analysis shows the publication and research authors.

The author from California State University, East Bay, Hayward, United States Ciribini Angelo Luigi Camillo, contributed five publications.

- **Documents by subject area** (Figure 7)**.**

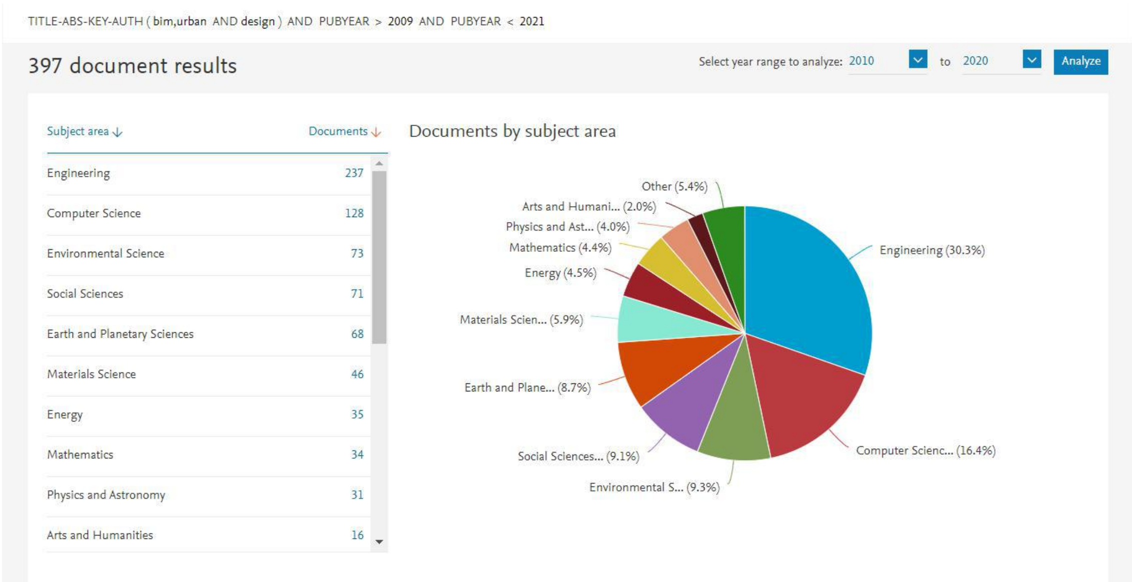


Figure 7. Analyze “BIM urban design” Documents by subject area. (Author research)

The analysis shows that most of the subject area is from engineering, 237 publications, which represents 30.3 percent. Computer science has 128 publications, taking 16.4 percent. Then environment science, 9.3%.

- **Documents by year** (Figure 8)**.**

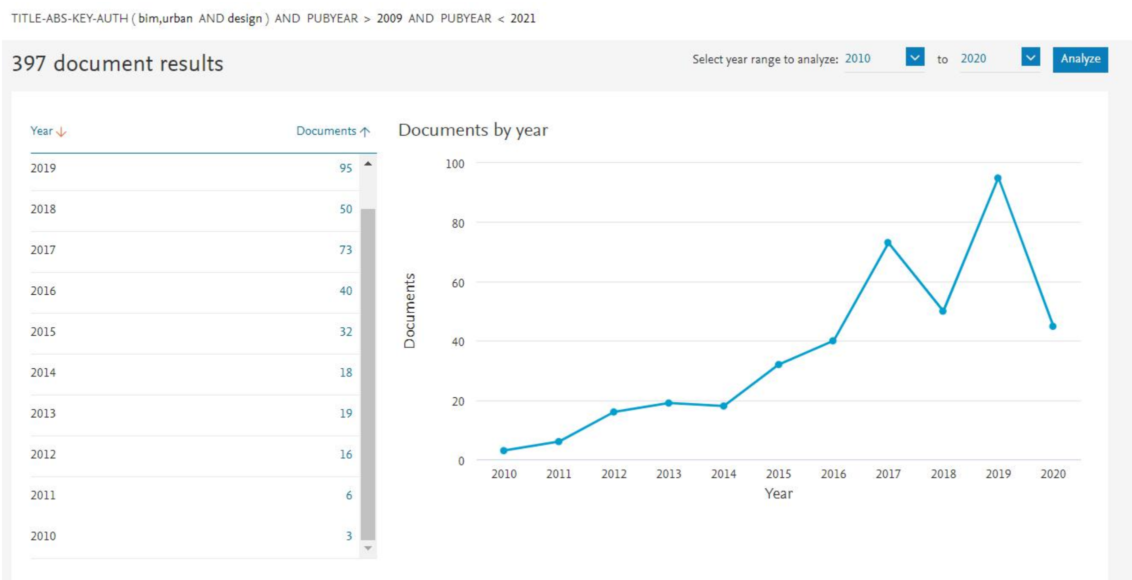


Figure 8. Analyze “BIM urban design” Documents by year. (Author research)

Research into BIM in urban design was rare until 2010. It has become more popular since then, but it is still quite limited. There were 95 research publications in 2019, compared to other research, such as " architecture design", which had 16306 research publications, and "urban design" which had 7961 research publications.

2.3 Visualization of BIM research in urban design

2.3.1 The concept of scientometric analysis

The basic analytical units are: "items" and "links". (Figure 9)

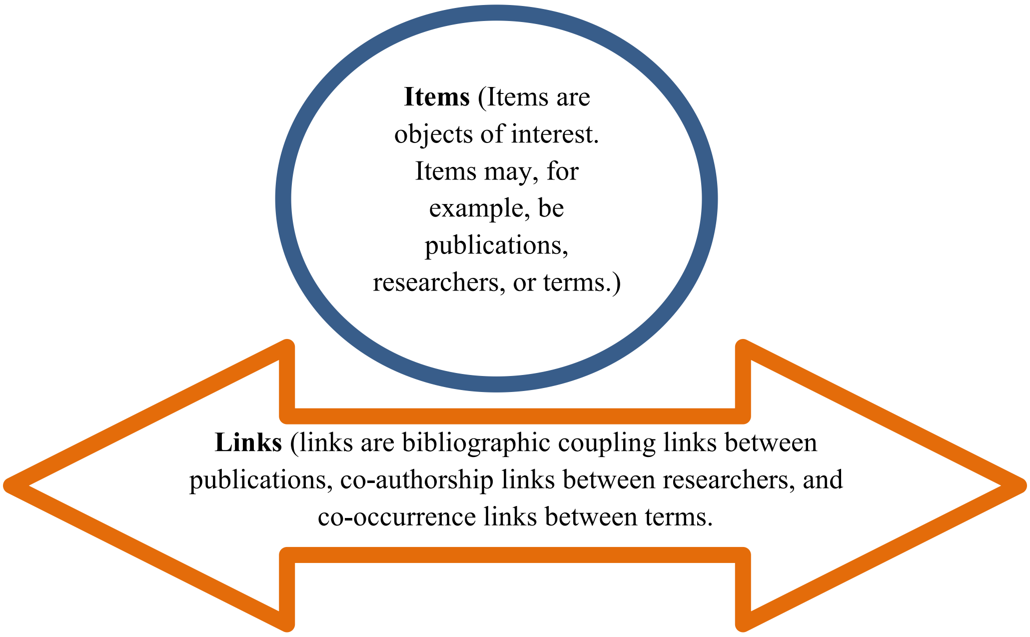


Figure 9. Items and Links. (Author research)

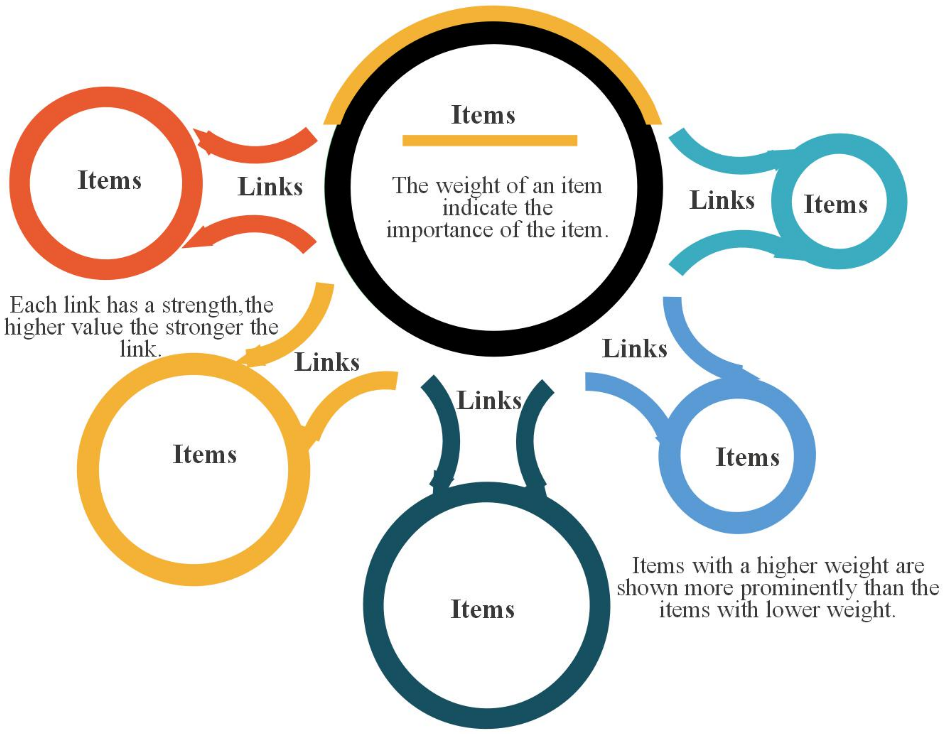


Figure 10. Concept of Scientometric analysis diagram. (Author research)

From the conceptual diagram of scientific measurement analysis in Figure 10, the visual analysis diagram shows that items with higher weights appear more prominently in the analysis diagram. [47]

2.3.2 The visualizations of Scientometric analysis

Cumulative method of analysis cover: **Co-occurrence** of the terms, and **Co-authorship**, combined with **keywords (index keywords)**, countries, organizations, number of documents, citations, and link strength.

Some occurrences of keywords, the total strength of the co-occurrence links with other keywords. The keywords with the greatest total links were selected.

- **"BIM urban design" Co-occurrence of the research areas.** Figure 11.
  The analysis of Figure 11 shows that "Architecture design" has the most Co-occurrence of the research area with "BIM urban design", the next is "Building information model" and "Urban planning".

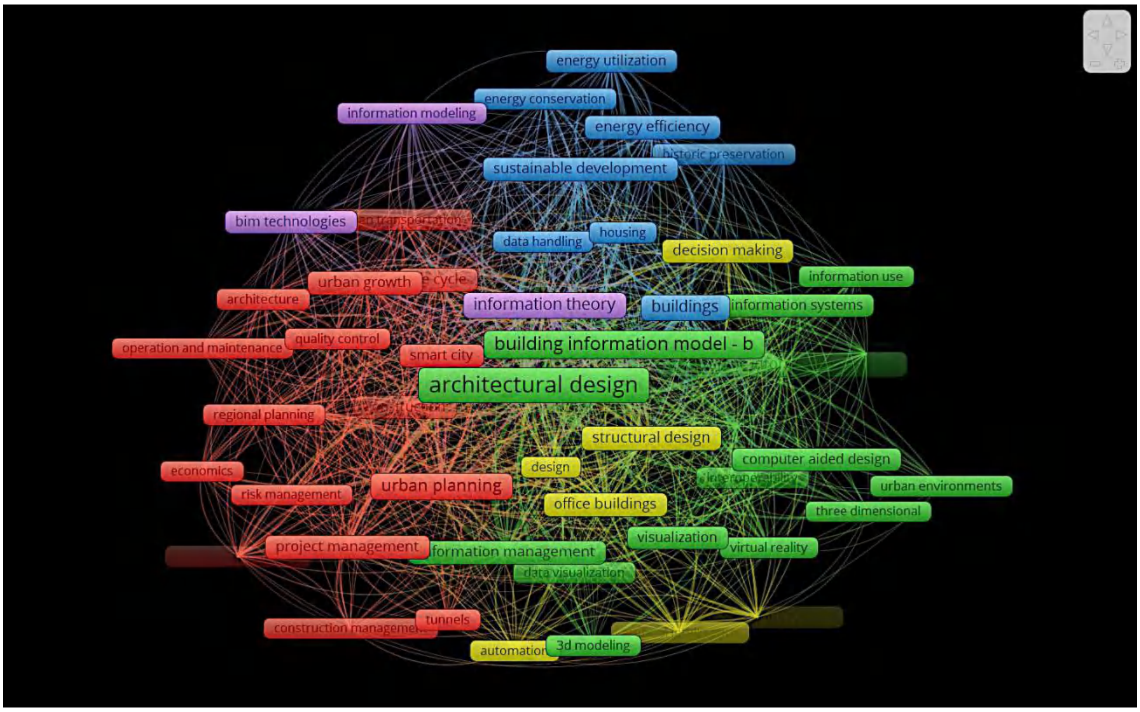


Figure 11. "BIM urban design" Co-occurrence of the research areas. (Author research)

- **Links "Architectural design" (Co-occurrence of the "BIM urban design").** Figure 12.

[47] https://www.vosviewer.com/. (Accessed on 02 July 2020)

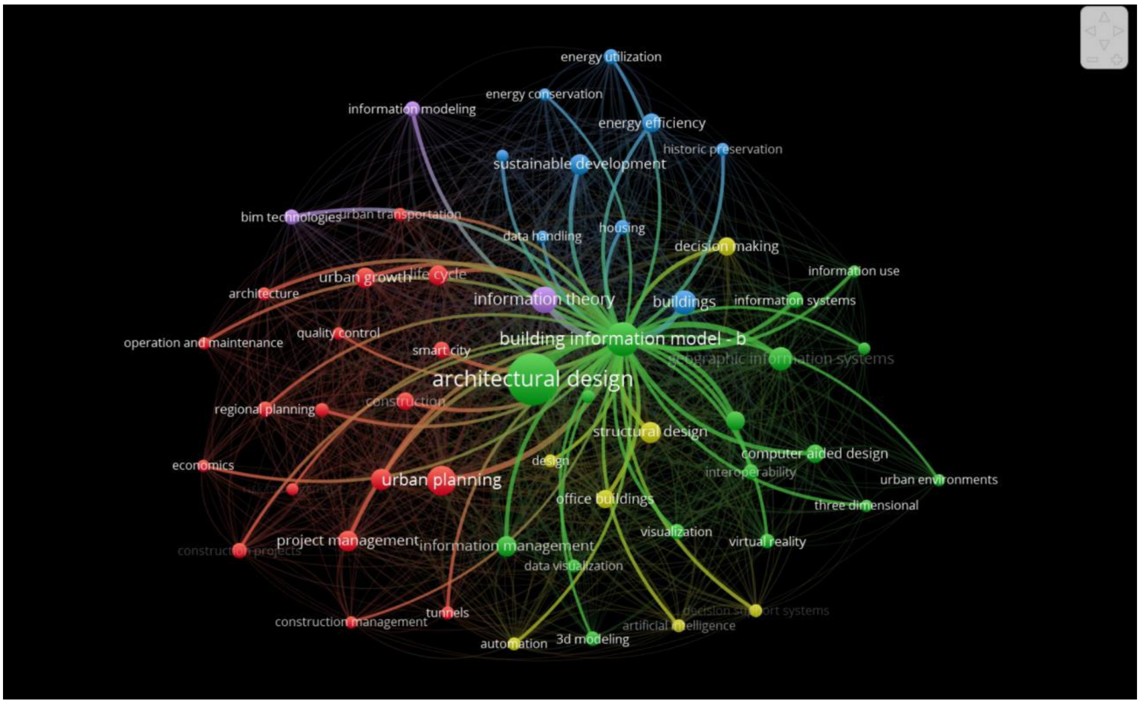


Figure 12. Links “Architectural design” (Co-occurrence of the “BIM urban design”). (Author research)

- **Links “Urban planning” (Co-occurrence of the “BIM urban design”).** Figure 13

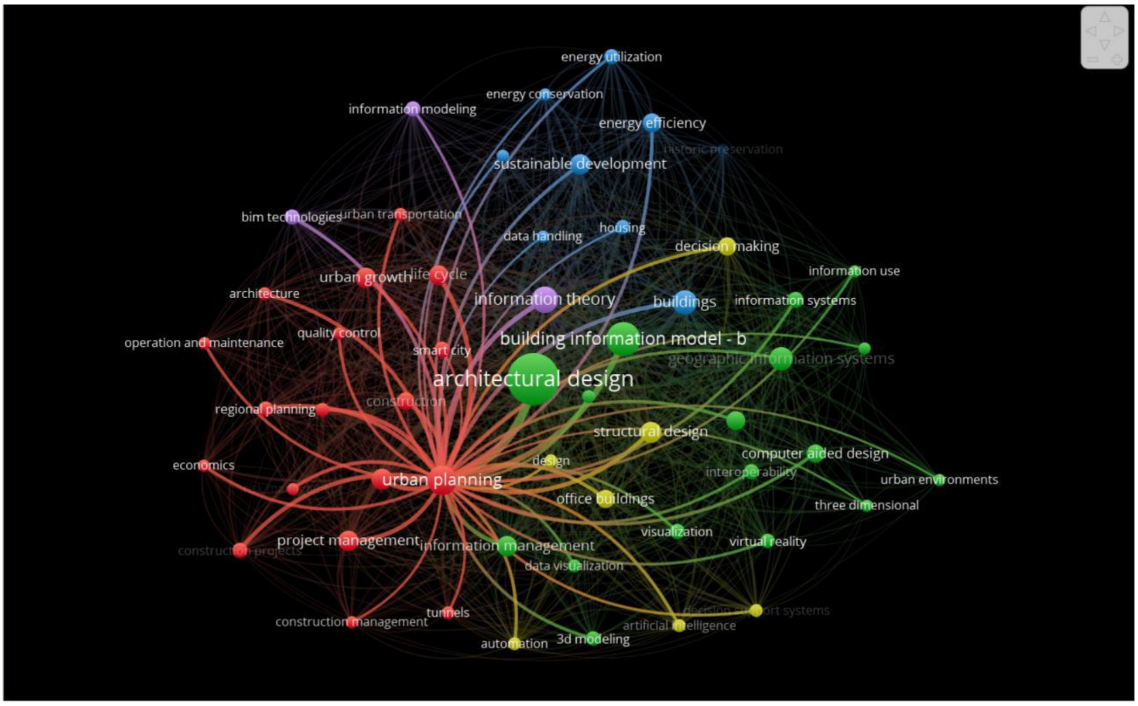


Figure 13. Links “Urban planning” (Co-occurrence of the “BIM urban design”). (Author research)

- **Links “Sustainable development” (Co-occurrence of the “BIM urban design”).** Figure 14.

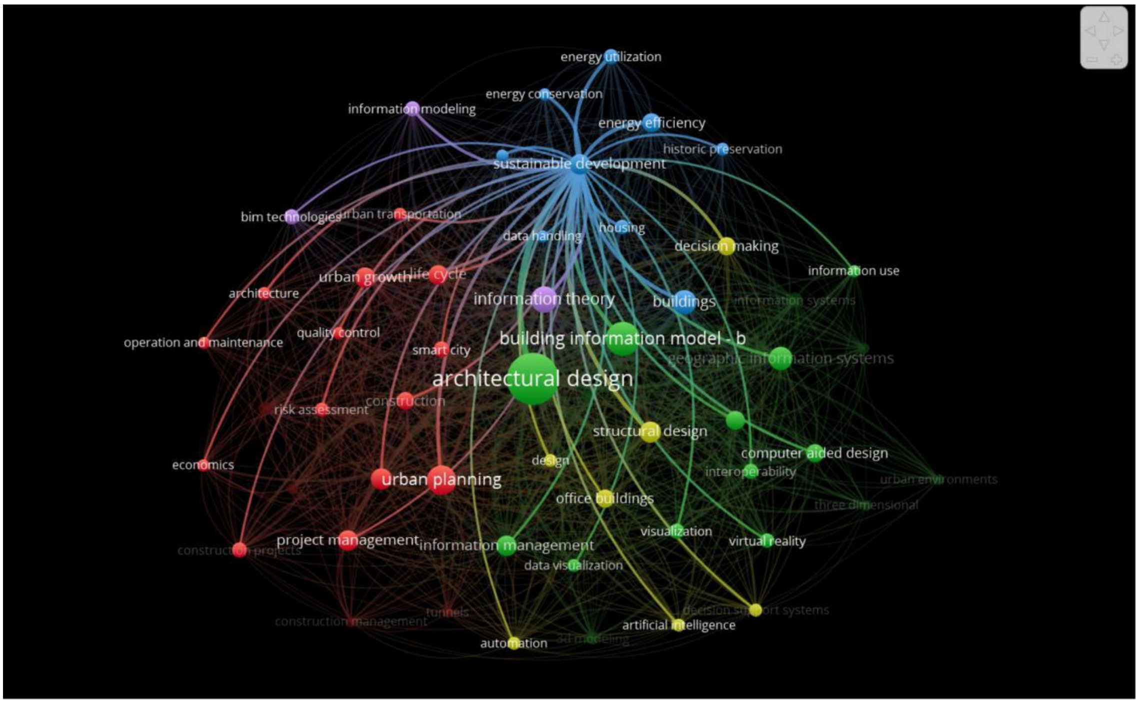


Figure 14. Links "Sustainable development" (Co-occurrence of the "BIM urban design"). (Author research)

When the "BIM urban design" is the Co-occurrence link of the research area, the analysis has shown different strengths between them. The keywords as "Architectural design", shown in Figure 12; The keywords as "Urban planning", shown in Figure 13; The keywords as "Sustainable development" shown in Figure 14;

- **Links "GIS" (Co-occurrence of the "BIM urban design").** Figure 15.

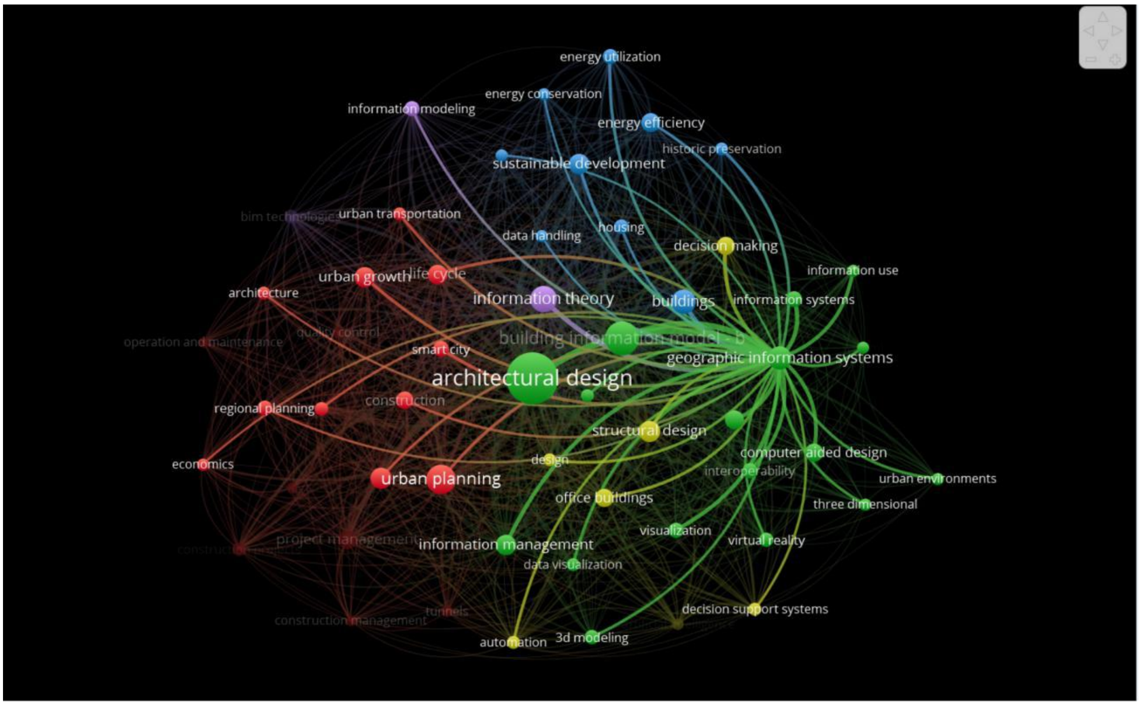


Figure 15. Links "GIS" (Co-occurrence of the "BIM urban design"). (Author research)

- **Links “Citygml” (Co-occurrence of the “BIM urban design”).** Figure 16.

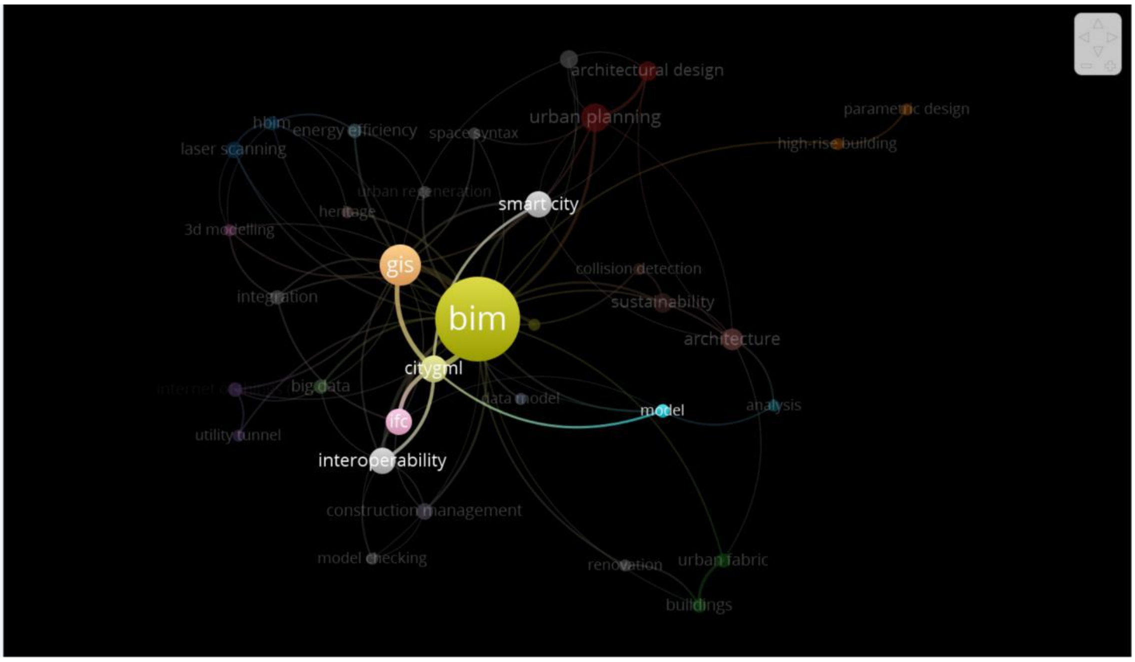


Figure 16. Links “Citygml” (Co-occurrence of the “BIM urban design”). (Author research)

The keywords as “GIS” are shown in Figure 15. The keywords as “Citygml” are shown in Figure 16. If the appearance of words is greater, it means they have more strength.

Figure 17, Figure 18, “BIM urban design” research intensity in countries/territories (impact factor of publication), this analysis shows China has the most research intensity in “BIM urban design”, followed by USA and UK.

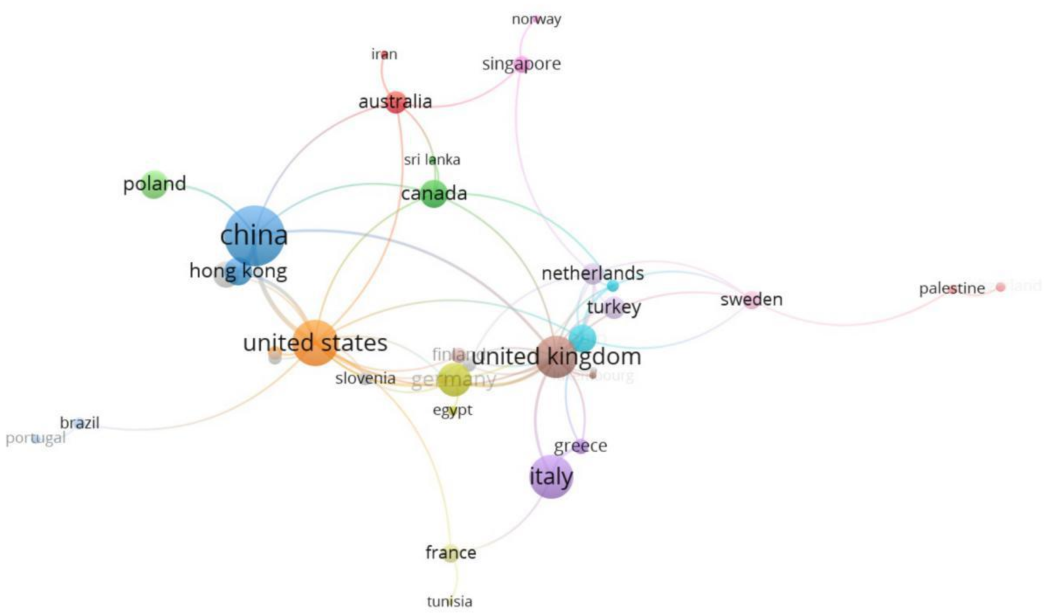


Figure 17. “BIM urban design” research intensity in countries/territories (impact factor of publication). (Author research)

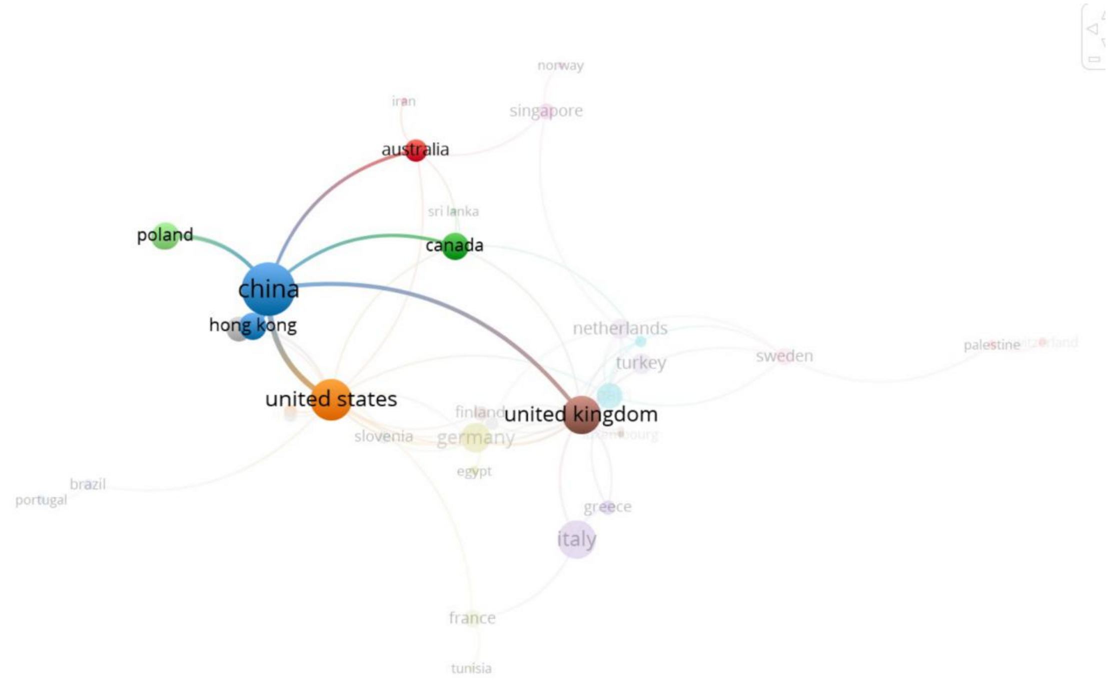


Figure 18. “BIM urban design” research intensity in countries/territories (impact factor of publication). Polish research associations. (Author research)

From the Polish research associations, the intensity center is in China， as shown in Figure 19.

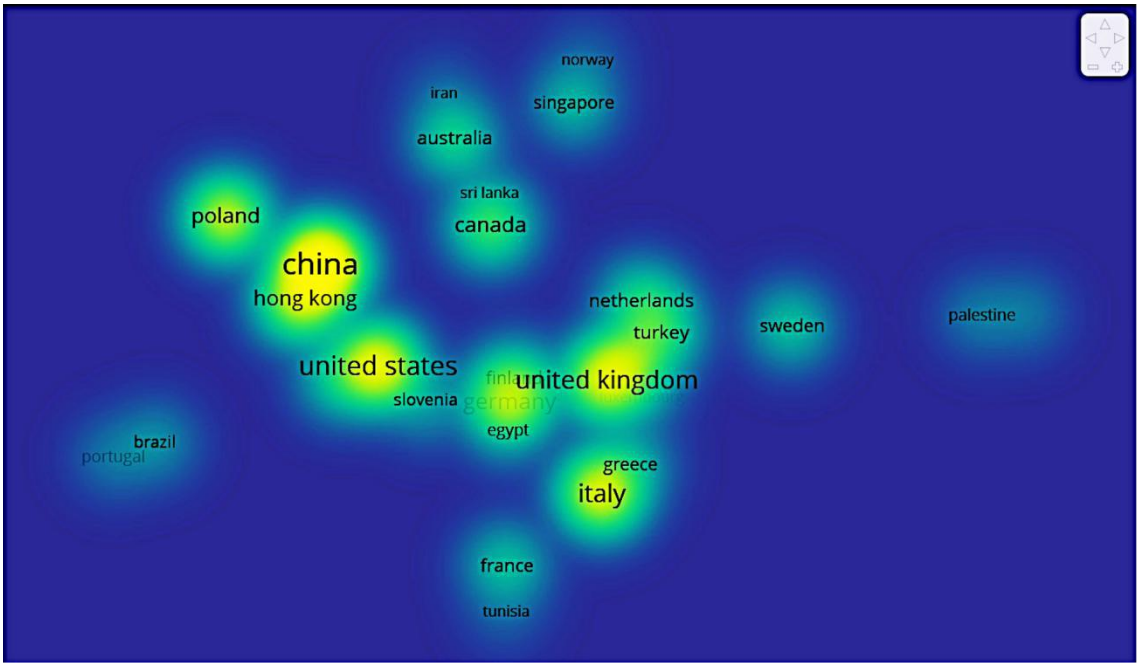


Figure 19. “BIM urban design” research intensity in Polish research associations (impact factor of publication). (Author research)

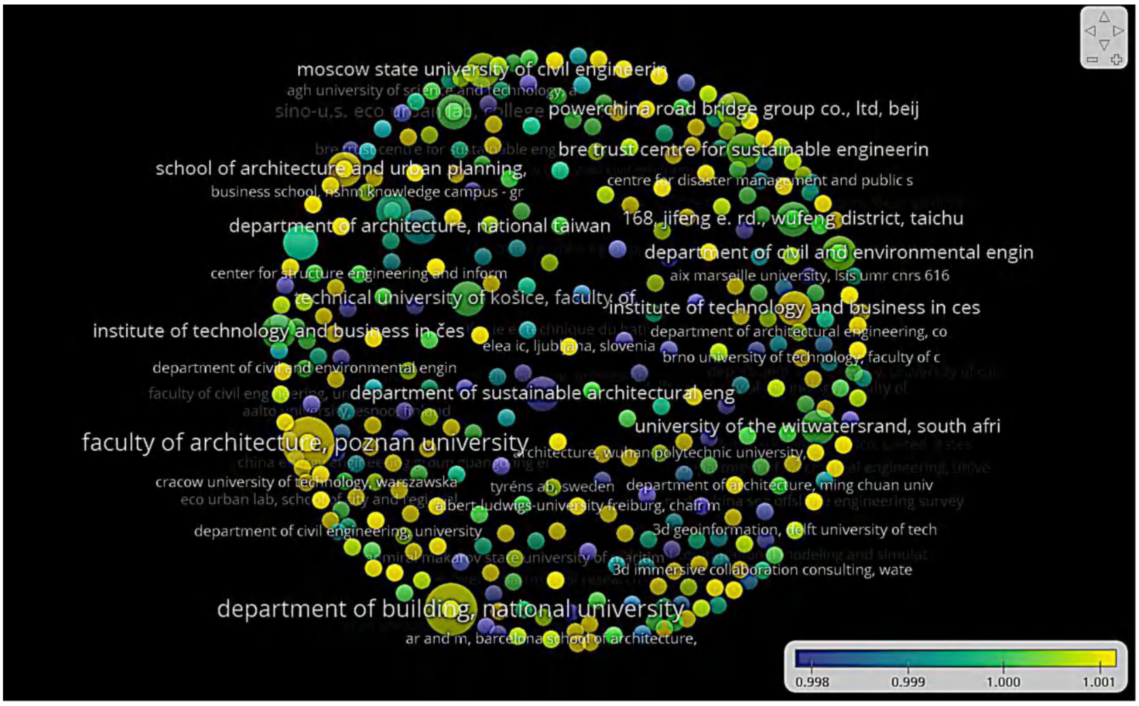


Figure 20. “BIM urban design” research centers (all over the world). (Author research)

Figure 20 shows “ Faculty of Architecture, Poznan University of Technology”, “Department of building national university” has the most researchers in the “BIM urban design” research field.

Figure 21, Figure 22 show the name of “BIM urban design” authors of the research.

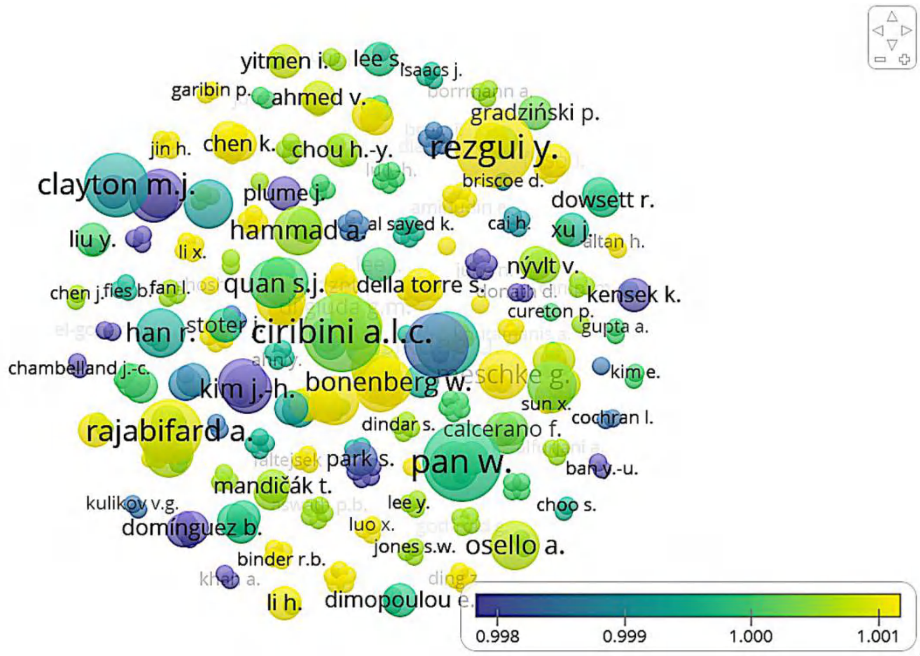


Figure 21. “BIM urban design” authors of research (all over the world). (Author research)

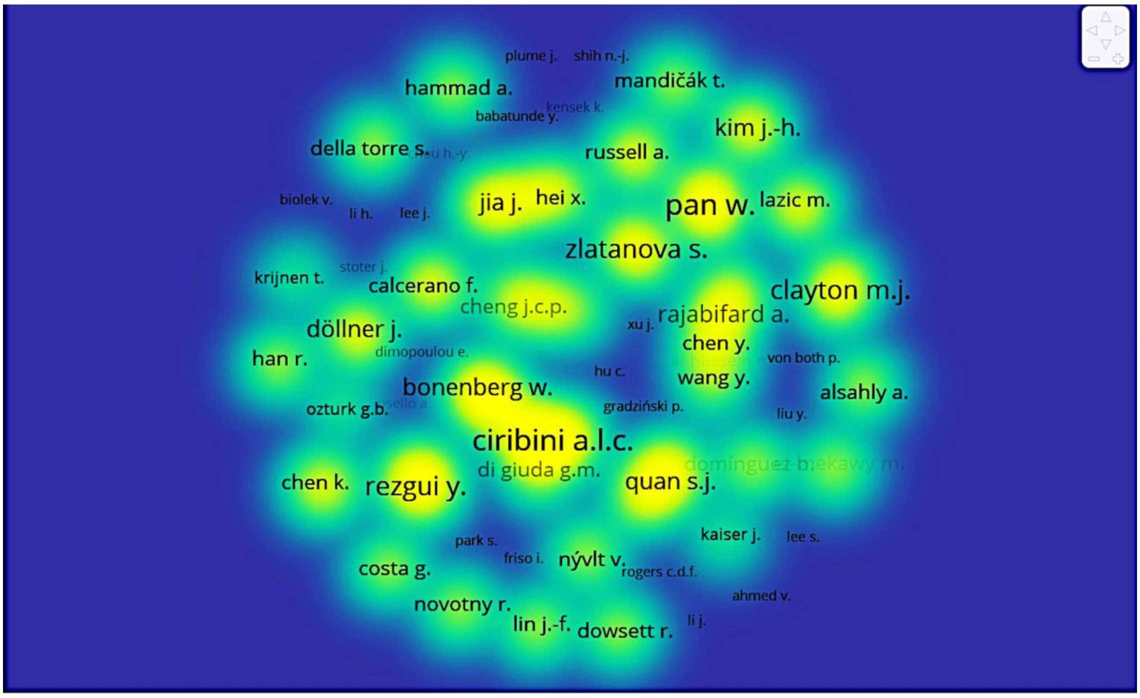


Figure 22. "BIM urban design" authors of research (all over the world). (Author research)

2.3.3 The results of Scientometric analysis

The fields where "BIM urban design" is most widely used were identified, and the boundaries of BIM's use in urban design were identified. The analytical tools used were PAJEK[48], Gephi[49], UCINET (NetDraw)[50].

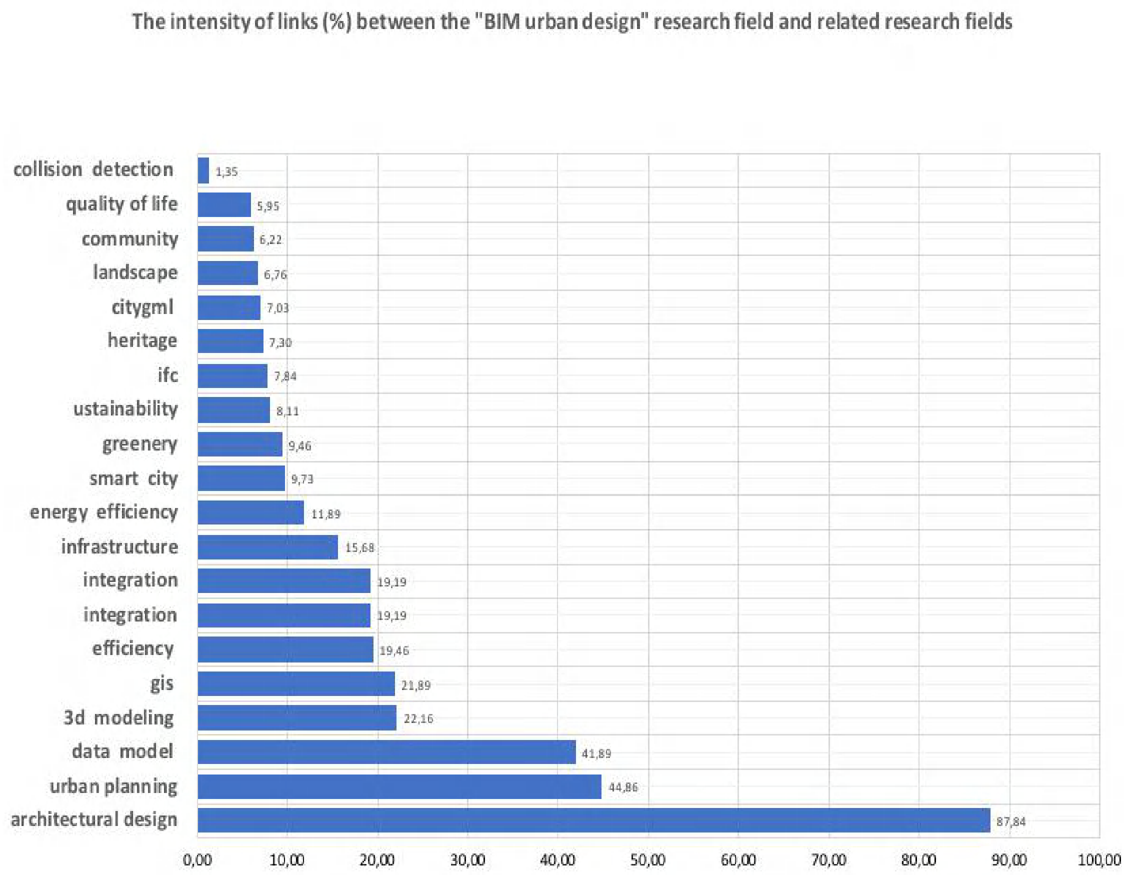
19 research fields most closely related to the use of BIM in urban design were identified (Table 2):

Table 2. The intensity of links (%) between the "BIM urban design" research field and related research fields. (Author research)

[48] Batagelj, V. and Mrvar, A., 1998. Pajek-program for large network analysis. Connections, 21(2), pp.47-57.

[49] Bastian, M., Heymann, S. and Jacomy, M., 2009, March. Gephi: an open-source software for exploring and manipulating networks. In Third international AAAI conference on weblogs and social media.

[50] Johnson, J.D., 1987. UCINET: a software tool for network analysis.



From Table 2, we could clearly see the information about the intensity of links (%) between the "BIM urban design" research field and related research fields:

- Architectural design 87,84
- Urban planning 44,86
- Data model 41,89
- 3d modeling 22,16
- GIS[51] 21,89
- Efficiency 19,46
- Integration 19,19
- Infrastructure 15,68
- Energy efficiency 11,89
- Smart city 9,73
- Greenery 9,46
- Sustainability 8,11
- Ifc 7,84
- Heritage 7,30
- Citygml[52] 7,03

[51] Bolstad, P., 2016. GIS fundamentals: A first text on geographic information systems. Eider (PressMinnesota).
[52] CityGML is an open standardised data model and exchange format to store digital 3D models of cities and landscapes. Source: https://en.wikipedia.org/wiki/CityGML. (Accessed on 2 Oct. 2019)

- Landscape 6,76
- Community 6,22
- Quality of life 5,95
- Collision detection 1,35

2.3.4 The conclusion of scientometric analysis

The comparison of trends in the number of scientific publications in the areas of “architecture design”, “urban design”, “BIM urban design” is shown in Figure 23.

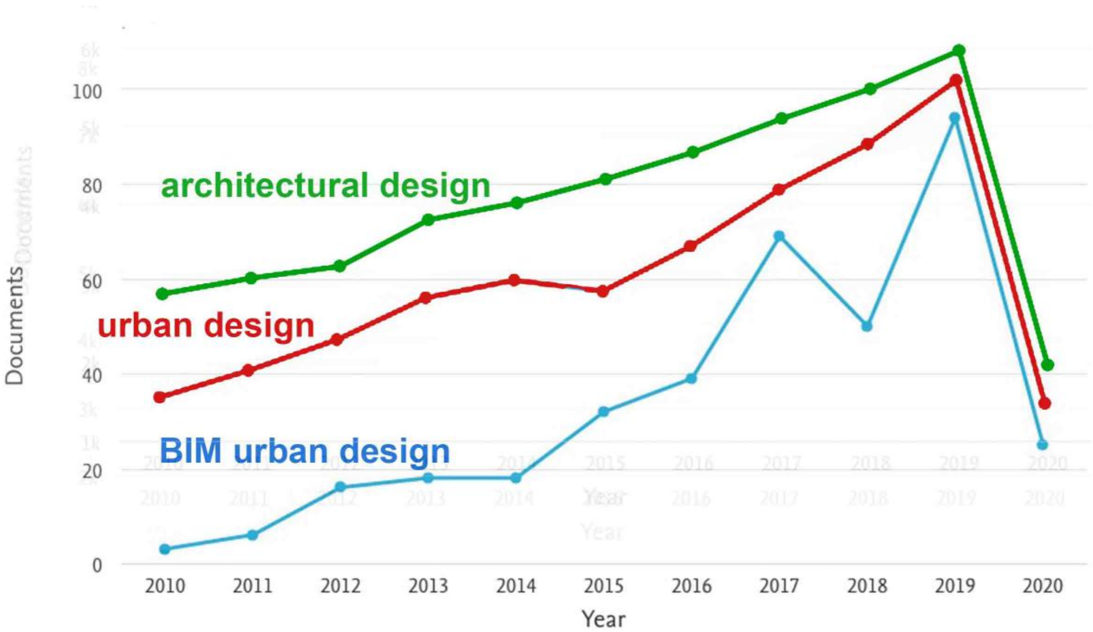


Figure 23. The comparison of trends in the number of scientific publications in the areas of “architecture design”, “urban design”, “BIM urban design” (Author research)

The number of publications over the last 10 years:
The subject of "urban design" had 54,118 publications.
The subject of "BIM urban design" had only 397 publications.
The graph Figure 23 shows trends. In 2010 there was almost no publication on "BIM urban design" at all. In recent years, interest in this topic has clearly increased. Hence the conclusion that the subject is very topical.

2.4 Chapter summary

BIM has developed rapidly in architectural design, and the current research and use of BIM have been quite advanced. There has been almost no research on BIM in the field of urban design since 2010. In the past ten years, this topic has begun to attract the attention of researchers. This dissertation uses scientific measurement methods to analyze and study the development trend of BIM in urban design.

This research carried out scientific measurement by using keywords, cited references, countries/regions, authors, and some other aspects to analyze, and used CiteSpace to carry out visual analysis to find the current development status of BIM in urban design, history and future development trends.

In this dissertation, Scopus is used as the basic database of the search engine. The time is defined between 2010 and 2020, and "BIM urban design" is used as the keyword to find 397 relevant research results.

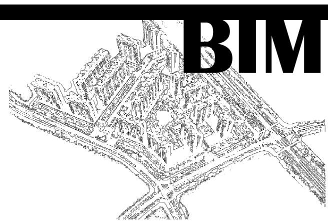
By analyzing "BIM urban design" document counts for countries/territories, we can see that China, Italy, the United States, and the United Kingdom are the countries that have studied most in related fields.

Analyze "BIM urban design" Documents by author Ciribini Angelo Luigi Camillo, PAN WEI, Rezgui Yacine contributed five studies, respectively.

Analyze "BIM urban design" Documents by subject area. Engineering (30.3%), computer science (16.4%), and environmental science (9.3%) are the three subjects with the strongest relevance.

Analyze "BIM urban design" Documents by the year. 2016 to 2017 is a period of the rapid development of BIM in urban design. In 2019, 95 research documents were contributed.

From the above analysis, we can see that BIM in urban design is an excellent research topic and has great potential in future research.



3 Definition of Building Information Modeling (BIM) and Urban Design

3.1 BIM Technology

3.1.1 The concept of BIM

BIM technology is a data application tool for planning, design, construction, and management of construction projects. It plays a vital role in improving production efficiency, saving costs, and shortening the construction period.[53] By integrating various data of the building into a digital information model, the application method of sharing and using this digital information model in the entire life cycle of the construction project is realized. The information sharing and transmission of BIM technology enable engineers and technicians of various disciplines to understand and respond to various building information correctly. It also provides a basis for collaborative work for the design team and all parties involved in the construction and operation of the organization.[54]

The definition of BIM is referenced by the National BIM Standard (NBIMS). “The definition consists of three parts:

- BIM is a digital representation of physical and functional characteristics in the process of construction projects;

[53] Smith, D.K. and Tardif, M., 2009. Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. John Wiley & Sons.
[54] Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R. and Liston, K., 2011. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

- BIM is a way of sharing construction resources and a process of sharing construction project information. BIM can provide a reliable basis for all decisions in the entire life cycle of a construction project, from concept to demolition[55].
- At different stages of BIM construction projects, various stakeholders can insert, extract, update and modify the model information in the BIM digital information model to achieve the purpose of collaborative work.[56]

3.1.2 Development history of BIM

The generation of BIM can be traced back to the dissertation published by Eastman in 1974[57]. However, the correct formation of a world-class application still depends on the IAI [58] Association's decision to introduce the IFC standard in 1995. It has been more than twenty-five years. This section analyzes the BIM industry's development trend based on the significant events in the BIM industry over the past twenty-five years.
Three apparent trends over the past twenty-five years are:

- Modeling to usage
- Construction to the full life cycle
- Software to hardware, the Internet of Things (IoT), and big data.

Table 3 below is a summary of the historical time nodes of BIM development.

Table 3. BIM Historic Overview.

Year	Title	Events	Description
1975	**BDS**	Building Description System[59]	Eastman of the Georgia Institute of Technology proposed the concept of "Building Description System", a computer software system that can intelligently simulate buildings. The only data source in the construction process ensures that all drawings are consistently related. With functions such as visualization, quantitative analysis, and automatic inspection of regulations, they can provide more convenient cost calculation and material statistics. It has

[55] Azhar, S., Khalfan, M. and Maqsood, T., 2012. Building information modeling (BIM): now and beyond. Australasian Journal of Construction Economics and Building, The, 12(4), pp.15-28.
[56] Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R. and Liston, K., 2011. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.
[57] Daniotti, B., Pavan, A., Spagnolo, S.L., Caffi, V., Pasini, D. and Mirarchi, C., 2020. BIM-based collaborative building process management. Springer.
[58] The IAI started in 1994 as an industry consortium of 12 US companies invited by Autodesk to advise on developing a set of C++ classes to support integrated application development. In 2005, it was renamed buildingSMART. https://en.wikipedia.org/wiki/BuildingSMART (Accessed on 15 July 2020)
[59] Eastman, C., 1974. An Outline of the Building Description System. Research Report No. 50.

			the essential characteristics of BIM and lays a theoretical foundation for BIM's future research. Therefore, Eastman is also known as the "father of BIM".
1980	**PIM**	Product Information Model	Finnish scholars proposed the concept of the "Product Information Model", which is a computer intelligent model system.
1982	**3D**	Collision Detection	The first 3D collision detection program was created to check an atomic reactor's service system.
1984	**VB**	Virtual Building	Graphisoft ArchiCAD 1.0 was released for the Apple Lisa personal computer.
1986	**BM**	Building Modeling	American scholar Aish proposed "Building Modeling", which is remarkably close to the industry's widely accepted BIM concept.
1992	**BIM**	Building Information Modeling	The first paper on BIM was published in 1992 at the Technical University of Delft. Dutch scholars Nederveen and Tolman proposed the theory of Building Information Models. However, due to the limitations of computer hardware and software, the research on BIM only stayed in academic study. It was not promoted and applied in the industry.
1995	**IFC**	International Foundation Class (IFC) file format	The model file created in the Industry Foundation Classes (IFC) format, an open file format used by Building Information Modeling (BIM) programs, contains a building or facility model, including spatial elements, materials, and shapes[60].
1998	**NURBS**	Surface Modeling	Robert McNeel & Associates release Rhinoceros 1.0 in 1998.
2000	**Parametric**	Modeling	Revit Technologies announced Revit 1.0 in 2000 for Microsoft Windows operating system. After 2000, with the development of computers and related technologies, especially the promotion of CAAD software vendors, many designers began to pay close attention to and study BIM.

[60] Thein, V., 2011. Industry foundation classes (IFC). BIM interoperability through a vendor-independent file format.

2002	**CPN**	Comparing Pommes and Naranjas	American scholar Laiserlin's article "Comparing Pommes and Naranjas" was a "milestone" article in the global BIM field, and the term BIM has since become widely known. This article tells the story of Laiserlin's co-ordination of the parties to unify the things represented by "BIM".
2005	**OPEN**	Open collaboration	BuildingSMART initiated OPEN BIM in 2005.
2007	**NBIMS**	National Institute of Building Sciences	The National Institute of Building Sciences (NIBS) has launched the long-awaited BIM standard: The National BIM Standard (NBIMS Version 1-Part1) through its buildingSMART Alliance (BSA). The promotion and application in the US construction market provide national-level standards support.
2008	**IPD**	Integrated Project Delivery	IPD is a method that utilizes the early contribution knowledge and professional skills of team members to enable all team members to better realize their maximum potential by applying new technologies. This delivery method achieves the maximum value of team members throughout the entire life cycle of the construction project.

From the initial proposal to the development of standards, the BIM-related software and interoperability standards have rapidly developed and have been widely recognized by the construction industry. The software developed based on the BIM concept includes the Revit series of American Autodesk, Architecture series of Bentley, ArchiCAD series of Nemetschek of Germany (acquisition of Graphisoft of Hungary), Digital Project series developed by Dassault, etc. BIM is no longer just an object of academic research, but a commercial tool applied in engineering practice.

The penetration rate of BIM technology in the US construction industry has exceeded 60%. It has been applied to large-scale applications such as construction, design, construction, and consulting services involved in the building's whole life cycle, which have significantly promoted increased productivity in the US construction industry. To achieve standardized management, the National Academy of Building Research has launched the corresponding BIM standards based on its national conditions and is continually optimizing and improving them. Simultaneously, in order to promote internal communication within the industry, the United States has also established many

BIM technology research associations to further support the research and application of BIM technology.

3.1.3 BIM usage of the world

As early as 2006, the American Institute of Architects proposed that architects should learn and understand the use of BIM to improve the industry's competitiveness. It can be seen that from this time the era of BIM applications had arrived. In addition to the United States, BIM technology has been fully and widely applied in various developed countries in Europe and Asia. The popularity of BIM technology has become an essential indicator of national construction industry information development. Greater requirements have also been placed on architectural designers.

The development time point of BIM in various countries of the world.

- **The United States.** The United States was the first country to start applied research on building information. Since this study, most construction projects in the United States have begun to apply BIM, so, as a result, BIM applications in the United States have always been the most advanced. There are many BIM applications associations, and BIM standards in the United States. According to the study of "McGraw Hill", the proportion of the U.S. engineering construction industry adopting BIM has risen from 28% in 2007 to 71% in five years.

Table 4. The development time point of BIM in the United States.

2003	In 2003, a national 3D-4D-BIM program was launched.
2004	BIM was implemented in the project in November 2004.
2006	In 2006, a 15-year rule for BIM development was issued.
2007	BIM was required for all large projects in 2007.
2007	The first part of the first version of NBIMS was released in 2007.
2012	The second edition of NBIMS was released in 2012.

- **The United Kingdom.** The development of BIM applications in the United Kingdom is different from that of most other countries. In the UK, the government requires the use of BIM in engineering construction. In May 2011, the British Cabinet Office issued a government construction strategy document stating that[61], by 2016, the government requires the comprehensive and collaborative use of BIM technology in construction projects and information to manage all documents in construction projects. The AEC (UK) BIM Standards Committee of the British

[61] Liu, B., Wang, M., Zhang, Y., Liu, R. and Wang, A., 2017, October. Review and prospect of BIM policy in China. In IOP Conference Series: Materials Science and Engineering (Vol. 245, No. 2, p. 022021). IOP Publishing.

Construction Industry BIM Standards Committee supports the government's mandatory use of BIM.

Table 5. The development time point of BIM in the United Kingdom.

2010	Only 13% use BIM in the survey.
2011	In the survey, 31% used BIM. The Cabinet Office of the United Kingdom released the "Government Building Strategy".
2012	In July 2012, several pilot projects used 3D and BIM technologies to deliver projects collaboratively.
2016	All construction groups that have obtained government engineering projects must have second-level BIM capabilities.

- **Northern Europe.** The Nordic countries of Norway, Denmark, Sweden and Finland have been developing and applying BIM. These are the locations of some important information technology software vendors in the construction industry. And these countries are also the first countries in the world to adopt information model-based construction project design. For example, IFC promotes information interactive sharing and open standards for building information model technology.

Table 6. The development time point of BIM in Northern Europe.

2007	The Finnish National Property Service Agency and the Senate Property project require the use of BIM.
2010	The Norwegian government is committed to adopting BIM.

- **Poland.** In Poland, according to "Art. 91," Firstly, the awarding entity shall choose the most advantageous offer based on the criteria for the evaluation of proposals specified in the specification of essential terms of the contract. Secondly, the requirements for the assessment of offers are the price or cost, or cost-plus other criteria related to the subject of the contract, in particular: Article 10e. For works contracts or competitions, the contracting authority may require electronic building modeling tools or similar tools. In this case, the contracting authority provides a means of access to these tools by "Article 10d" until such tools become publicly available.

Table 7. The development time point of BIM in Poland[62].

[62] Bartosz Jankowski MRICS REWITECH, Implementing BIM in Poland the regulatory and legal barriers. Source:http://bpcc.org.pl/uploads/ckeditor/attachments/13516/20181001_RICS_BPCC_BIM.pdf (Accessed on 15 July 2020)

2014	European directive 2014/24/eu regarding BIM
2015	More tenders with "BIM" aspects
2017	Ustawa PZP" with additional points Government consultations Report by KPGM regarding BIM in Poland PN-EN ISO 16739: 2016-12E Tenders
2018	Handbook for the introduction of Building Information Modeling by the European Public Sector Tenders - For example BIM Manager for "Pracownia Przewrotu Kopernikańskiego".

- **Singapore.** Singapore's National Agency for Construction "Building and Construction Authority" (BCA) attaches great importance to information technology in construction projects.

Table 8. The development time point of BIM in Singapore.

1982	BCA has the idea of Artificial Intelligence plan checking.
2000-2004	The world's first automatic approval system began to be used in construction projects in Singapore. This is a development system for online project planning and automatic approval of projects.
2010	BCA established the "6 million BIM" fund project in 2010. In order to encourage Singapore universities to offer BIM training courses, it even established a professional degree system for BIM.
2011	The Singapore BCA established a demonstration project in cooperation with some government agencies.
2013	BCA will be required to submit building BIM models.
2014	BCA will be required to submit structural and electromechanical BIM models
2015	Eventually, all projects with building areas more significant than 5000 square meters must submit BIM model goals by 2015.

- **South Korea.** In January 2010, the Ministry of Land, Infrastructure, Transport and Tourism of the Republic of Korea issued the "Construction BIM Application Guide" and the "Civil Engineering BIM Application Guide". In December of the same year, PPS issued the "Guidelines for BIM Application in Facility Management", which guides BIM application in the preliminary design, construction drawing design, and construction phases[63]. The Korea Public

[63] Kim.I, 2012. BIM Activities in Korea. BuildingSMART International Conference Tokyo 2012.

Procurement Service Center (PPS) released the BIM roadmap in April 2010. The contents of this BIM roadmap include:

Table 9. The development time point of BIM in Korea.

2010	In 2010, BIM was applied to 1-2 large engineering projects.
2012 - 2015	4D • BIM technology (3D + cost management) was adopted for large-scale engineering projects of more than 500 million won;
Before 2016	BIM technology was applied to all public projects.

- **China.** In China, an example of the emerging application technology of construction engineering, BIM has not only received more and more attention from the government, but professional designers in the industry are also paying more and more attention to the development of BIM and are investing in it. At present, China's construction industry is in a critical period of continuous transformation and upgrading to modernization, informatization, and industrialization[64]. BIM has become a recent trend in the development of the construction industry. In recent years, China has successively promulgated several related policies, and many professionals have worked under the support and guidance of these policies and have achieved significant results. However, there are still some difficulties in the research and application of BIM in the country. The China Construction Industry Association conducted a survey of 388 companies in 2012, and less than 15% of them were using BIM technology. The development of BIM relied on the government encouraging the use of technology, but it lacked in China. The Ministry of Housing and Urban-Rural Development has included BIM in its five-year plan for urbanization and agricultural modernization. The Ministry of Science and Technology has also approved the normative national standards formulated by the China BIM Alliance. At the same time, the Hong Kong Building Information Modeling Institute (HKIBIM) was established in 2009, and the Housing Authority formulated the BIM implementation roadmap in 2014. The Ministry of Housing and Urban-Rural Development of the People's Republic of China proposed on June 16, 2015 that, before the end of 2020, housing construction units with a first-class qualification and a survey and design institute Class-A qualification must also have an integrated application level of BIM technology, 90% of all government investment projects should use BIM. From this guidance, the Chinese government attaches great importance to the development of BIM and has advanced the support of BIM technology from a recommendation level to a mandatory standard level.

[64] He, J.K., 2016. Global low-carbon transition and China's response strategies. Advances in Climate Change Research, 7(4), pp.204-212.

Table 10. The development time point of BIM in China.

2005	BIM technology was introduced to China.
2007	China's Ministry of Construction issued the "Digital Standards for Building Objects", which heralded BIM technology's widespread promotion.
2011	Huazhong University of Science and Technology has established China's first BIM research center, which reflects the recognition of BIM technology by universities and plans to train BIM technical talents for the market.
2015	The Ministry of Housing and Urban-Rural Development issued "Guiding Opinions on Promoting the Application of Building Information Models". By the end of 2020, the proportion of projects with integrated applications in the survey, design, construction, operation, and maintenance of new projects will reach 90%.[65]
2018	The Ministry of Housing and Urban-Rural Development has issued the "Building Information Model Construction Application Standard".
2019	The Ministry of Human Resources and Social Security thirteen new professions, including building information modeling technicians.

In summary, the application of BIM has achieved good results and has consistently improved the popularity of BIM in all stages of the entire life cycle of construction projects. The application characteristics of BIM are:

- BIM technology is valued by countries all over the world, especially developed countries.
- BIM is an important factor in the degree of informatization in the construction industry.
- In the development of BIM applications, various software has become more and more efficient.
- Compared with traditional CAD, BIM occupies a huge advantage, and BIM can already participate in the whole life cycle of construction projects.

[65] Tiangang, C., Ningshan, J., Dan, Z., Yu, Z. and Guibo, B., 2018, May. Based on the development status of British BIM, exploring China's BIM road. In IOP Conference Series: Earth and Environmental Science (Vol. 153, No. 5, p. 052040). IOP Publishing.

3.2 Understanding BIM

3.2.1 IFC

Traditional engineering data is often fragmented, fragments are stored in different places, and data formats are also matched in various forms. The most common are graphics (construction drawings, large-scale drawings, cross-section drawings, flowcharts, etc.), text (various explanatory documents), and numbers (various statistics, quantity, or price data), all of which continue as the project progresses. As the data increases, so too does the correlation between the data.
Throughout the life cycle of a building, multiple disciplines need to process and exchange data in the same project. This complex data exchange process is likely to be unrealized due to the different disciplines and the need to share and interact with each other on different timelines. The Industry Foundation Class (IFC), proposed by the International Alliance for Interoperability (IAI) in 1995, now provides support and standards for such data exchange and sharing. Figure 24 and Figure 25.

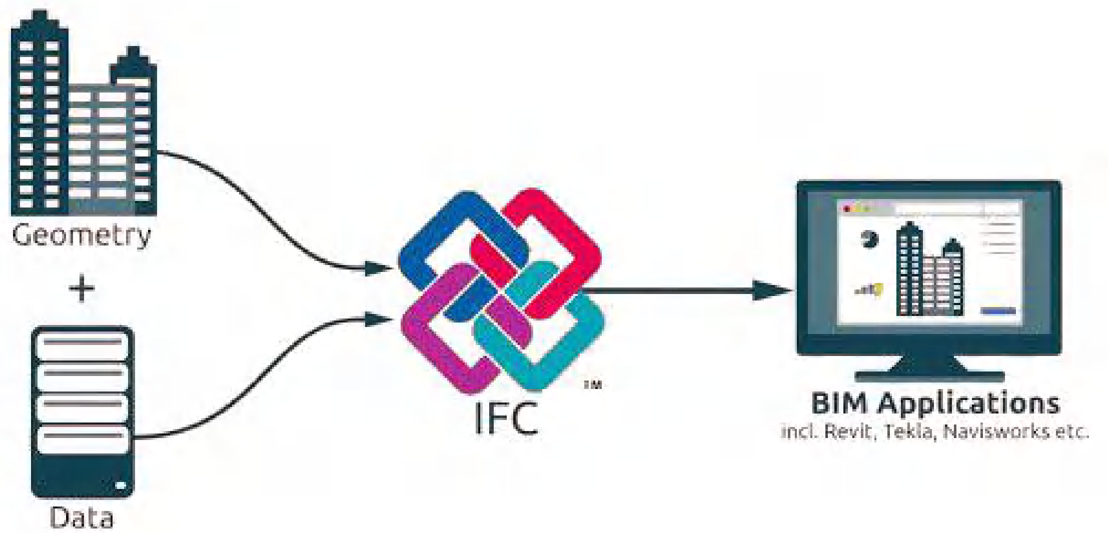


Figure 24. BIM and IFC. Source: https://www.bimcommunity.com/news/load/910/ifc-why-now.

BIM is an extensive database that stores all the data related to buildings throughout their life cycle. It needs to maintain the relationship between data and data through various methods.[66] In the past, in the process of electronic sizing data, storage space was a high-cost issue. With the advancement of hardware storage technology, data storage space is no longer a big issue. The problem is that too much data cannot be found quickly.
For this reason, the complete storage and use of engineering information is bound to face two key issues:

[66] Vanlande, R., Nicolle, C. and Cruz, C., 2008. IFC and building lifecycle management. Automation in construction, 18(1), pp.70-78.

- How to correctly and effectively store various BIM model data?
- How to correctly and quickly find the required BIM information?

Figure 25. IFC provides data transfer for software. Source: https://b2b.partcommunity.com/community/blogs/405757/3257/cadenas-supports-ifc-exchange-format-for-bim.

At present, the standard BIM model building software on the market supports the import and export of IFC format. Files can be stored in IFC files, and the modeling software in the previous stage cannot be. As long as the IFC output format data is supported, it can be imported into the OpenBIM system.

3.2.2 OpenBIM

BIM is a digital representation of building models and related information content. Model information sharing is one of the characteristics of BIM models. The second feature of the BIM model is that it covers the entire life cycle of the building project, from "design" to "destruction."

“OpenBIM extends the benefits of BIM (Building Information Modeling) by improving the accessibility, usability, management and sustainability of digital data in the built asset industry.”[67] Open BIM is a concept jointly initiated by multiple companies in the construction information industry. The purpose is to solve the problem of data exchange so that all digital information is based on an open standard and process for collaborative design, construction, and operation management[68]. In addition, OpenBIM certification has also been developed to provide AEC software suppliers with improved, tested, and certified data connections, helping data exchange to connect with other OpenBIM software solutions. Figure 26.

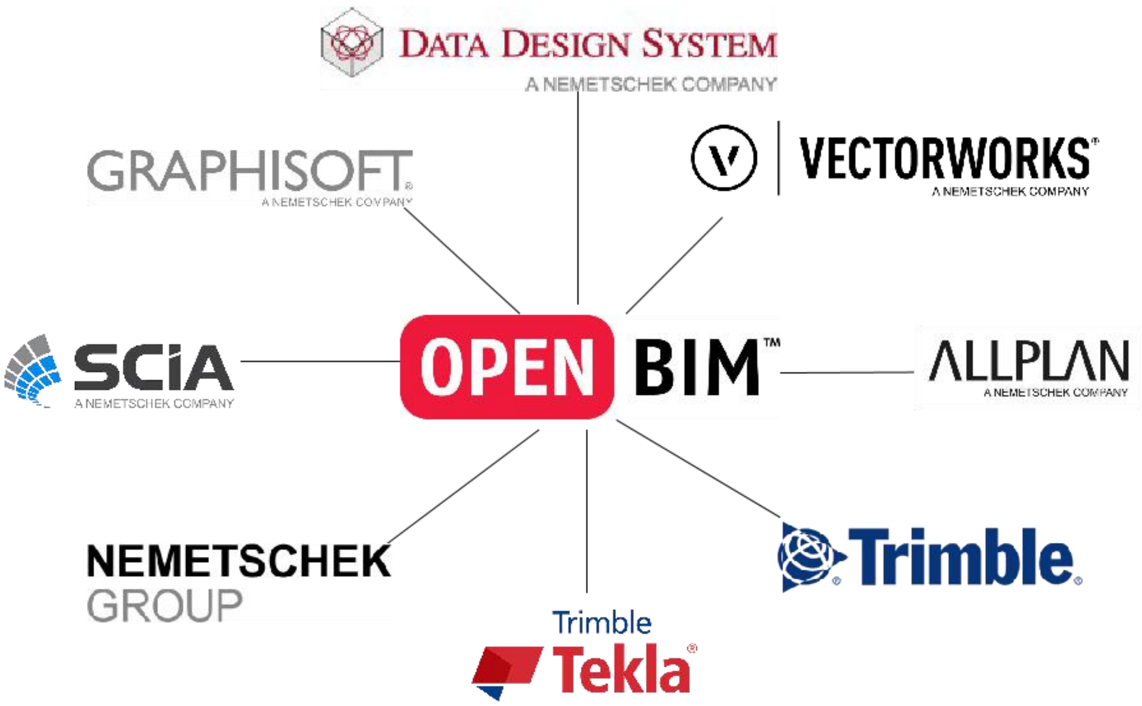


Figure 26. The Open BIM Partners. Source: https://www.graphisoft.com/archicad/open_bim/

In terms of basic information, the object of BIM is mainly a project data. Sharing means that professions (such as architects, structural engineers, construction personnel, project managers, etc.) can exchange information more effectively through the "information model" throughout the project life cycle.

The object of OpenBIM is BIM software. The initiative’s aim is that all BIM software can be compatible with the data model of building SMART (such as IFC). The software used at each stage in a specific engineering project has interoperability.

[67] What is openBIM?. Source: https://www.buildingsmart.org/about/openbim/openbim-definition/ (accessed on 05 July 2019)

[68] El-Diraby, T., Krijnen, T. and Papagelis, M., 2017. BIM-based collaborative design and socio-technical analytics of green buildings. Automation in Construction, 82, pp.59-74.

3.2.3 CityGML

CityGML is an open standard for the presentation, storage, and exchange of three-dimensional virtual city models and terrain models, introduced by the Open Geospatial Consortium (OGC). This standard includes geometric, topological, and semantic features of these models and their appearance. One of the ideas behind creating the CityGML standard was, when building virtual models, to enable a combination of data obtained from various sources, such as data from aviation laser scanners and aerial photos.[69]

3.2.4 BIM Level

The British government defines four stages of BIM, from Level 0 to Level 3. This is a way to express the different levels and processes of BIM use. Figure 27.

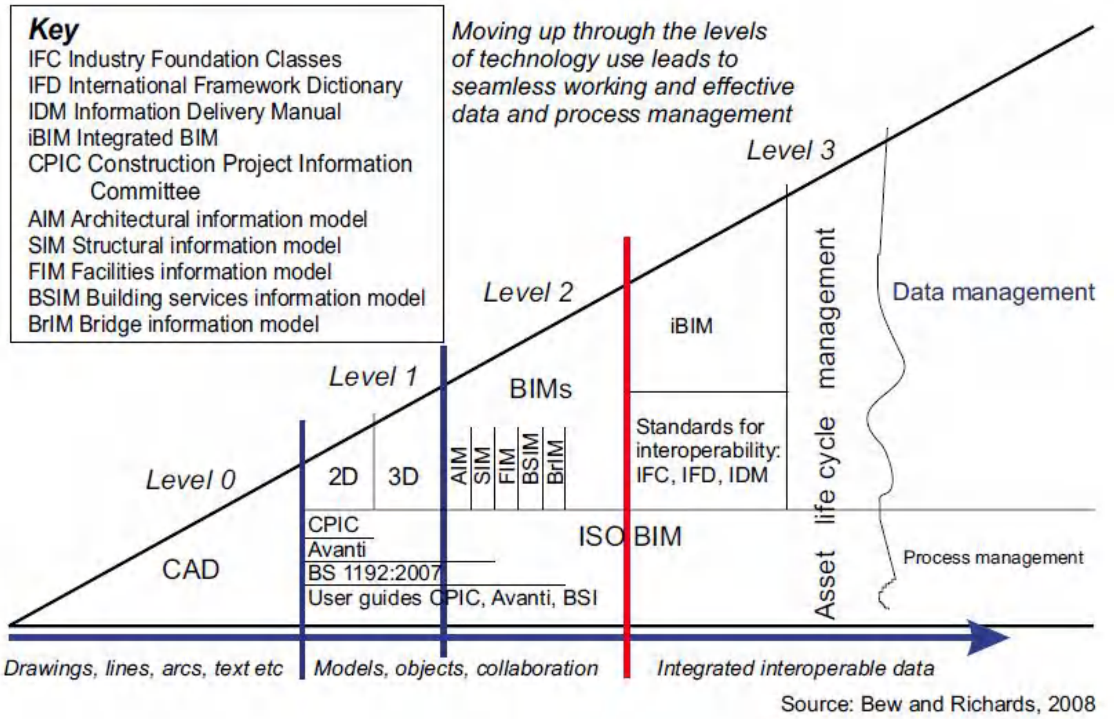


Figure 27. The "Wedge" Diagram showing BIM Technology Maturity Levels [70]

- **BIM, Level 0.** Level 0 means no collaboration, and the two-dimensional computer-aided drawing is only used to generate drawing information.[71]
- **BIM, Level 1.** Many organizations are now at this stage. Typical examples include the use of 3D computer assistance in the conceptual design stage and 2D drawing in

[69] https://pl.wikipedia.org/wiki/CityGML (Accessed on 12 July 2019)
[70] Kumar, B. and Hayne, G., 2017. Implementation of level 2 Building Information Modelling strategy for asset procurement. Proceedings of the Institution of Civil Engineers-Management, Procurement and Law, 170(5), pp.190-206.
[71] Aibinu, A. and Venkatesh, S., 2014. Status of BIM adoption and the BIM experience of cost consultants in Australia. Journal of Professional Issues in Engineering Education and Practice, 140(3), p.04013021.

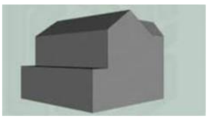
the later construction drawing stage. The electronic version of data sharing is performed in a shared data environment, usually managed by contractors. Models are not shared among project members.[72]

- **BIM, Level 2.** This stage mainly depends on whether the various project participants are working together. All participants use their own 3D information models and do not share them. Each participant provides a data model based on its own data and integrates the various data models into an integrated BIM model. The method of this integration model is to use a standard file format, such as IFC. The British government has set this method of working as the minimum target for all public works by 2016.
- **BIM, Level 3.** As far as the current level of development is concerned, reaching this stage is challenging. All participants share the BIM data model at this stage and can access and edit the same model.

3.2.5 BIM LOD (Level of Details)

The level of detail of the model is also known as the Level of Development. This level of detail describes and defines the different presentation accuracy of the BIM model. Literally understood, a model from a simple model at the conceptual stage to a detailed construction drawing model at the final construction drawing stage represents different stages and different levels of detail. The definition of LOD has two purposes: determining the model phase output (Phase Outcomes) and assigning modeling tasks (Task Assignments). The level of detail of the model is defined as follows (Table 11):

Table 11: The Level of Development, level of detail [73][74].

LOD 100 Conceptual design	LOD 200 Design development	LOD 300 Detailed design	LOD 400 Construction	LOD 500 As-built modeling
				
Basic volume information such as length, width, and height.	Building's approximate number, size, shape, etc.	Accurate data information such as size, position, and direction.	Information required for complete manufacturing, assembly, and detailed construction.	The actual size, quantity, location, direction, and other data information after completion.

[72] Sacks, R., Eastman, C., Lee, G. and Teicholz, P., 2018. BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers. John Wiley & Sons.

[73] The Level of Development, level of detail. Source:https://www.bimandco.com/en/management-lod. (Accessed on 12 July 2019)

[74] LOD-Level of development para projetos BIM. Source:https://engenhariadigital.com/lod-level-of-development-para-projetos-bim/. (Accessed on 12 July 2019)

Development in Level refers to the information that a BIM model needs to carry at different development stages, from initial design to construction to delivery, operation, and maintenance.

It has several most significant differences from Level of Detail[75]:

- The first is that it represents different people at different project stages and different needs for the BIM model. These requirements include the appearance and size of the model and a lot of other non-geometric information. The extra information at each stage has a significant specific feature rather than making the model look more realistic.
- The second is that it is not a criterion for judging the quality of a model. A healthy BIM model must gradually develop from the conceptual design stage to the completion stage, and each step should not be omitted. One cannot skip the first few levels and get a model with a high LOD level directly.
- The third is that the BIM model of the previous stage must be passed on to the next step and passed on to different users. In this way, the model during the last phase can further develop the previous stage without overturning it.

[75] BIM Level of Development. Source: https://www.united-bim.com/bim-level-of-development-lod-100-200-300-350-400-500/ (Accessed on 12 July 2019)

3.3 Urban Design

3.3.1 The definition of urban design

Figure 28. An urban design example. Source: Case study, the project “Wantun Affordable Housing Design." (Author design)

Many designers and theorists have different views as to the definition of urban design. However, the generally accepted definition is “urban design is a discipline that pays attention to urban planning and layout, urban appearance, and urban functions, especially paying attention to urban public space.”[76] Compared with the design of urban planning, the content and focus of urban design are different, and the content of an urban design is more detailed. Architectural design and landscape design are part of urban design, so the urban design cannot be defined as solely architectural design or landscape design. The purpose of urban design is to make an overall design for the future development of the entire city. It is different from urban planning. It uses the overall design of each element in the urban design, such as architecture, landscape, and space, to integrate the city. The people living in China, the urban landscape and other elements are considered together. Urban design must create a good living environment and consider the sustainable development goals of the city and of human development.

[76] Lang, J., 1994. Urban design: the American experience. John Wiley & Sons.

Urban design has always been an important task for many throughout human history[77], but, it was not until the 1950s that universities and colleges in Europe and the United States began to extensively set up relevant courses. The field of urban design became a new concept and began to be widely recognized by the world. Ever since human beings began to build cities, they have begun to do urban design. Its purpose is to constitute the substantial social urban living environment units, such as houses, shops, factories, schools, offices, and transportation facilities. Parks and green areas are appropriately arranged to meet human needs in terms of living functions, society, economy, and aesthetics. The scope and scale of urban design are varied, and it can be for a residential area or a landscaped park. Urban design is the overall design of a certain area in the city, not just a single building. It also includes the building group and the connection between the entire buildings, such as traffic and landscape, space design, etc. In the city's overall development, urban design is the link between urban planning and architectural design, which can coordinate and integrate the connection between planning and architecture.

3.3.2 The design scope of urban design

In the past, the research scope and working objects of urban design were limited to the narrow level of architecture and city. However, like the more historic and traditional categories such as urban planning, landscape architecture, and architecture, urban design has begun to change in the middle of the twentieth century. It also gradually appeared in urban engineering knowledge and practice categories, urban economics, urban sociology, environmental psychology, public management, and sustainable development. It has therefore become a complex and comprehensive interdisciplinary discipline. The derived urban design theory focuses on the design practice and theoretical development of urban public space.[78]

- The different urban design and urban planning design.

Urban design mainly solves various factors in the urban design space and establishes a complete urban engineering system. Urban planning focuses on the two-dimensional plane with the land area as the media boundary. Therefore, urban design and urban planning design involve different dimensions.

[77] Larice, M. and Macdonald, E. eds., 2013. The urban design reader. Routledge.
[78] Trancik, R., 1991. Finding lost space: theories of urban design. John Wiley & Sons.

Figure 29. The urban planning design example, Land integration planning, and urban design on both banks of Nanchuan River in Xining, China. Source: http://tushuo.jk51.com/tushuo/10063941_p2.html

Urban design is the design of the city's entire system, including the comprehensive design of the environment, architecture, and even psychology. Usually, the content of a city design should be based on the historical and cultural background, combined with the psychological factors of human behavior, etc., in order to construct an urban system with artistic accomplishment and atmosphere.

Key issues in urban planning are technical data such as building heights, densities and floor area ratios, which are data balancing issues, for example, controlling floor area ratios on the ground floor of buildings in urban projects is a typical planning practice. Urban design focuses on building height (as opposed to the planned height requirements), outdoor spaces, wall elevations of streets, pedestrian and vehicle separation schemes, overall material colors and so on.

Generally, urban design can be used as a part of urban planning, but the design content is more specific and detailed. Unlike urban planning, urban design focuses more on designing a space part of the city in the design of space. According to the urban planning design, the urban design will include more detailed design for this area than in the corresponding residential area or public building area, the corresponding road traffic design and landscape design are also included.

Figure 30. The urban design scope example, master plan. Source: Case study, project “Wantun Affordable Housing Design”. (Author design).


Figure 31. The urban design scope example, bird view. Source: Case study, project “Wantun Affordable Housing Design”. (Author design).

Urban planning deals with a larger spatial scope than urban design. The spatial scale of urban planning work transcends the zoning in the city. It involves the entire city’s overall composition and the relationship between the city and the surrounding urban and rural areas.

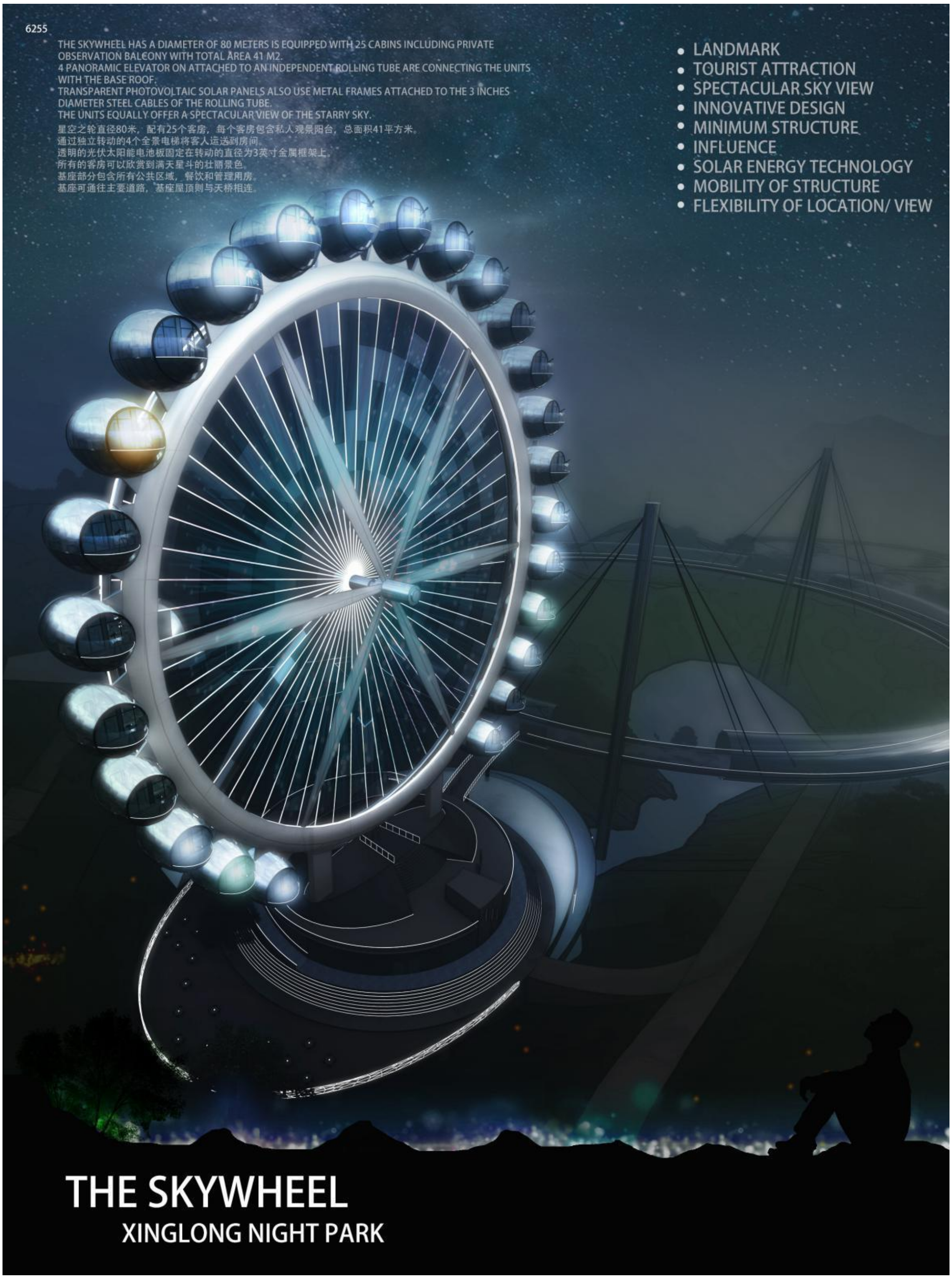


Figure 32. The sky-wheel concept. Source: International competition “Sky Station in Xinglong Night Park”, 2019. (Author design)

- What is the difference between urban design and architecture design?

The spatial scale of urban design processing is much greater than that of architectural design. It deals with blocks, communities, neighborhoods, and even entire cities.

Usually, the realization of urban design is set between fifteen and twenty years. Compared with the architectural design, only the construction work within a single land area needs to be processed. The building's completion only takes three or five years, but urban design has a considerable difference in space and time.

Urban design also faces more variables than architectural design. The scope of urban design in general involves urban transportation systems, neighborhood identification, open space, and pedestrian space organization. Factors that need also to be considered include urban climate and society. These numerous variables make the content of urban design more complex. In addition to the lengthy time required to implement urban design solutions, the result is a high degree of uncertainty between urban design solutions and the results.

Due to the complexity of factors involved in urban design, urban design methods are more indirect, unlike architectural design which can directly control individual buildings. Therefore, the tools and strategies used in urban design are quite different from those in architectural design.

Through the above, and to better distinguish the similarities and differences between urban planning, urban design, and architectural design, Table 12 presents an overall analysis from various aspects.

Table 12: The different of urban planning, urban design, and architecture design.

	Urban Planning	**Urban Design**	**Architecture Design**
Example image	 Figure 29. The urban planning design example, Land integration planning, and urban design on both banks of Nanchuan River in Xining, China	 Figure 31. The urban design scope example, source: Project "Wantun Affordable Housing Design" (Author design)	 Figure 34. Large plane system model of Beijing New Airport
Definition	"Urban planning can be described as a technical and political process concerned with the welfare of people, control of the use of land, design of the urban	"Urban design deals with the larger scale of groups of buildings, infrastructure, streets, and public spaces, entire neighborhoods and	Architectural design refers to the design to meet a specific building's construction purpose, including specific contents such as

	environment including transportation and communication networks, and protection and enhancement of the natural environment."[79]	districts, and entire cities, with the goal of making urban environments that are equitable, beautiful, performative, and sustainable."[80]	environmental roles, architectural functions, and visual perception.[81]
Scale	Entire communities, regions, and even cities.	District, part of the city. The space between buildings, streets, parks, and transit hubs.	Single or multiple buildings.
Purpose	Mainly land use.	Mainly in urban form.	Mainly in building design.
Characteristic	Logic control	Design guidance	Building construction
Focus	City planners focus on ensuring that everything meets local standards and regulations.	Urban designers mainly focus on the look and feel of the space.	Architects mainly focus on the design of individual buildings.
Designer's responsibilities and design content	The regional functional zoning of the entire city, including commercial districts, residential districts, and industrial districts. More attention is paid to the overall development design of land use. Use maps and population	Study the area to create a design plan suitable for the existing space. Use spatial dimension data to create a scale map of a space or building.	Architectural design is the detailed design of a single building, which creates the plane function of the building according to different architectural requirements. It is a human-oriented

[79] "What is Urban Planning". School of Urban Planning, McGill University. Archived from the original on 8 January 2008.
[80] Urban design Theory. Source: https://en.wikipedia.org/wiki/Urban_design (Accessed on 25 July 2019)
[81] 建筑设计. https://zh.wikipedia.org/wiki/%E5%BB%BA%E7%AD%91%E8%AE%BE%E8%AE%A1(Accessed on 25 July 2019)

	density analysis data to work hard to protect historical buildings and monuments.		space design under reasonable and certain artistic expression conditions—the comprehensive coordination of related technologies, such as buildings and structures, buildings, and various equipment. The ultimate goal is to make the building applicable, economical, safe, and beautiful.
Design expression	Two-dimensional graphics are expressed through maps.	Three-dimensional graphics, expressed from a human perspective.	Three-dimensional digital information model.
Inter -disciplinary	Economics, Geography, Environment, Public policy, Transportation planning, etc.	Landscape, Sociology, Psychology, Architectural design, etc.	Planning, Landscape, Gardening, Interior design, Environmental art.

3.3.3 The purpose of urban design

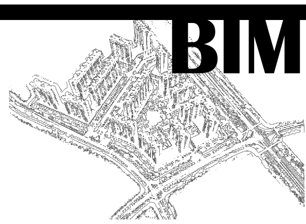
Modern urban design is the unified design of various elements such as buildings, landscapes, and spaces in a specific area. The purpose is to create a comfortable, convenient, hygienic, and beautiful urban space environment. The city can coordinate multiple facilities and functions, the unity and perfection of space form, and the optimization of comprehensive benefits. There are two specific methods: one is to carry out multi-professional overall design under unified leadership; the other is to carry out the professional design based on consolidated design guidelines and then integrate them. In this way, people who are engaged in various aspects of designing the city must

consciously carry out their engineering design following the overall intention of the urban design.
In addition to studying and drawing on traditional and modern excellent examples, modern urban design should understand the various problems arising from modern urban life and use advanced technologies and methods to solve them. Attaching importance to functions, including people's flow and interaction, is an essential element of urban design. The physical space of a city is the "stage" for people to carry out various activities. Just as the design stage must understand drama, the design city must be familiar with and study urban life and pursue an ideal urban society. Adapting to the times is another important part of urban design. The automobile era's road landscape design is not the same as the carriage era; the parks and squares for mass activities and the ancient private house gardens enjoyed by a few people are also hugely different in design methods. Urban designers need to create an urban body environment that is compatible with the times.[82]

3.4 Chapter summary

It has been forty-five years since the emergence of BIM in 1975. During this period, BIM has experienced rapid development. Today, many developed countries, such as the United States and the United Kingdom, have formulated BIM-related policies and standards. China, which is developing rapidly, has also incorporated BIM into its future critical development plans.
By comparing urban planning, urban design, and architectural design, we understand the concept, scale, design focus, and direction of urban design.
The application of BIM in the construction industry has been very mature. The "full life cycle" of a building is an application feature that we often associate with BIM. The BIM information model can be applied to the design from the beginning of the project, and it plays an active role in the construction and later management. Therefore, can BIM technology be as useful in urban design as it is in architectural design?

[82] Trancik, R., 1991. Finding lost space: theories of urban design. John Wiley & Sons.



4 BIM in Urban Design

4.1 Introduction

4.1.1 Demand for BIM in urban design

With the rapid growth of urbanization worldwide, the rapid decline in resources, and the deteriorating environment, the conflict between architecture, cities, and the environment is increasingly visible to everyone. Traditional cities and buildings are based on “graphic thinking”. A series of conceptual processes from concept to planning, two-dimensional to three-dimensional, and external to internal are all based on graphical thinking. The city is continually developing and growing, and the traditional urban design space analysis has highlighted substantial limitations. With the advent of computer information technology, urban designers have begun to seek a new tool that can improve analysis and decision-making functions, thereby solving the problem of quantifying the micro-level ecological indicators when designing urban spatial forms. Therefore, BIM’s information technology happens to be a tool that combines computing, communication, and performance capabilities. BIM technology can effectively promote urban design development, improve the integration between links in the design process, and complete the transition from extensive to refined. The application of BIM technology in urban design is mainly reflected in the urban model. The information model based on BIM is based on a three-dimensional space model. It is based on the same data structure and contains all 3D and multidimensional planning system models.

4.1.2 Introduction to BIM and architectural design

The application of BIM in architectural design is currently most extensive. BIM technology provides a unified digital model expression method. During the design process, the BIM model standards are constructed through specifications to make full use of the information combined by the BIM model for collaborative work, enabling effective transmission of information between professions at various design stages. A BIM example “BIM Application in the Design Phase of Beijing New Airport”.

Figure 33. Overall view of the terminal area of Beijing New Airport. Source: http://www.bimcn.org/BIMal/2018011115228.html

Beijing New Airport is an extremely large, complex and sophisticated project and has no precedent in the world. The Architectural Design and Research Institute (BIAD) is the general contractor for this project’s design, condensing the wisdom and hard work of all project participants to achieve creativity. In this project, BIM technology presented such an opportunity, using BIM as the overall coordination platform, with integrated sub-item design technologies such as parametric design, surface modeling, analysis and simulation, and standardized BIM construction drawing design. Not only did it allow completion of the design work of such a complex project with greater efficiency, but also, through BIM simulation construction, analysis of building information enabled glimpses of the results of this super building after its completion. BIM technology promotes the advancement of ultra large and complex building design technology. It is also a significant development in reshaping the design process. The challenges and experiences summarized have created a solid foundation for the design technology of future airport projects.[83]

[83] Wang.B,. "BIM Application in the Design Phase of Beijing New Airport". General Manager of BIM Consultant, DTree, Fourth Architectural Design and Research Institute of Beijing Architectural Design and Research Institute Co., Ltd. Source: https://www.mnews.cc/doc/20181205/430246/view.html (Accessed on 20 April 2019)

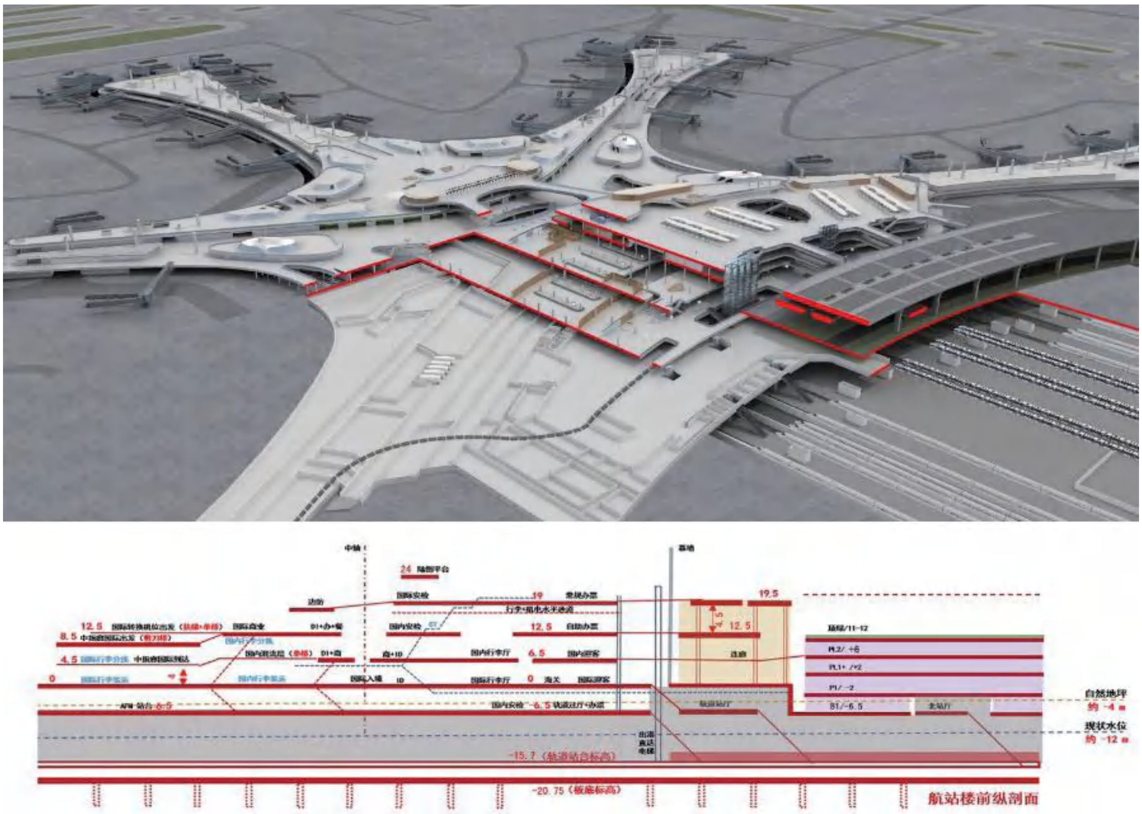


Figure 34. Large plane system model of Beijing New Airport. BIM Application in the Design Phase of Beijing New Airport Passenger Terminal and Integrated Transfer Center (Author: Beijing Architectural Design and Research Institute Co., Ltd. The Fourth Construction of Beijing Architectural Design and Research Institute Co., Ltd. Design Institute / Airport Research Center.

A summary of the BIM application in the Beijing New Airport project is as follows:[84]

- Use BIM technology to model temporary transportation of super large and long structural engineering, plan layout simulation and plan comparison and selection, optimize design, save materials, reduce investment costs, and ensure the efficient completion of material transportation.
- Use BIM technology to model and simulate nearly twenty construction procedures, shorten the time for technical disclosure, and ensure the uniformity and quality of construction procedures.
- In steel structure engineering, BIM technology is used to simulate the construction plan. Combining BIM technology with 3D scanning and the Internet of Things has improved the fineness and management efficiency of engineering management and control.
- Use BIM technology to deepen electromechanical systems' design and reduce the workload of labeling by more than 80% by creating various family files. Using Revit software to draw directly, the drawing time is shortened by more than 70%. Before the formal construction, problems in drawings of electrical and mechanical specialties and pipeline collisions were discovered. It shortened more than 60% of

[84] 北京新机场项目 BIM 应用(4). Source: http://www.bimcn.org/BIMal/2018011115228_4.html# (Accessed on 20 April 2019)

the time spent in solving on-site technical problems. The construction efficiency of the electromechanical profession has increased by 10-15%.

- Using BIM 5D to increase the information transmission of project technology, progress, quality, and safety management by 15-20%, and decision-making efficiency. Using the BIM 5D platform to generate standardized material extraction orders based on the model directly, the time for material extraction is reduced by 15-20%.
- Clarify data usage requirements. Before creating a model, firstly clarify the requirements for using model data, and establish model creation standards based on the criteria in order to ensure that the model is created once and not modified or rebuilt twice.
- Make good use of Revit family files. By making all kinds of openings, annotations, frames, and catalogues into parameterized families, the repetitive operations and human errors in drawing can be significantly reduced. The standardization and unification of drawing files can be improved. Through the establishment and transmission of view template files and shared parameters, multi-party collaborative operations' efficiency can be enhanced. The consistency of their standards can be ensured. In the in-depth design of collaborative work by many participants, BIM technology can achieve with greater value.

4.1.3 The current status of BIM in urban design

At present, there are not many application cases of BIM in urban design, and most projects are in the initiation stage or scheme design stage. The following project cases are from China and other countries.

- **Kalyani Group uses BIM to helps Khed City become a new standard for enhanced infrastructure development.[85]**

This project is located at the junction between the Western Ghats and the Deccan Plateau. The purpose of the design is to use BIM technology to create a global urban model so that the residents of the city can coexist with nature and the environment.
To use terrain reasonably and reduce the waste of resources, advanced technology must be used, establishing a smart city model. This model includes 3D geospatial data, 3D building data model, and road data model. The data of these models should be able to communicate with each other and be well utilized from the initial stage of design to the final project delivery and maintenance stage.[86]

[85] BIM Community. Case Studies. Source: https://www.bimcommunity.com/experiences/load/101/kalyani-group-uses-bim-to-help-khed-city-become-a-new-standard-for-enhanced-infrastructure-development (Accessed on 20 June 2020)
[86] Khed City India's Emerging Smart Industrial City. Source: https://www.khedcity.com/(Accessed on 20 June 2020)

Among the more typical BIM technology applications are road design, utility design, collision check, and early project visual design.

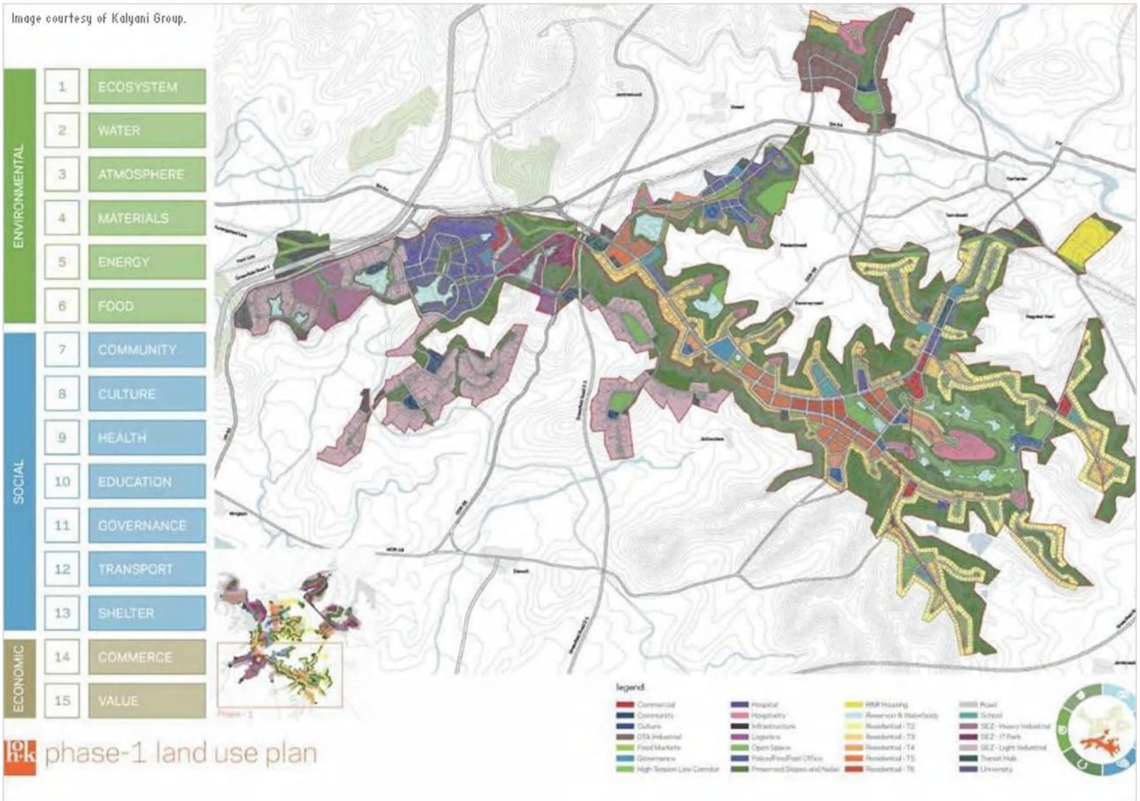


Figure 35. Rendering of the proposed mixed used main street. Source: https://www.autodesk.com/solutions/bim/hub/building-a-bim-city-featuring-kalyani-group.

Figure 36. Downtown or city center organized around public squares, plazas and bazaars. Source: https://www.autodesk.com/solutions/bim/hub/building-a-bim-city-featuring-kalyani-group.

Khed City is a landmark project. With Autodesk's comprehensive solutions for planning, design, construction, and infrastructure management, all of this will become a new paradigm for enhanced infrastructure development.

- **China Xiong'an New District Planning and Construction BIM Management Platform (Phase I, 2019)**

China can be considered the largest construction market in the world. Although the government is paying more and more attention to the sustainable construction industry, the policy requirements for green building projects are becoming increasingly stringent. However, as far as the final effect is concerned, these policies emphasize technological means while ignoring the overall sustainable design of the city. Several personalized green buildings have been built, which are a good start and have had a positive impact on the city's sustainable development in some aspects. However, from the city's perspective as a whole, it is still difficult to achieve the ultimate green and sustainable development of the entire city design. People living in cities have yet to get a real green living space, and the environment has not really been improved. There is still a long way to go before urban green buildings and sustainable development are achieved.

With the latest development of information technology, the technology researched on "information" as a platform will continue to broaden, and BIM will be used more in urban design. With the increasing emphasis by the Chinese government on BIM, smart cities' development with BIM as the core has begun to mature. Urban-level BIM models have been established, and many provinces and cities have promoted the establishment of building information model (BIM) information platforms to realize the full life cycle management. The most recent case is the start of the construction of the Xiong'an New District Planning and Construction BIM Management Platform (Phase I). This platform will realize the recording, management, and management of the entire growth process of the Xiong'an New District, laying a solid foundation for the construction of a green and smart city.

According to China Xiong'an Group, Xiong'an New District planned to build a BIM management platform (Phase I) to start construction on 17 September 2019.

Introduction by the relevant person in charge of China Xiong'an Group Digital City Technology Co., Ltd. Planning and construction of BIM management platform (Phase I) includes data layer, application support layer, and application layer. This platform also covers the display, check, interaction, approval, decision-making, and other services of the six major links of the status quo space, overall planning, detailed planning, design plan, engineering construction, and project completion.

Figure 37. Xiong'an New District plans to build a BIM management platform, urban data visualization, future human-computer interaction (Author: Alibaba Cloud Computing Co., Ltd., China Urban Planning and Design Institute Consortium). Source: https://www.31zaojia.com/12990.html.

Platform (phase I) construction includes a platform and a set of standards.

A platform. This platform refers to the BIM management platform for urban planning and construction of Xiong'an New District (Phase I).

Including the layers:

- Data layer,
- Application support layer,
- Application layer.

It covers the status quo space:

- (BIM 0)-Master plan

- (BIM 1)-Detailed plan
- (BIM 2)-Design plan
- (BIM 3)-Engineering Construction
- (BIM 4) -Project Completion
- (BIM 5)-Management

Six major links including:

- Display,
- Query,
- Interaction,
- Approval,
- Decision-making,
- other services.

The layers, statuses and links were set to achieve the recording, management, and management of the entire growth process of the Xiong'an New District.

A set of standards. The standard refers to the data management standard system and comprehensively explores the application depth of GIS and building information model. Geological "Digital Xiong'an Planning and Construction Management Data Standard", combined with XDB (Xiong'an New Area Planning and Construction BIM Management Platform (Phase I) Digital Delivery Data Standard) data conversion standard, realizes the whole process of data planning and construction management of the six BIM phases of the new area, and sets guidelines for the realization of digital space and digitization of real space.[87]

- **Rublyovo-Arkhangelskoye Smart City**

The Rublyovo-Arkhangelskoye Smart City, also known as the Moscow International Financial Center, in the Kuntsevo District of Moscow, Russia, is being developed by Rublyovo-Arkhangelskoye CJSC, a subsidiary of the Sberbank Group[88]. This project, which is expected to be completed in 2035, was approved in October 2016 by decree of the Moscow City Government of Russia for the smart city's site design.

Rublyovo-Arkhangelskoye will become the global benchmark for smart, sustainable cities[89]. "Supported by the EDF Group's energy and urban scenario 3D simulation platform, the project will optimize the consumption and production of sustainable local energy while integrating electric vehicles, new technologies, services, and infrastructure in order to improve connectivity and efficiency."[90]

[87]The first target of Xiong'an BIM management platform, https://www.31zaojia.com/12990.html (Accessed on 20 June 2020)

[88] Rublyovo-Arkhangelskoye Smart City, Moscow, Russia. Source: https://www.designbuild-network.com/projects/rublyovo-arkhangelskoye-smart-city-moscow-russia/ (Accessed on 20 June 2020)

[89] Zaha Hadid Architects. Rublyovo-Arkhangelskoye smart city. Source: https://www.zaha-hadid.com/masterplans/rublyovo-arkhangelskoye-smart-city/ (Accessed on 20 June 2020)

[90] zaha hadid architects chosen to build entirely new smart city near moscow. Source: www.designboom.com(Accessed on 20 June 2020)

Figure 38. City BIM is the logical extension of Building Information Modeling to use in urban development. Source: https://www.designbuild-network.com/projects/rublyovo-arkhangelskoye-smart-city-moscow-russia/

Zaha Hadid Architects and TPO Pride Architects were jointly selected to build the new Rublyovo-Arkhangelskoye smart city. Rublyovo-Arkhangelskoye is designed to accommodate 66,500 residents, in addition to medical clinics, new schools, shopping areas, cultural institutions, and of course, transportation infrastructure. The smart city will also have 800,000 square meters of office space for Moscow's growing financial, consulting, legal, and audit departments. In the past twenty years, Moscow's population has increased by 12.4 million, and Rublyovo-Arkhangelskoye will become an indispensable city. There will be 4 million square meters of new buildings on 460 hectares west of Moscow. As the city will become an important new residential area in the west of Moscow, a 19-kilometer-long new subway line will be planned for 2020. Construction has started of the Serepica interchange station that connects Lublevovo-Arkhangelskoye and the Moscow metro system. Rublyovo-Arkhangelskoye will become a smart and sustainable city that will optimize local, sustainable energy consumption and production while integrating electric mobility, new services, new technologies, and modern infrastructure to improve connectivity, productivity, and efficiency.[91]

[91] Zaha Hadid Architects. Rublyovo-Arkhangelskoye smart city. Source: https://www.zaha-hadid.com/masterplans/rublyovo-arkhangelskoye-smart-city/ (Accessed on 20 June 2020)

Smart technology is embedded in the urban structure of Rublyovo-Arkhangelskoye. Its design also allows residents and visitors to relax with family, friends, and with the natural world all over the city center, creating an urban environment of ecological technology, seamlessly integrating natural and human-made systems[92].
Christos Passas, Project Director of Zaha Hadid Architects, explained: “We have worked with professional teams in Russia and Europe to develop a human-centered design for smart and connected cities.[93] Through innovative technologies and organizing public domains to bring people together. The community combines the natural aspects of the community with the principles of openness and inclusiveness to adapt to the high-quality architecture of the 21st century.”[94]

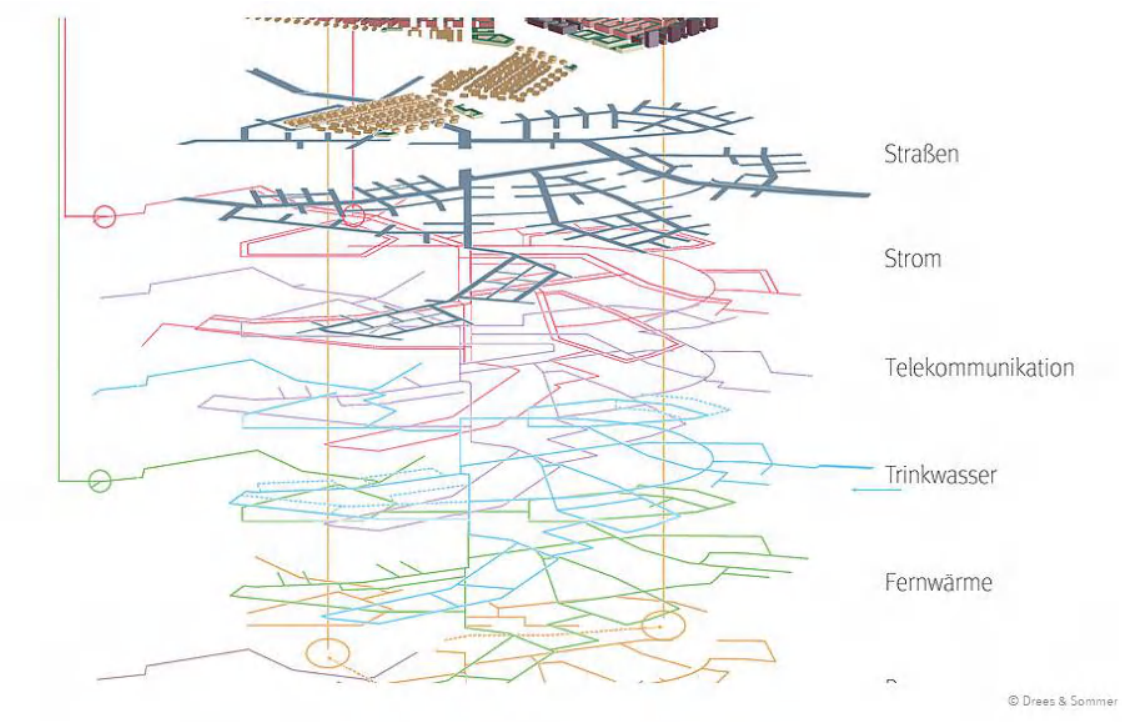


Figure 39. City BIM is the logical extension of Building Information Modeling to use in urban development. Source: https://www.dreso.com/en/press/press-releases/2016/international-financial-center-in-moscow/

The total area of this project is 460 hectares of land, and the designed residential area provides housing for 65,000 people. This project uses BIM as the overall coordination platform, with integrated sub-item design technologies such as parametric design, surface modeling, analysis and simulation, and standardized BIM construction drawing design.

[92] Zaha Hadid Architects selected to build smart mega-city west of Moscow. Source: https://igsmag.com/press-releases/zaha/zaha-hadid-architects-selected-to-build-smart-mega-city-west-of-moscow/ (Accessed on 20 June 2020)
[93] Zaha Hadid Architects. Rublyovo-Arkhangelskoye smart city. Source: https://www.zaha-hadid.com/masterplans/rublyovo-arkhangelskoye-smart-city/ (Accessed on 20 June 2020)
[94] https://archello.com/project/rublyovo-arkhangelskoye-smart-city (Accessed on 20 June 2020)

4.2 BIM Technology

4.2.1 The advantages of BIM technology in Urban design

In urban design projects, the traditional CAD design system uses a two-dimensional way to record and express the geometric size, shape, location, and other construction project information. However, non-graphic information is difficult to express clearly. BIM integrates all two-dimensional graphical information and non-graphical information into a data-based information model. This model not only contains information such as the shape and size of various building components, it also contains some non-graphic information such as manufacturers, materials, and costs are all integrated into this three-dimensional information model. This new application system can completely virtualize the real information of the project, avoiding many design errors in the early stage of design, saving time and construction costs. At the same time, through the simulation and analysis of related model data, it can evaluate whether the design project is realistic.

With smarter planning, design, construction and facilities, and BIM management, BIM technology has diversified into many ways of implementing BIM projects, such as buildings, roads, bridges, tunnels, and factories, plus improved communication.

Increasing efficiency, timelines, and cost consistency between project stakeholders is more guaranteed and reduces risk. BIM allows us to deliver a high-quality product in the most efficient way for our customers. One result of BIM's application is to create a collaborative atmosphere whereby customers, designers, material manufacturers, and construction companies work together to achieve the best possible goals. BIM is more than just a technology solution. It helps produce new ways of working together across all professions and enables more collaborative and informed building design and use processes across all disciplines. Customers can imagine what solutions and alternatives are available to them. The visualization of the model, whether it is a simple observation point or the ability to travel or fly, can surround the entire virtual model of the project and provide opportunities for communication and understanding by the parties' designers and owners, which can thus enable decision-makers to make better decisions. By investing in BIM-based design and construction, meeting the needs of customers makes their projects more manageable. BIM offers several ways to benefit different aspects of a project: design, pre-construction, development, and facility management. The design can be easily understood and reviewed to help ensure accuracy and integrity of its design. Alternatives make it easier to understand and evaluate costs and other project parameters. Sustainability can analyze projects' calculations in different types, spaces, materials, and quantities. Another advantage of BIM is that it allows, through analysis, the project team to determine what combination is best.

Building a project by linking the model proposes a project schedule and permits study of the various plans' sequencing concepts. These processes can reduce timelines and, overall, minimize lifecycle costs, can generate more accurate information to support decision-making on investment, increase mutual understanding, and reduce project risk. The construction team can get the material information, and it is easy to get information from the model and the building. Through the visual timetable for building and starting the actual work, the safety plan becomes more acceptable and effective at the time of production. Teams can check virtual buildings before they become reality and can plan to deal with any issues. Working with conflict detection techniques can make it easier to coordinate and address issues and resolve them. Finally, the model can be completed with as-built information and combined with all operations and maintenance. The project information model can be delivered to the operator or user as part of its facility management strategy.[95]

BIM will be a significant part of our construction industry in the future. In the BIM technology arena, we are happy to have this dynamic tool, and we are always working to improve our overall delivery process. From office buildings to shopping malls, hospitals, and residential construction projects, BIM has proven its potential at all stages. From initial design to production, coordination and overall efficiency can be significantly improved, and all risks are better controlled. BIM can also achieve sustainable design through its focus on energy, green, and carbon dioxide.

BIM strengthens the sharing and collaboration between various industries. The BIM data model format can be converted into different file types and run in construction software. Through the update of the data model, designers' models in various professional fields will also be updated simultaneously. The data model is used in the entire life cycle of urban construction projects, from design to management. For example, after a building is completed, managers can quickly find the problem parts' location through model information and various information about related products and deal with them accordingly after a problem occurs in a certain link. This process greatly saves time and money and provides the best post-management of the building.[96]

Technology saves costs during the construction process. Since everyone is involved and has access to the full 3D model throughout the process, every possible spatial conflict is identified at the beginning of development. There is no need for ad hoc cost increases during the construction process. In addition, the model allows the optimization of materials and lifting equipment, since the objects therein also include weight information. The three-dimensional construction organization design, which uses the time and space of the construction site as design dimensions, allows for an effective reduction in the amount of stored materials and an increase in prefabrication work. Individual activities are easy to plan while reducing the risk of potential conflicts on site.

[95]Kjartansdóttir, I.B., Mordue, S., Nowak, P., Philp, D. and Snæbjörnsson, J.T., 2017. Building Information Modelling-BIM. Warsaw: Civil Engineering Faculty of Warsaw University of Technology.

[96] Building information modeling. Source: https://en.wikipedia.org/wiki/Building_information_modeling. (Accessed on 21 June 2020)

This, combined with the minimization of on-site solution planning and design issues, can reduce construction time. The BIM model saves a lot of time at the construction site and no longer requires on-site coordination and inspection. Since the design of the construction site has been simulated in the design stage, site construction errors are greatly reduced. These coordination tasks have been well analyzed and adjusted during the simulation process of BIM design. If the entire urban design project participants, whether architects, engineers, or construction personnel, use the same working model, from design to completion to management, all coordination and adjustments are completed in the BIM model. This application method makes the design work of each link more accurately and systematically completed.

Effective management of building information can improve the operational efficiency of construction projects, increase productivity and reduce costs. It dramatically shortens the project construction phase's cross-reference and approval time, thus ensuring work efficiency and productivity. Conversely, an increase in productivity is likely to reduce the construction time and cost of the project. Research by Carnegie Mellon University shows that only 3.8% of the building's productivity will enhance the design, construction, operation, and maintenance of the facility, thereby increasing efficiency.

Duplication of work will be reduced between designers in various fields and between designers and customers, for example, if the information cannot be updated in time, it is likely to cause a lot of reworking. It is completely different when using BIM, because BIM is centralized, any updates or changes are immediately reflected, highlighting inconsistency of information and work, thereby avoiding construction errors.

Although some design graphics files have confirmed the infrastructure design, other non-graphic related information such as details, tenders, product descriptions, construction, timetables, etc., are absent. BIM can significantly improve the effects of 2D drawings, providing a full view of the building and elevation, which enables the correction of errors.

Unlike a department that does not fully understand other departments' general practices throughout the project, building information management services provide a holistic view of the entire project for stakeholders, engineers, designers, managers, and so on. This offers reliable information for project-related personnel and makes it easy to capture and track project assessments, communications, coordination, cost estimates, and schedules.

With BIM, a department can be aligned with other departments by focusing its work on BIM data for indexing. This improves coordination and provides (Figure 40) the:

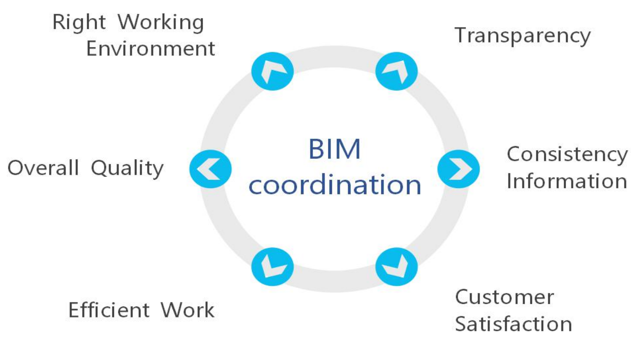


Figure 40. BIM coordination and provides (Author research)

4.3 Chapter summary

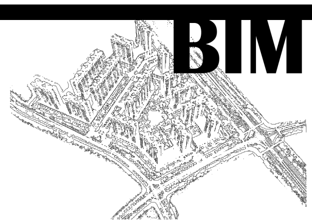
It can be seen from the previous description that the scale of urban design is a volume between urban planning and architectural design. The urban design contains not only some planning characteristics of urban planning, but also architectural design.

BIM is an intelligent digital information model, which plays a vital role in planning, design, management, construction, and other aspects. From the perspective of the construction industry, the characteristics of BIM can improve the general level of the urban construction industry, reduce economic and social problems caused by misjudgment, and ensure that the timely and quality completion of the project is more likely.

In the initial stage of urban design, the control of the building's overall interface is discussed, and a corresponding appropriate block model can be obtained before the construction bidding. BIM can also simulate the construction plan, helping to improve the construction level and speed. Additionally, it can evaluate unreasonable or unfeasible construction plans based on BIM analysis before construction. BIM can dynamically manage the construction plan, visually analyze and correct the project at different stages.

For example, in BIM application, the construction progress is simulated, and the 3D, 4D, and 5D simulations are carried out through Navisworks. The 4D simulation reflects the progress of the construction cycle at different times and the impact on the traffic, noise, etc., generated in the surrounding blocks estimate. In the 5D simulation process, the most realistic cost calculation can also be used under different schedules. For the main building in the plot, a fully parametric visual design can be achieved, which is convenient to improve the communication efficiency of related disciplines and is beneficial for improving efficiency and saving time and cost.

In short, the application of BIM in urban design is both established and feasible.



5 Application of BIM in Urban Design

5.1 Application process of urban design based on BIM technology.

5.1.1 Application Roadmap

BIM is mainly used in the information model of urban architecture in urban design. At present, CAD and GIS [97] (Geographic Information System) are the leading platforms in the field of urban design information.
Different BIM model structures can be used at various management levels of urban design. BIM is used as the application layer. The GIS data that needs to be extracted is correspondingly imported into the three-dimensional BIM model to realize the symbiosis in the two-dimensional and three-dimensional directions. It can present the advantages of GIS platform management and also present the benefits of BIM data integration.
Additionally, BIM also has a huge technical advantage in urban design as its technology provides a convenient visualization function for the design of urban high-rise buildings. It can observe the interactive influence between high and low-rise buildings between different plots, plus the import of related GIS light, heat, wind, and other plot data. It can simulate the degree of light and noise pollution generated by surrounding buildings and can simulate high-rise buildings' wind environment. Projects can be predicted and corrected in a visual state from design to construction, which improves the overall urban construction standard and reduces chain problems caused by misjudgment. It has also brought ground-breaking ideas on how to control high-rise buildings at the urban design

[97] A geographic information system (GIS) is a conceptualized framework that provides the ability to capture and analyse spatial and geographic data. https://en.wikipedia.org/wiki/Geographic_information_system (Accessed on 10 September 2020)

level. Model design delivery based on BIM technology can avoid information loss in converting from 2D design drawings to 3D processing models and can accurately transfer various index control data to architectural design and construction, directly affecting the construction effect.

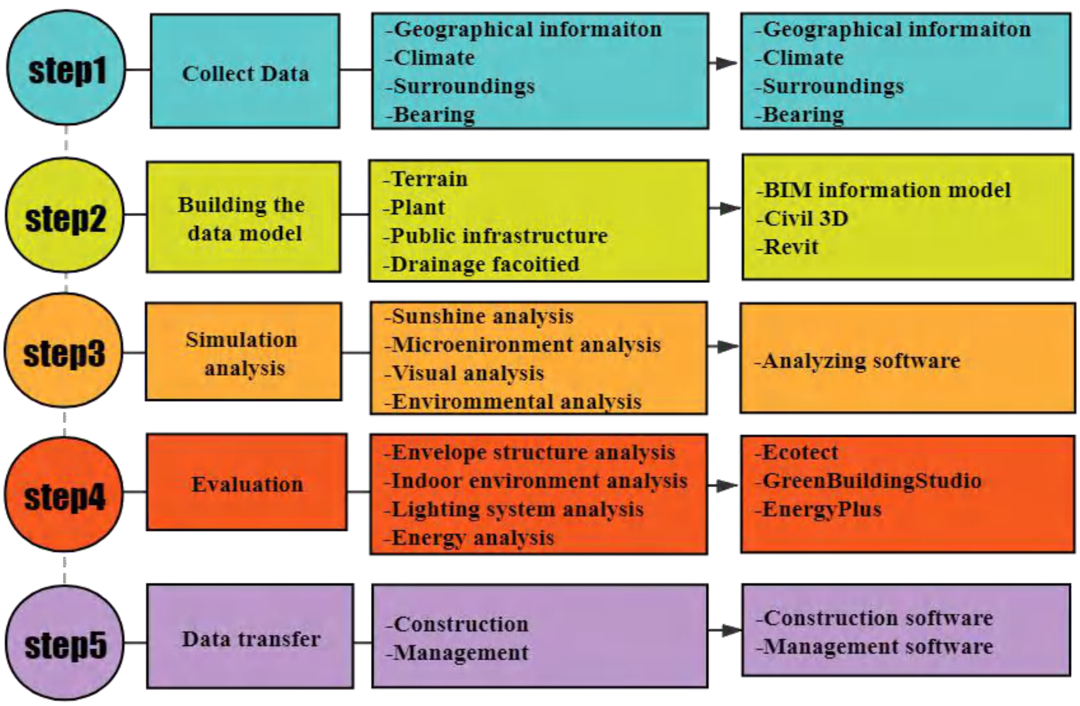
The application of BIM technology in urban design has changed various parties' information communication methods in the past. Both the pre-design and the post-construction have significant effects and have further been incorporated into the urban design field's development.

5.1.2 Application steps

First of all, one needs to create project-related information models in urban design projects. These models include 3D site information models, single building information models, green landscape model information, etc. They utilize BIM's simulation analysis function to simulate and analyze the entire design project, including energy consumption, lighting, wind direction, visualization, cost, etc. The simulation analysis results are used to evaluate the sustainability of the entire project, to evaluate the design project based on the analyzed data, make corresponding design improvements and updates, and finally achieve a sustainable green urban design.[98]

The design process based on BIM technology is as follows (Table 13):

Table 13: Specific process of urban design based on BIM technology.



[98] Horman, M.J., Riley, D.R., Lapinski, A.R., Korkmaz, S., Pulaski, M.H., Magent, C.S., Luo, Y., Harding, N. and Dahl, P.K., 2006. Delivering green buildings: Process improvements for sustainable construction. Journal of Green Building, 1(1), pp.123-140.

- **Data collection:**
  In urban design, because it involves multiple disciplines and is relatively complex, two-dimensional images cannot meet the design requirements. When applying BIM technology to urban design, it is necessary to integrate a large amount of data into a data model and use this data model to simulate and analyze the project in order to obtain accurate data and conclusions and correctly evaluate the rationality of the project design. For example, the project's local altitude, climate, precipitation, soil type, water flow, etc., are all relevant urban design factors.
- **Establish a data model:**
  For urban designers, what is most needed when using BIM is to have a rich and complete digital model library. Without the most basic "accessories", without the building's information model, it is difficult to start doing BIM design. Therefore, one needs to use the building information model (BIM) tool to use data and processes to complete the designer's daily work, such as scheme, design, planning, and detail design in urban design. The information model can bring visualization, simulation, and analysis, whether it is a minimal 3D space, or a large space designed for the entire city. Using BIM can improve efficiency for ordinary design tasks.
- **Simulation analysis:**
  The analysis software of the BIM platform has many basic analysis functions useful for design projects. This analysis has significant benefits and can provide more scientific design applications. The city itself is a very complex system. Both urban planning and urban design require a large amount of digital information to support them. The simulation analysis of BIM's digital model can grasp the direction of urban development macroscopically at the initial stage of design and create a reasonable, sustainable environment for human settlements. Some design errors and deviations can be effectively avoided in the project design stage through the visual simulation design.
- **Evaluation:**
  Building energy efficiency evaluation is an important task. Scientific and accurate evaluation can guide the optimization of design schemes. The rapid development of BIM technology provides strong technical support for this work. This dissertation proposes that the best stage for BIM to be applied to building energy efficiency design evaluation is at the pre-planning and design stage. Its purpose is to make the evaluation serve the design better and optimize the design scheme.
- **Data transfer:**
  Data transmission is the implementation and management of the full life cycle of project design, construction, and operation of 3D digital models.

5.2 Model requirements for urban design based on BIM technology.

5.2.1 The 3D model creation process.

In the progression from CAD to BIM, there is a preliminary and intermediate 3D modeling stage. Designers can use some 3D modeling software to create a model, but this model is a model with only a small amount of information, such as size and shape. Such a model can be used as a visual design for urban design. However, it cannot be used for material manufacturers, cost, and other non-standard graphical information assigned to each model component. It is difficult for such a building model to reach the final construction drawing stage. Therefore, the difference between an ordinary 3D building model and a BIM model is whether the model has complete digital information. For example, for any window in a building model, in addition to basic information such as size, shape, and material, BIM information also needs to include detailed data information such as the window material manufacturer, purchase cost, installation method, and installation process. Moreover, these information models are data that designers in various fields will use, such as use of the AutoCAD Civil 3D model to solve planning and design problems. Preliminary simulation data includes site location, climatic conditions, ecological value, site information, transportation infrastructure, etc. The AutoCAD Civil 3D model is used to generate three-dimensional visualization effects in the early stage of design, the mid-term construction drawings and later management can also be used.

The planning and design project's application starts from the terrain and uses the data and information in the terrain file. The terrain file is the DWG suffix file created in the CAD file. The file contains the contour data of the altitude and the surrounding environment of the construction land, geographical location, plot shape, etc. After collecting and sorting the terrain information, the CAD terrain is built into the AutoCAD Civil 3D software to create a three-dimensional model of the original terrain, which is beneficial to the later single design and is advantageous to the better application of BIM to the entire life cycle of the building. From the Civil3D model, the specific conditions of the plot's use can be expressed very clearly, such as the position of the water body, the height difference of the plot, and the height relationship between the surrounding buildings and the design plots.

As shown in Figure 41, AutoCAD Civil 3D is used to simulate the project base, including the surrounding environment. From the model, it is easy to understand all the project base conditions, such as height difference, greening environment, relationship with urban roads, water body position and size, and many more. According to the analysis results, the overall project planning can achieve a more reasonable design plan. Simultaneously, because the AutoCAD Civil 3D model has digital information, it can calculate the amount of earth and stone. The designer can combine the design plan with the terrain to find the digging and filling elevation point to achieve the aim of sustainable greening design. Figure 41 is a schematic case study based on an international design competition. The project's location and requirements can adapt to various climates, facilitate construction, form a local cultural atmosphere, and inspire new holiday styles. It is a phenomenon worthy of attention as the purpose of the competition was to minimize the natural environment's impact.

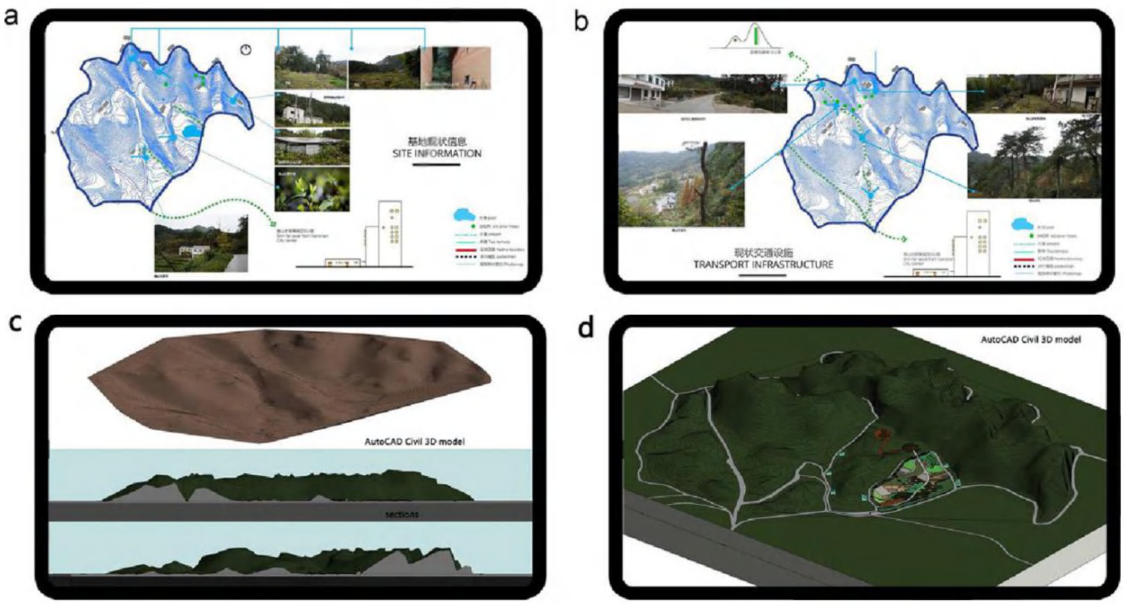


Figure 41. Tent Hotel in Hengshan NaShan Village. Site information; AutoCAD Civil 3D@ site model and sections. (Author design)

The site analysis of the project will affect the overall layout of the design, such as site selection, building orientation, undulating slopes of roads in the site, and location of landscape points. Many factors in the site are interrelated and affect each other. For example, when considering the height of high-rise buildings, it is necessary to analyze the impact of their shadow on the north-facing buildings. It is necessary to carry out landscape design according to the locations of people's activities, the sightline of the landscape and the height of the site. These will affect the direction and slope of the road and the location of the buildings. The traditional site analysis method has difficulty in dealing with such complex data information. If BIM and GIS are used to build a simulated three-dimensional model, including traffic flow analysis, landscape line-of-sight analysis, sunlight analysis, etc., all will be resolved. [99]

5.2.2 The model of BIM requirements in urban design

The model of BIM technology in urban design needs to meet the requirements of the following Table 14.

[99] Bonenberg, W. and Wei, X., 2015. Green BIM in sustainable infrastructure. Procedia Manufacturing, 3, pp.1654-1659.

Table 14: Model requirements.

Model stage	Stage description	Model requirements
Base conceptual design stage model	This stage is the model stage in the early part of the engineering project plan design, helping to submit the design plan quickly. One can use this model to compare different options.	The project base's environment is needed, such as buildings, urban roads, greening, water bodies, etc. This model needs basic volume, size, area, basic material, and other information.
Design development, detail design stage model	The model is for further confirmation of landscape design, such as preliminary design confirmation of structural design, site design, hydropower, etc.	It is necessary to provide a landscape facility model with a vertical profile, which needs to reflect the size, appearance more accurately, and materials of the design objects. This will prepare for the later space and design analysis drawings and project cost estimates.
Construction work drawing stage model	This stage includes the detailed design of all components to reach the drawing stage of the construction drawing level.	The model needs to have a precise statistical quantity, an exceptional model that can compile the project budget and automatically output all construction drawings. The information of the model must include information about the material manufacturer, brand, and so on.

5.3 Urban design application software based on BIM technology.

5.3.1 Functions that BIM application software needs to meet in urban design.

- **Object and information exchange of BIM software.**

BIM is not an independent software. The software used in BIM projects needs some specific functions to meet the conditions of use.

The first software function is object-based design. BIM object-based design connects information describing the object with the geometry used for visualization and geographic details, and defines it spatially [100]. The software used as part of the BIM

[100] Liu, X., Wang, X., Wright, G., Cheng, J.C., Li, X. and Liu, R., 2017. A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). ISPRS International Journal of Geo-Information, 6(2), p.53.

project process needs to have characteristics regarding the interaction between the object and the data that defines it.
The second software function is information exchange. Information exchange or interoperability refers to using and sharing information with other software packages without losing or changing data.

- **BIM software parameterization.**

The degree to which the software connects the representation and description of the object with its data. Parameterization refers to the establishment of specific relationships. When one basic element of this relationship changes, other elements also change [101]. The focus of simple parameterization is the correlation between elements. The changes made to an object in BIM are associated with each view of the object so that the form of the object and its related information can be better controlled.

- **BIM software simulation.**

The designer can create a virtual project model using objects and object properties. The model can show characteristic features such as physical data of shape and size, geographic location, and climatic conditions. After the virtual model is generated, it can be used throughout the construction project's life cycle. The visualization and analysis at the initial stage of the design provide accurate data support for the rapid calculation and evaluation of the project.

5.3.2 BIM software in urban design

Table 15: Introduction of BIM software in urban design.

Type	Software	Introduction
BIM modeling software	Autodesk Revit	Revit was originally a Revit Technology company and was acquired and merged by Autodesk in 2002. Autodesk's BIM software consists of basic BIM application software series such as Revit Architecture, Revit Structure and Revit MEP.
	Bentley	Bentley architecture, structure, and equipment series design software have great advantages in plant design and infrastructure.
	ArchiCAD	"ARCHICAD is an architectural BIM CAD software for macintosh and windows developed by the Hungarian company Graphisoft. ARCHICAD offers computer-aided solutions for handling all common aspects of aesthetics and engineering during the built environment's whole design process — buildings, interiors, urban areas, etc." [102]
		It is mainly used when designing topographical sites and

[101] Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R. and Liston, K., 2011. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.
[102] https://en.wikipedia.org/wiki/ArchiCAD (Accessed on 25 June 2020)

	Civil3D	municipal design.
BIM concept sofeware	Sketchup	SketchUp is a software widely used in 3D modeling, including architecture, interior design, landscape architecture, movie and video game design, etc.[103]
	Rhino	Rhino is a professional curve modeling software originally used for industrial product design, such as cars with many streamlined shapes. Now it is more used in parametric design. Rhino interacts with Grasshopper for interactive modeling, which can realize parametric modeling.[104]
BIM visuali-zation software	3DS Max	Powerful 3D modeling software can also be used for designing visual animation and rendering software.
	Lumion	Lumion is a 3D rendering software specially designed for architects and designers.
BIM analysis software	Green Building Studio	Green Building Studio is operated on the web, and the analysis items are annual or monthly operating carbon emissions, water consumption, and other fuel energy consumption analysis.
	Autodesk EcotectAnalysis	Autodesk Ecotect Analysis is a software operation, including sunlight analysis, building total energy analysis, line-of-sight impact analysis, carbon emission report and cost evaluation, solar radiation analysis, etc.
	EcoDesigner	ArchiCAD's energy analysis software is EcoDesigner, and its energy analysis types are mostly the same. It estimates monthly or annual energy usage data (gas, electric energy, oil, nuclear energy) and overall carbon emissions data of buildings, exported to PDF files for display.
	AECOsim	It is used to design, simulate, and analyze the construction machinery system, environmental conditions, and energy. It can create 2D and 3D energy-saving models and documents and analyze annual energy, carbon emissions, and fuel cost reports. Supporting multiple different software platforms, the AECOsim energy simulator can receive MicroStation, AutoCAD, and Revit.
	IES	IES is an integrated building simulation software developed by the British IES company. Its core idea is to analyze various building functions by establishing a three-dimensional model, which reduces repeated modeling and ensures the accuracy of data and the speed of work.

[103] https://en.wikipedia.org/wiki/SketchUp (Accessed on 25 June 2020)
[104] https://www.rhino3d.com/6/features/ (Accessed on 25 June 2020)

5.4 Simulation analysis of urban design based on BIM technology.

To make better decisions in the early stage of urban design and to choose the most suitable urban design plan for the project, a simulation analysis of the BIM information model is required. The following are the commonly used analysis methods.

- **Solar thermal radiation analysis.**

The application of BIM technology can analyze and calculate the solar radiant heat of building's surface and visualize it, showing the different solar radiant heat calculated in any period of the year. The data can provide landscape designers with shading reference for facility layout or plan design.[105]

- **Sunlight, shadow, and lighting analysis.**

Sunlight, shadow, and lighting analysis can be performed in Revit, Ecotect, and other software. After setting the latitude and longitude coordinates and azimuth correctly, the software's simulation can present the accurate sunshine hours and light and shadow analysis results for any date and time.

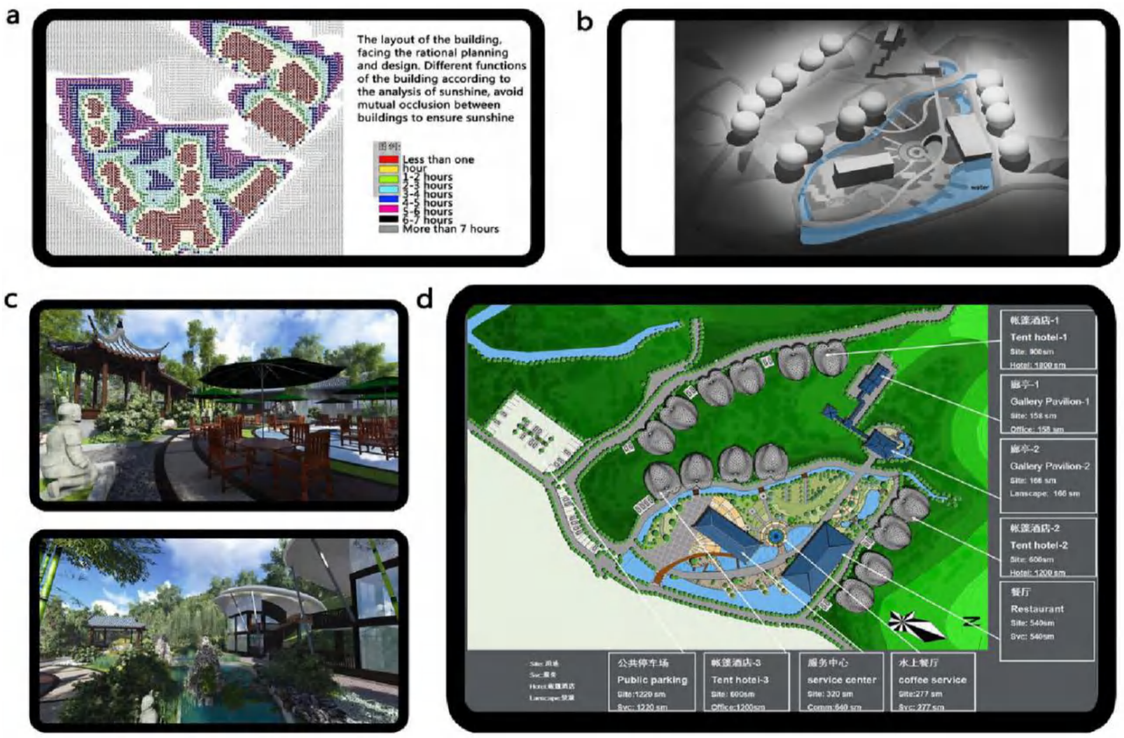


Figure 42. Tent Hotel in Hengshan NaShan Village. Sunlight analysis and application diagram. (Author design)

In the application of urban design, analysis of the time, angle, and occlusion of sunlight between buildings and the surrounding environment is an important part of sustainable design; especially for some functional buildings that have special design requirements for daylight effects, such as residential buildings, kindergartens, and buildings for the

[105] Wei, X., Bonenberg, W. and Zhou, M., 2019, July. The Application of BIM in the "China Beautiful Rural" Design Project–Yangyou Village River Ecological Landscape Reconstruction Design Project. In International Conference on Applied Human Factors and Ergonomics (pp. 135-145). Springer, Cham.

elderly. In addition, the shadow occlusion analysis of the building complex in the city center is also an important design point, which determines the orientation and height of the building. The light and shadow relationship between plants and buildings should also be considered in landscape design. Figure 42(a) is the sunshine analysis chart. From the sunshine analysis chart, one can see the number of full-window sunshine hours for the entire day of the design building at the winter solstice. Red indicates that there is no sunshine time at all, and yellow is one-hour full window sunshine time, so that the position of the building and the height of plus and minus zero and zero floors can be adjusted to meet the design requirements through analysis. There are different sunshine time requirements for different areas and different building requirements for various functions. After analysis, one can also analyze whether the relationship between the building and the surrounding buildings will block each other's sunlight. Figure (b) is a shadow analysis. This analysis can indicate whether the building will be blocked by the shadow of the surrounding buildings or landscape and make corresponding elevation adjustments. Figure (c) is a landscape sightline analysis diagram. Through analysis, the visualization of the sightline point of view is simulated. Figure (d) is the general plan made after analysis and adjustment.

- **Wind field analysis.**

When designers are carrying out urban design, they need to make accurate data analysis of the external environment of the building, especially the factors that influence the comfort of the microclimate environment as a result of the wind. The BIM model can be used to analyze the environment of the design project through analysis software such as Ecotect in order to analyze the wind field of the design project. This will provide the influence degree of each wind direction of the project base on the design project and will then modify the design according to the analysis result to obtain the best design plan, as illustrated by schematic diagram Figure 43.

In the case of the wind environment analysis in Figure 43, according to the simulation analysis of buildings in different orientations in the BIM information model, one can determine the best direction in the planning project to achieve energy-saving design purposes. The figure is an analysis of the natural ventilation of the designed building. As a residential building, it is essential to be able to ventilate naturally. For example, whether there is wind through the hall will affect the layout of the entire design.

Figures (b) and (c) are natural lightings analysis charts. They identify places where lighting is not possible and adjust accordingly. Figures (d) and (e) are wind environment simulations, which can judge the rationality of building design. Figure (f) is the conclusion after analysis, showing which position of the building is the best. [106]

[106] Bonenberg, W. and Wei, X., 2015. Green BIM in sustainable infrastructure. Procedia Manufacturing, 3, pp.1654-1659.

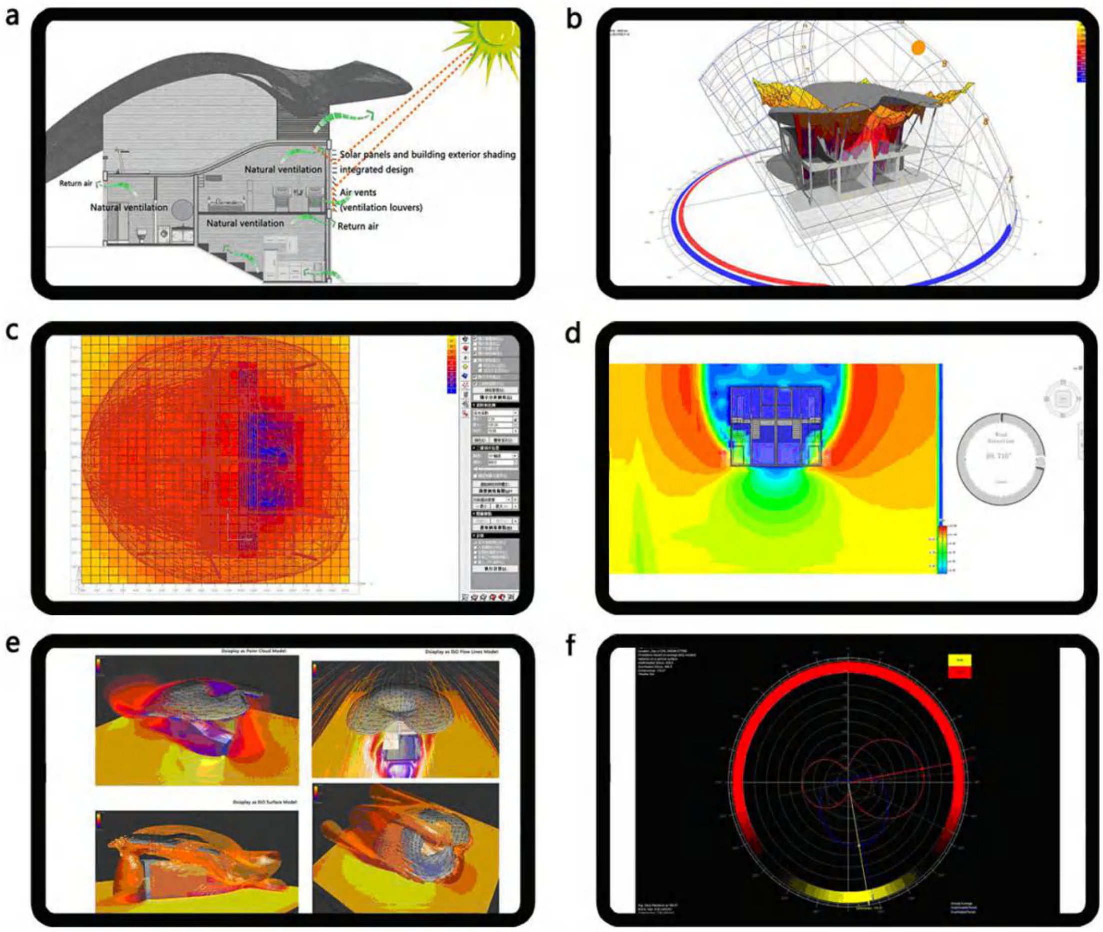


Figure 43. Schematic diagram of wind environment analysis (a) Natural ventilation analysis. (b) Natural lighting; (c) Natural lighting; (d)Wind environment simulation; (e) Wind analysis; (f) Best orientation. (Author design)

- **Sound field simulation.**

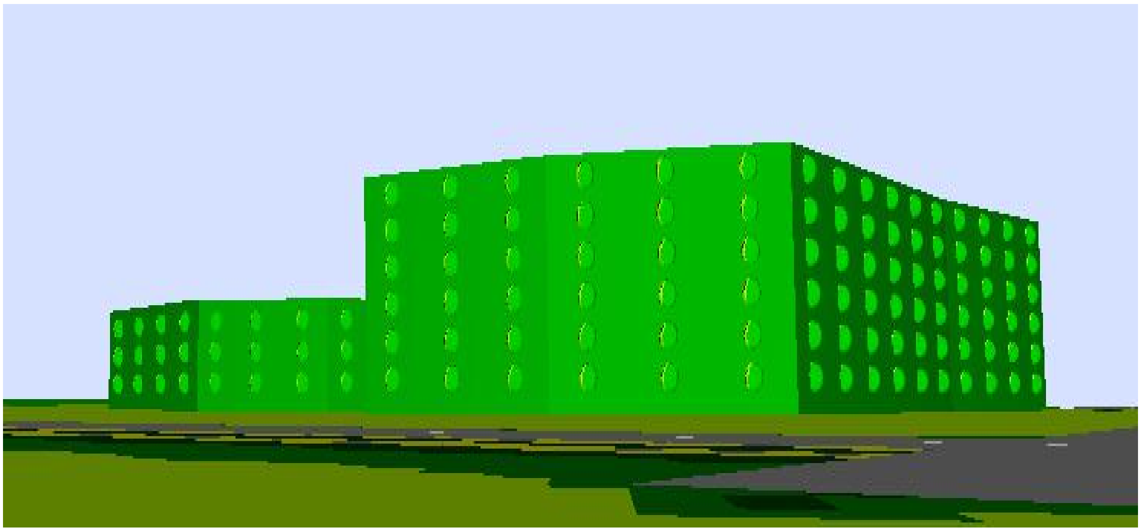


Figure 44. Noise analysis model. (Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Sound field simulation can be used in places with high requirements for sound quality or when the impact of sound or noise needs to be evaluated, such as outdoor performance venues, trains, MRT, or adjacent main arterial spaces.

Figure 44 is the noise analysis model of a project in the analysis software. To better analyze whether the building's design is reasonable, the design model of the building needs to be placed in the surrounding environment, such as other buildings, public facilities, roads, traffic, etc. One can analyze the data in the simulation analysis scene and judge the design's rationality based on the simulation analysis results. According to the analysis report, the plan can be revised by comparing it with the national design standards for noise.

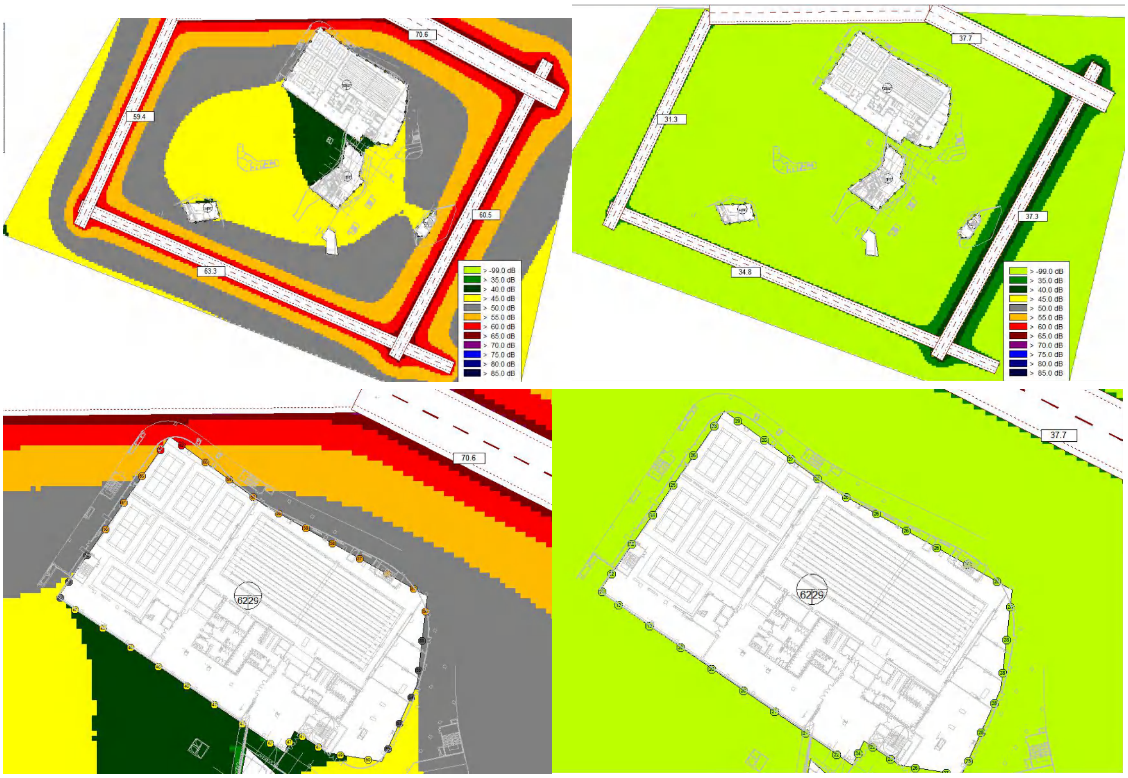


Figure 45. Distribution of sound pressure around the construction project. (Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Table 16: Model requirements (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Monitoring points	Monitoring time		Monitoring results	Average value
Project site Center	Daytime	25-04-2015	55.7	55.6
		26-04-2015	55.5	
	Nighttime	25-04-2015	47.3	47.5
		26-04-2015	47.7	
Project site West	Daytime	25-04-2015	58.2	58.8
		26-04-2015	59.4	

	Nighttime	25-04-2015	48.9	49.0
		26-04-2015	49.1	
Project site South	Daytime	25-04-2015	58.9	58.6
		26-04-2015	58.3	
	Nighttime	25-04-2015	47.6	48.0
		26-04-2015	48.4	
Project site East	Daytime	25-04-2015	61.6	62.1
		26-04-2015	62.6	
	Nighttime	25-04-2015	48.6	49.1
		26-04-2015	49.6	
Project site North	Daytime	25-04-2015	64.8	64.8
		26-04-2015	64.7	
	Nighttime	25-04-2015	54.6	54.7
		26-04-2015	54.7	

Table 16 is the noise status monitoring and evaluation result table of the project in China.

Comparing the data in Figure 45 and Table 16 shows that the average daytime monitoring average of the project's center, west, and south sides is between 55.6 ~ 58.8 dB (A), and the average nighttime monitoring is 47.5 ~ 49.0dB (A). The average daytime monitoring average of the east is 62.1 dB (A), and the nighttime monitoring average is 49.1dB (A). Since the east side road of the project under construction is constructed in the daytime, the daytime monitoring value is slightly higher. The project's ground center, west side, south side, and east side all meet Class 3 standards' requirements in "Acoustic Environmental Quality Standards" (GB3096-2008). The north side of the project is affected by the traffic noise of the sightseeing road. The average value of the measured daytime noise is 64.8dB (A), and the average value of the night noise is 54.7dB (A), which meets the "Acoustic Environment Quality Standard" (GB3096-2008) Class 4a standard requirements. In general, the current acoustic environment in the area where the project is located meets the corresponding acoustic environment function zone requirements.

- **Horizon analysis.**

The visual field analysis of the entire project can help analyze the sightlines of the landscape, evaluate visual impairment, etc. Landscape design places emphasis on the senses and experience of people in urban design for different design scenes, in different locations and directions. Visual field analysis allows designers to make good judgments based on the analysis results and make good landscape designs that are within sight of people from different angles.

Through the simulation evaluation of the wind direction and wind field throughout the year, the wind direction and wind speed distribution in different months in the base can be obtained. Scientific analysis tools can verify the rationality of urban design and create a high-quality microclimate environment.

5.5 The case study of BIM simulation in urban design

5.5.1 Introduction

The basic geography, infrastructure, and basic functions of a city are complex and encompass complex ecosystems. The digital design of the city needs to be supported by digital information, using the BIM model to simulate the entire urban design project, and macro-control the design plan and future development. Through the BIM analysis and evaluation function in the design stage, design errors and mistakes can be avoided early, and BIM technology can be effectively used in the entire life cycle of urban design.

5.5.2 Methodology

Using BIM technology, the virtual building information model created by the designer during the design process contains a large amount of design information, such as geometric information, material properties, component attributes, prices, etc. [107], of all building components. One can import this information model into the relevant BIM analysis software, and the corresponding data analysis results can be obtained. Based on the data obtained from these simulation analyses, designers and decision-makers can fully grasp the quality and development expectations of urban design projects in the early design stages.

- **Daylight and shadow simulation.**

By establishing a model to simulate and demonstrate the projection effect of sunlight and shadows for the whole urban design project, part of the sky radiation data is collected and integrated into the BIM model for analysis and calculation, which can determine the influence of the natural environment on the building group in a certain period of time; the simulation analysis can determine the amount and length of time of outdoor light received by different orientations of the building, thus solving the problems of house orientation and design height in the project.

- **Building dynamic thermal simulation.**

As an important indicator of building energy-saving design, building dynamic thermal simulation mainly uses the powerful analysis capabilities of BIM software to simulate and analyze the energy transfer between the building and the external environment, such as thermal energy and wind energy analysis. Based on the ability of BIM software to simulate and analyze, it can establish a 3D visualization information model of all buildings in an urban design project, and conduct an overall analysis through the collection of the building's own data and external data. For example, it can calculate the

[107] Azhar, S., Carlton, W.A., Olsen, D. and Ahmad, I., 2011. Building information modeling for sustainable design and LEED® rating analysis. Automation in construction, 20(2), pp.217-224.

energy consumption of the HVAC equipment of the building structure caused by the overall radiation of the sun on the urban design project, and use this as a basis to simulate whether the design plan is reasonable.

- **Visibility simulation of urban planning.**

BIM can simulate the construction effect of the urban design plan from different angles (pedestrian, vehicle, air), and analyze the effect of the plan’s building height, building volume, building color, etc., in the urban landscape.

- **Project Environmental Noise simulation.**

In the BIM information model, by simulating various adjacent buildings, urban infrastructure and landscapes in the design project and the surrounding environment, noise data from various places are integrated into the information model for simulation and analysis before the corresponding sound insulation design is carried out. For example, construction projects will inevitably impact the surrounding environment during the construction period, the most obvious being on traffic and noise pollution. Through the BIM virtual model and GIS system, it is possible to understand the traffic conditions around the building, the layout of local residential quarters, and the living conditions of residents. The analysis and simulation of the BIM model obtain the corresponding analysis results, and the impact of noise on the surrounding environment can be minimized through a reasonable design.

5.5.3 The case study project

The advancement of science and technology have brought about a technological leap from two-dimensional to three-dimensional urban design. It has become a reality to be able to study the effects of urban design schemes in real urban spaces. Traditional urban design methods are mainly based on two-dimensional drawings and three-dimensional static models. There is no overall objective evaluation system, and there are often deviations between the design drawings and the construction effect. BIM’s 3D urban design system is a brand-new technical means of urban design, using 3D space to realize 3D simulation, virtual reality, etc. The system mainly establishes a 3D urban project simulation platform that efficiently integrates urban design project status information and design information. This system acts as a carrier to visualize complex information such as geography, planning and design, landscape, and climate in urban design projects. BIM information model can accurately establish the three-dimensional space of urban design projects, effectively combine the two-dimensional and three-dimensional information of the city, and realize the reconstruction and simulation of the real three-dimensional space of urban design projects. In the design stage, the feasibility and rationality of the project is evaluated through the analysis of this 3D information model, so as to obtain the best design method. BIM information model can accurately establish the three-dimensional space of urban design projects, effectively combine the two-dimensional and three-dimensional information of the city, and realize the reconstruction and simulation of the real three-dimensional space of urban design projects. In the design stage, the feasibility and rationality of the project is evaluated through the analysis of this 3D information model, so as to obtain the best design method.

A. Project overview of the study case

This study case is the conceptual design of Beihu District, Binjiang District, Jinan. The design site of the project is located in Jinan Province, China, with a design area of 127.2 hectares. Figure 41. Jinan City is located in the west of the Shandong Peninsula, the capital of Shandong Province, and a well-known economic and cultural center. Jinan has beautiful scenery and is known as the "Spring City". It has countless water landscapes. This unique and charming city, with mountains, springs, lakes, and rivers, is one of the wonders of the world.

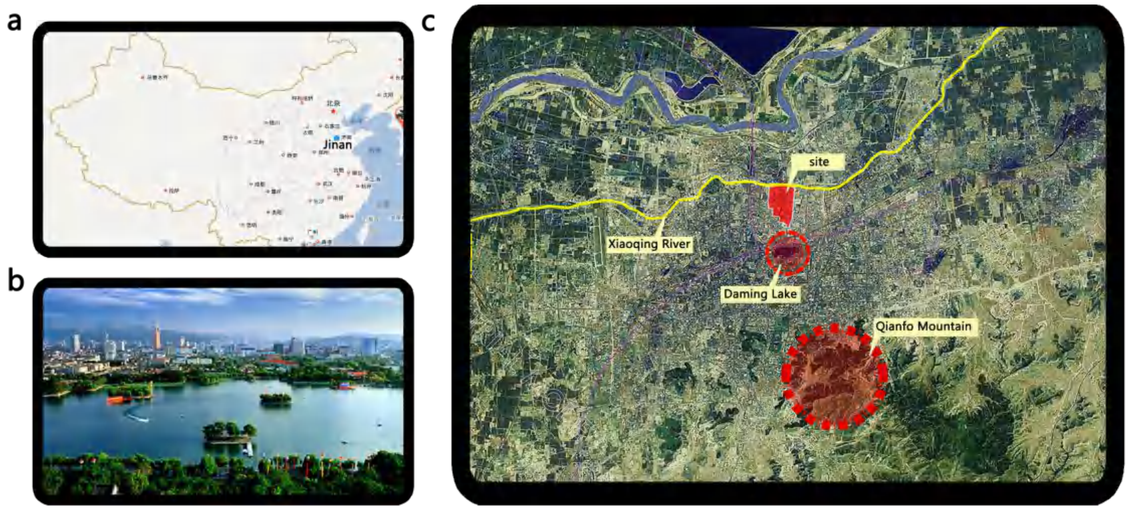


Figure 46. Case study. (a) Location in China; (b) Photo of area; (c) Site in Google map. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

The main purpose of this urban design project is to design a large-scale urban community with comprehensive functions, including residential, commercial, and urban public activity centers. The design requirements combine the topography of the actual site to create a large community with riverside, leisure, entertainment, and traditional cultural activities.

The core area of the Beihu area of the urban design project is located in the Binhe New District of Jinan City, with Beiyuan Street in the south, Binhe South Road in the north, Dongluhe Road in the east, and Shunhe Elevated Road in the west. (See Figure 47). The project faces the planned Peking University Resources and Business Complex across the Xiaoqing River to the north. It is located at the northern end of the city axis of Quancheng Square-Daming Lake-North Lake. The infrastructure in surrounding cities is mature and complete—with high development value. The planned construction land area in the zone is 127.2 hectares, including 79.09 hectares for residential and commercial office use, 9.02 hectares for education facilities, and 39.09 hectares for rivers, lakes, green spaces, and municipal facilities.

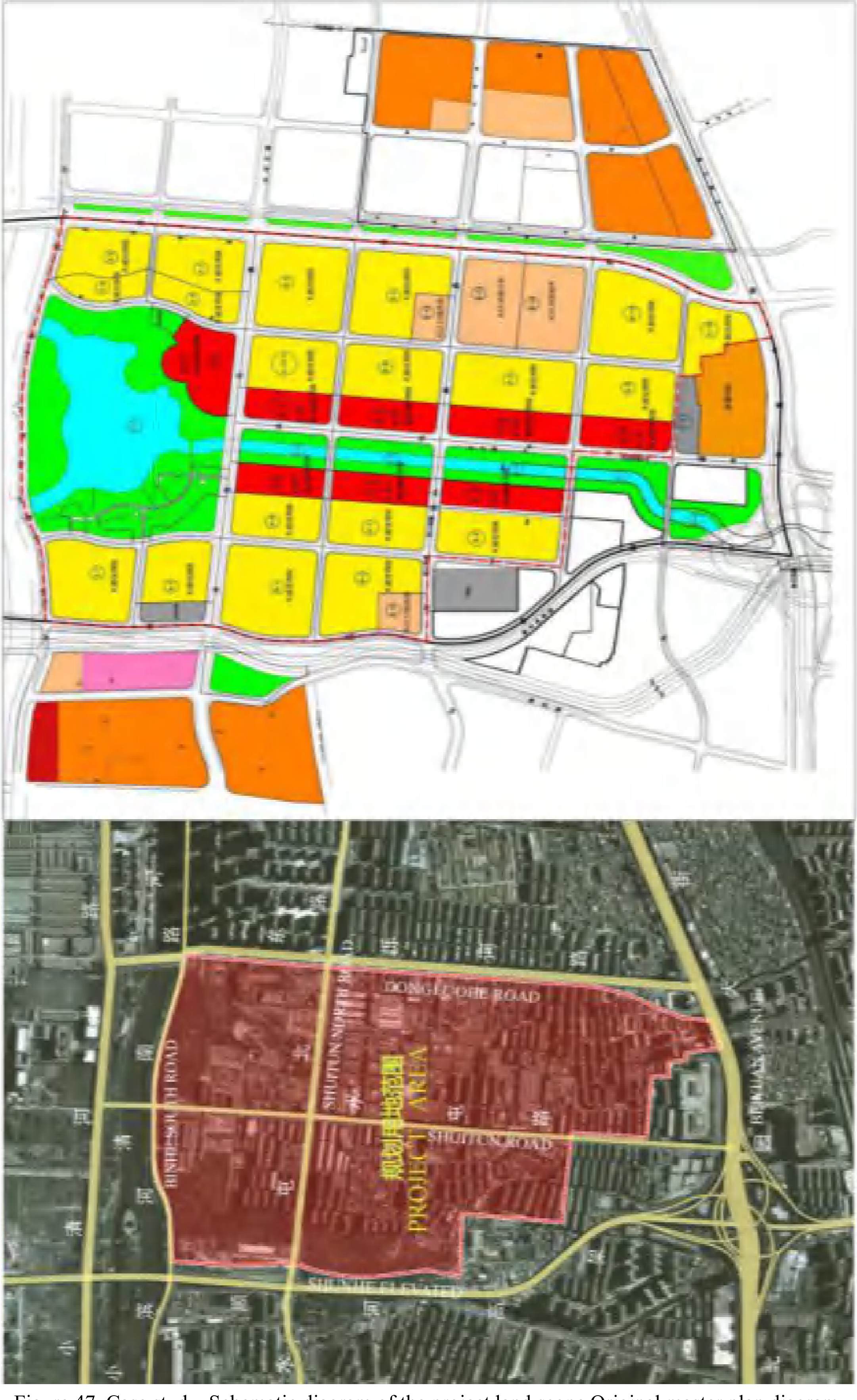


Figure 47. Case study. Schematic diagram of the project land scope Original master plan diagram. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

B. **Project design plan**

Figure 48. Case study. Master plan function design. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Figure 48 shows the original status quo plan for this urban design project. There are many issues in this plan that need to be addressed during the design process.

The problems to be solved in this urban design project are:

- Roads in residential areas are narrow and chaotic.
- The traffic in the business district is complicated and covers a large area, but the area is not convenient for vehicles.
- The intersection of pedestrian and vehicle routes in the green waterscape landscape belt in the center of the design block creates potential safety hazards. The quality of landscape design is not currently good, and there is no good interaction between people and landscape.

To address the problems with the status quo plan presented earlier, this urban design proposes corresponding planning adjustments (Figure 49).

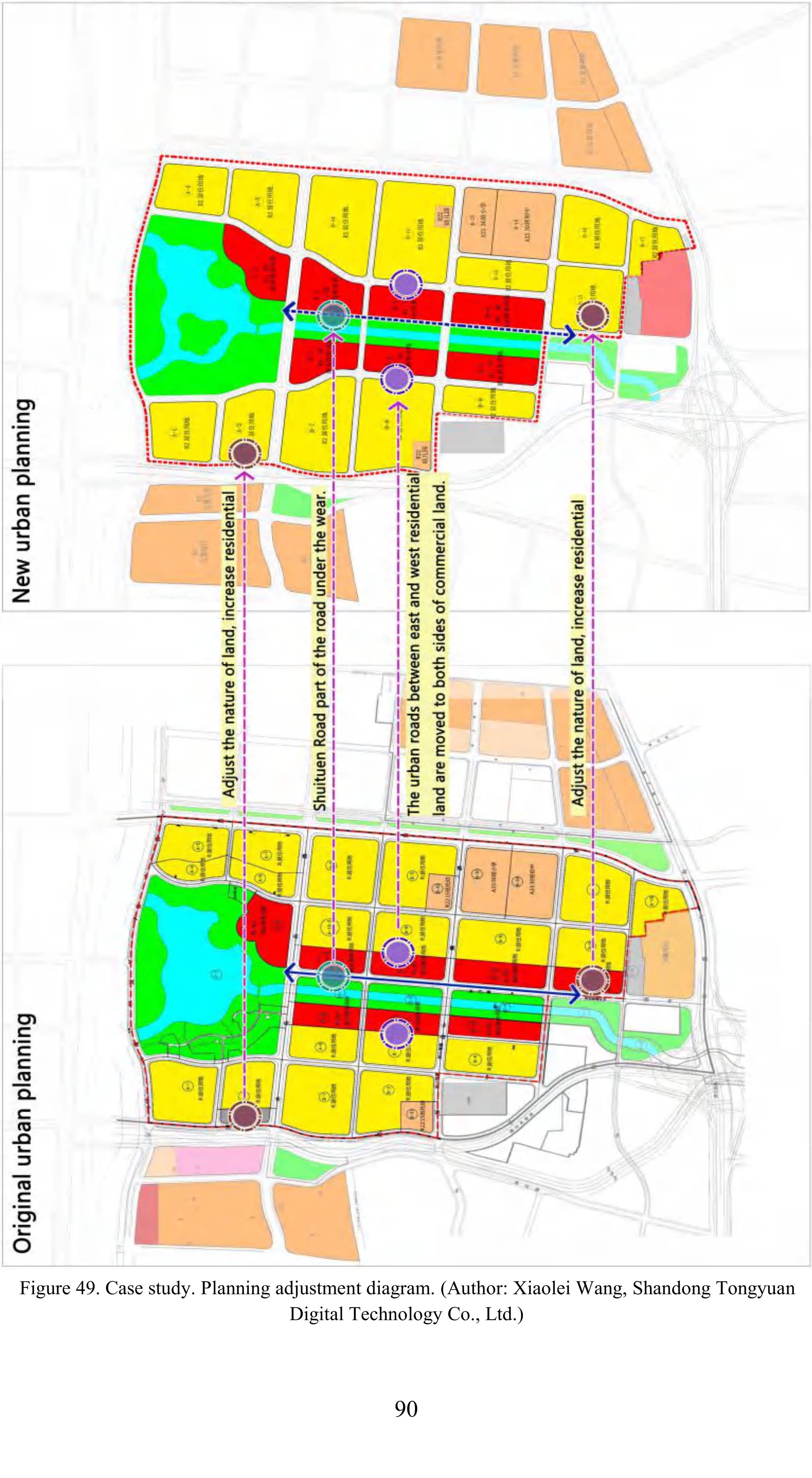


Figure 49. Case study. Planning adjustment diagram. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Figure 49 shows the original urban planning design and the adjustment plan of the urban design adjustment diagram.

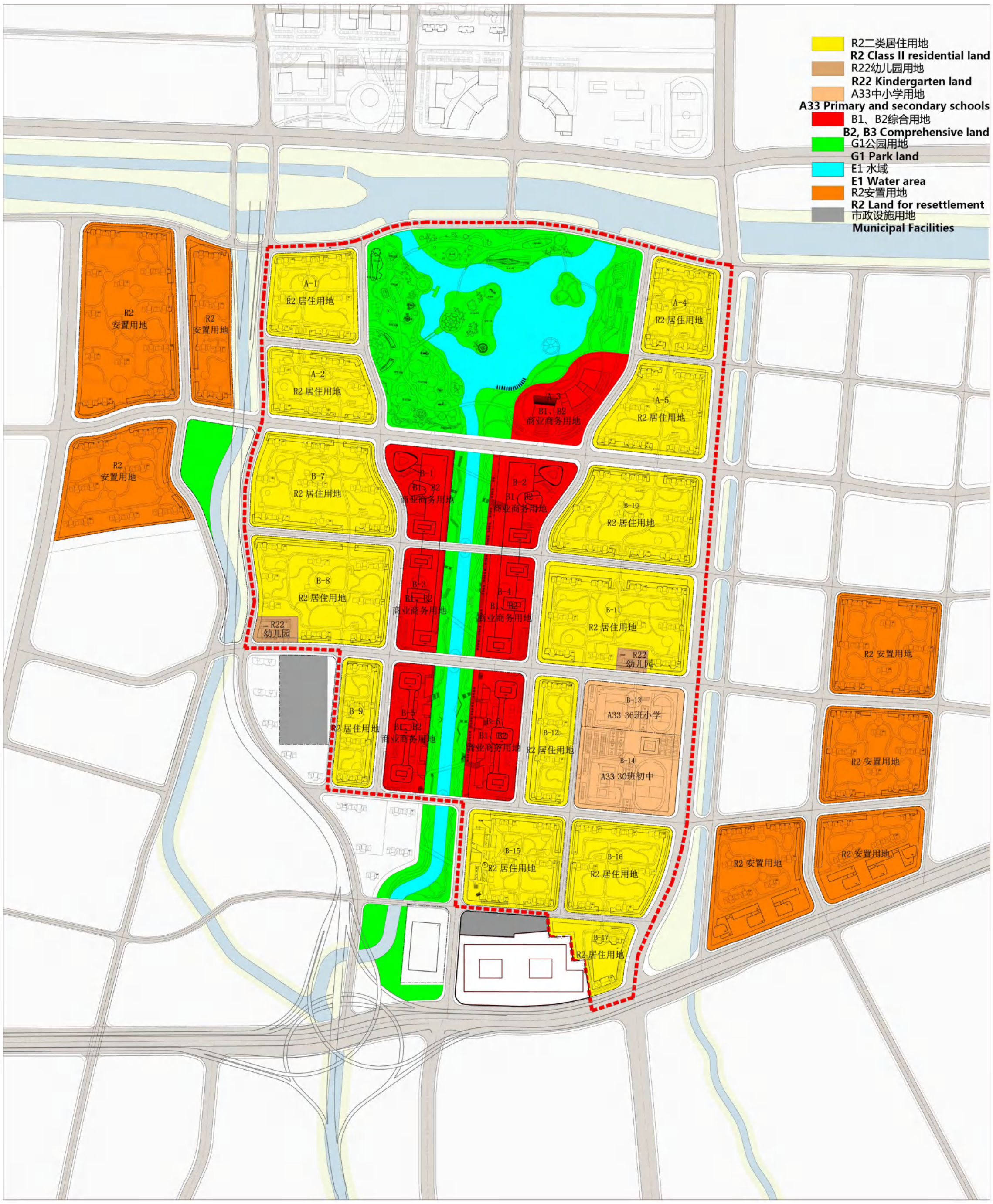


Figure 50. Case study. Adjusted master plan. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

To solve all the existing problems in the urban design, the following scheme design was carried out (Figure 50):

- Adjust the functions of the two plots on the northwest and south sides of the plot to increase residential plots.
- Part of the road of Shuitun Road is sunk to widen the sightline of the water feature.

Figure 51. Case study. Master plan. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

This master plan (Figure 51) scheme respects the original plan, combined with the adjustment of the road network, and makes corresponding changes to the scale of the plot as well as the area index, in order to improve the efficiency and value of land use. To better separate the commercial land from the residential land, move the vertical east-west roads inward and place them between the residential and commercial areas. The land in the residential area is more complete, along with the river view. Commercial plots can also create better open public spaces.

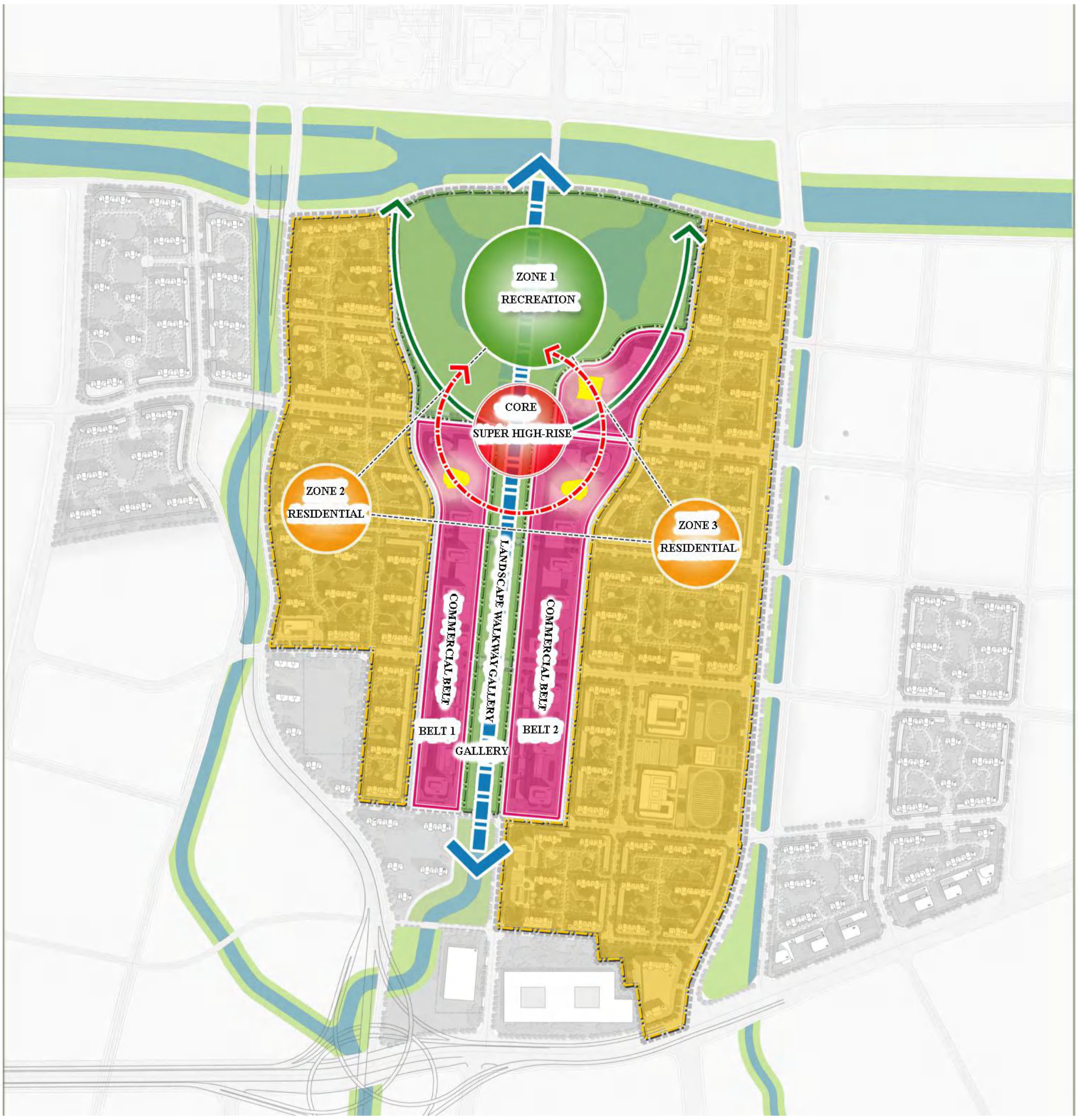


Figure 52. Case study. Structural analysis of master plan. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

The structure of the project master plan can be summarized as one core, one gallery, two belts, and three zones. (Figure 52)

- **One core.** On the north and south sides of the main road in the core super high-rise group area, 3 super high-rise complexes are planned and arranged. The concentration of super high-rises forms the space commanding height and visual center of the area. The 300-meter super high-rise capacity of 6E-class business office, star hotel, business apartment, CEO sky mansion, and other functions are integrated. The 180-meter and 140-meter towers create Haier’s e-commerce platform and help commercial enterprises to transform into e-commerce, and create space for cultivating e-commerce industrial clusters.
- **One landscape walking gallery.** The pedestrian gallery starts from the south side of the plot and connects with the open waters of Beihu and Xiaoqing River to the

north. The lower levels on both sides are combined with commercial pedestrian streets, integrated supporting commerce, commercial complexes, and other comprehensive commercial forms to create Haier. Cloud Street, a public open space for pedestrians, has become a living room for the new northern city residents.

- **Two belts.** The commercial and financial belt combines the good industrial foundation and commercial supporting needs to create two commercial and financial belts on both sides of the landscape gallery.
- **Third zones.** The layout of the Binhu Amusement Area is centered on Beihu Lake, with super high-rise landmark buildings and resort-style waterfront hotels on the east side, Haier Brothers Adventure Theme Amusement Park on the north and west sides, and two residential areas on both sides of the core landscape area. The residential area is divided into thirteen residential plots and supporting education one- plots near urban roads. The plot size is adaptable, and the development intensity is high.

C. The application plan and process of BIM

- Collect and organize the original data of the project.
- Use BIM modeling software to simulate a three-dimensional model of the entire urban design project. This model can be established from 3Dmax or Revit and then imported into the IFC format of BIM.
- Import the model into the microenvironment simulation platform for simulation calculation.
- Assign the collected geographic data, such as meteorological data, to the project model for parameterization.
- Analyze the simulation results of different schemes and evaluate the schemes.

D. 3D model making specification

- The three-dimensional model of the BIM urban design project includes basic geographic information data, planning geographic information data, three-dimensional data model, attribute data, etc. General data production needs to follow the corresponding data production process.
- The preliminary data collection preparation needs to collect and organize the surveying and mapping data of a specific scale, according to different production precisions.
- Data production standards and technical processes include the division of production accuracy and levels, coordination systems and production technical processes, etc.
- Data production process management mainly includes production task management, data security control, backup, quality control, etc.

E. Simulation analysis

Traffic analysis

Traffic design in urban design is the pulse and blood of the whole design, and how to design a reasonable traffic scheme determines the success of the project. The traditional design process often relies on the independent establishment of design models in analysis software, without any data connection between design drawings and analysis models, and many analysis means cannot be realized due to the limitation of two-dimensional design. Based on BIM technology, the three-dimensional design results can be seamlessly transitioned to various analysis-type software for corresponding professional analysis, and the analysis results can interact with the design model in real time.

BIM's three-dimensional design tools also greatly expand the types of analysis, so as to fully and effectively optimize project performance, shorten the design cycle, and reduce investment costs. For example, traffic sight distance analysis, traffic flow analysis, and other analysis tools can be achieved through the BIM workflow.

In urban projects, infrastructure is a matter of local development and public interest, and there is a lot of communication, exchange and reporting during the planning and pre-design process, and the reporting parties are often not professionals, so conventional drawings cannot clearly express the planning and design intentions. BIM design means can truly and very intuitively show and elaborate on the project, reduce the professional threshold, and enhance the scientific and efficient decision-making. At the same time, for professionals, 3D visualization technology can improve mutual understanding and communication among various professions, whether design, construction or project management personnel, they can understand the true intention of the design from macro and micro levels, reducing the cost of communication links.

- **Road traffic analysis** (Figure 53)

Through the simulation analysis of the 3D model, a reasonable road network density is designed in the traffic road network.

In order to strengthen the accessibility of the neighborhood and shape the vibrant street space, the road network density of the community is planned to be appropriately increased through urban feeder roads. The density of the road network is controlled at 8-10km/km^2, and the area of the neighborhood is about 4-9 hectares. The entrances and exits of the garages are reasonably solved, and the internal traffic of the group is divided into pedestrian and vehicular traffic.

Figure 53. Case study. Road traffic analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

➢ **Road section analysis** (Figure 54)

The principle of giving priority to walking and bicycling, reasonable layout of road cross-section forms, creating friendly pedestrian space, and making the middle landscape zone a living landscape corridor suitable for urban public activities.

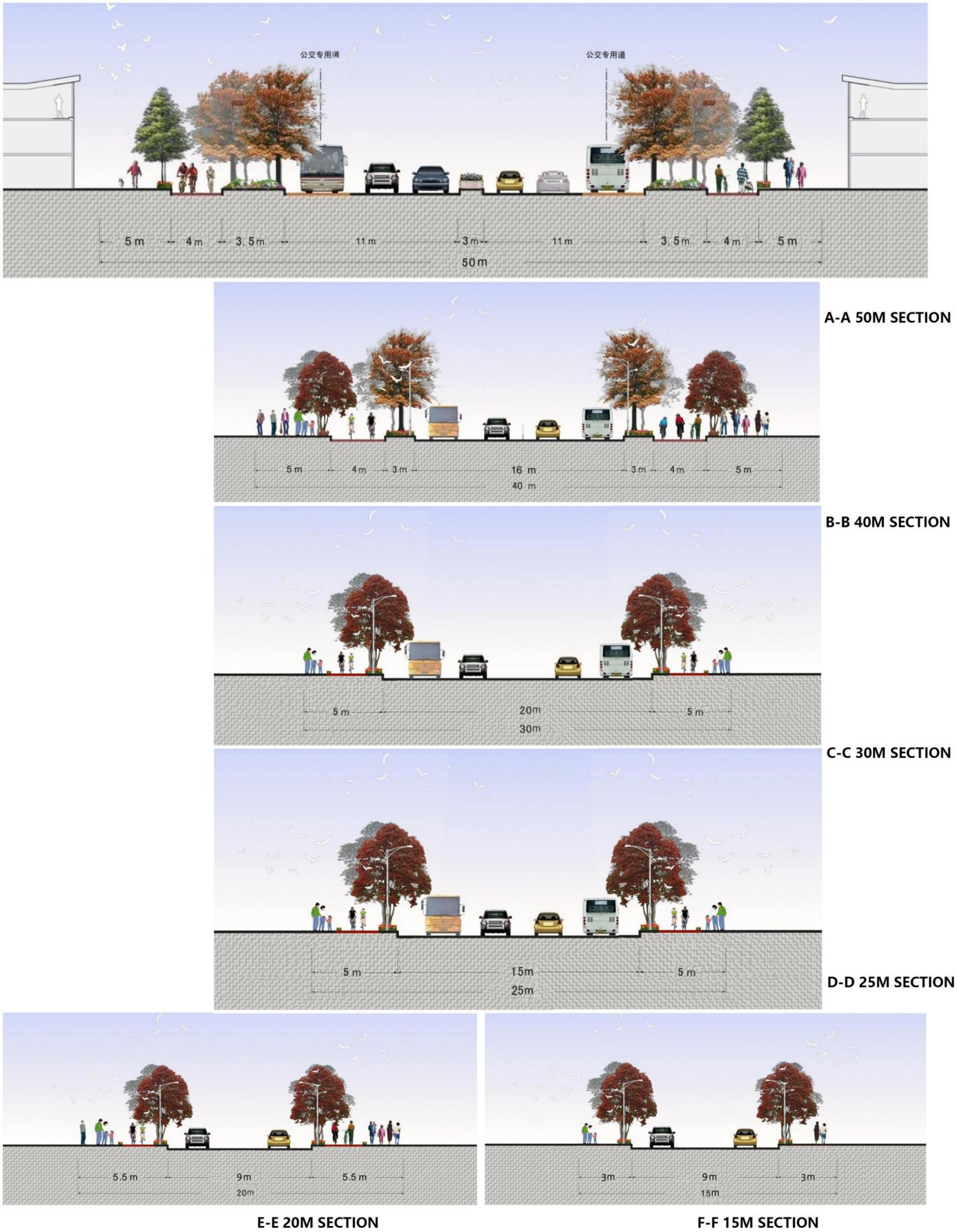


Figure 54. Case study. Road section analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital

➢ **Slow traffic system analysis** (Figure 55)

In this slow traffic system analysis, refined road form and cross-section design, reduce the negative impact of motor vehicles on the environment, make the pedestrians and motor vehicles live in harmony, realize slow traffic, enhance road vitality, so as to empower the whole area safe, economic, efficient use, social life attributes conducive to interaction.

Figure 55. Case study. Slow traffic system analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

- Combined with the middle ecological green vein, leisure pedestrian commercial street, etc. to form a continuous and complete pedestrian traffic network to connect various public facilities, transportation stations and residential blocks, through the water-friendly platform, slope greening, steps wood trestle, small square and other arrangements, to create a distinctive public activity space.

- The planning encourages bicycle traffic in the district, and the road section design takes into full consideration the bicycle traffic and the environment, and builds a bicycle road network system in the district.
- Fully consider the interchange requirements between bicycles and public transportation, and arrange centralized bicycle storage yards of appropriate scale around major interchange points and major public facilities.

➢ **Public transportation system analysis** (Figure 56)

Figure 56. Case study. Public transportation system analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Public transportation oriented and reasonable traffic diversion within the district community. In order to avoid difficult travel traffic problems in the morning and evening peaks, it is planned to set up special bus stops on the west side of the community's external traffic connection parcel and on the south side of the parcel to quickly evacuate the flow of people within the district. Encourage bus priority, optimize bus stops and routes according to the walking service radius and the location of community entrances and exits.

➢ **Static traffic analysis** (Figure 57)

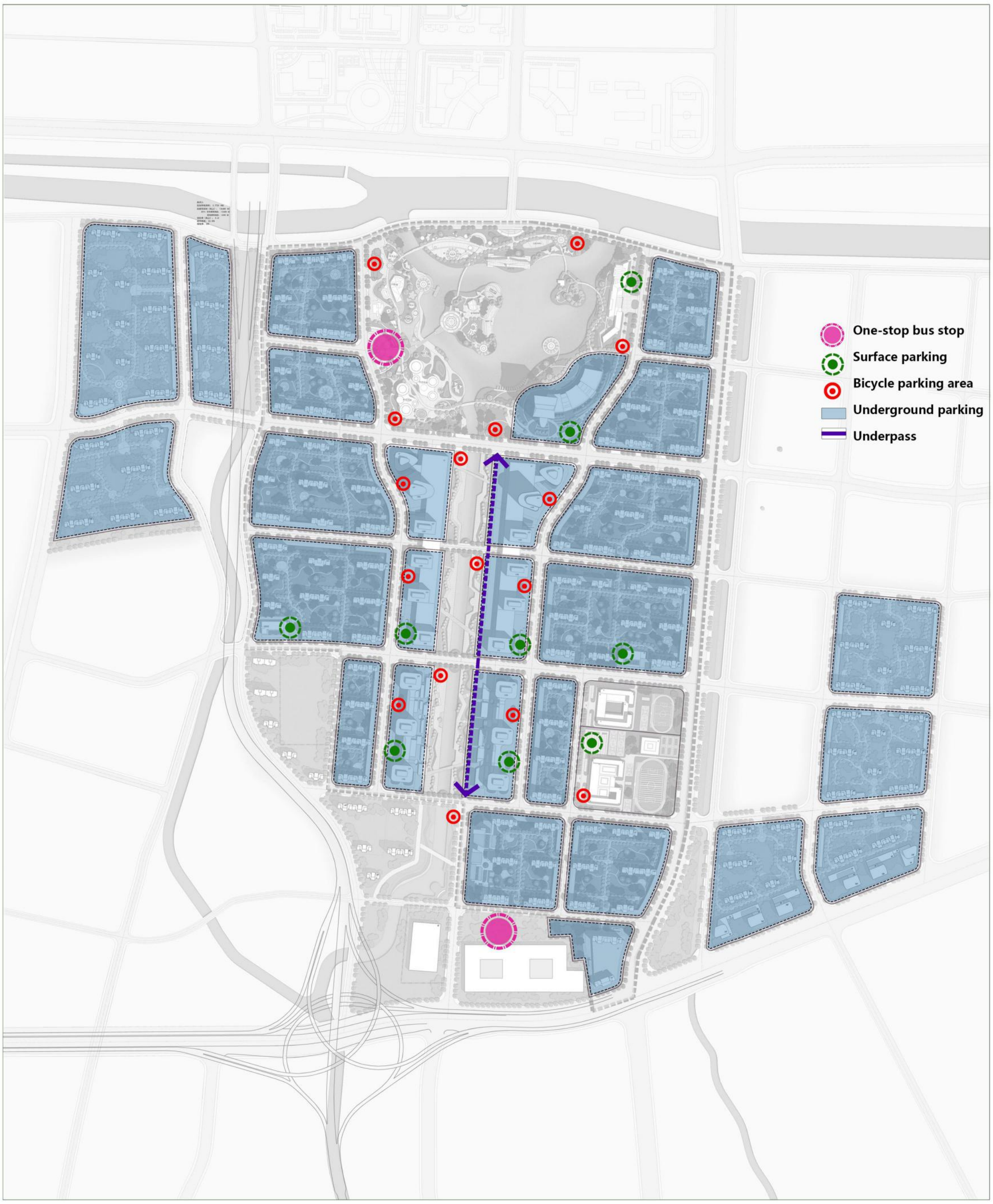


Figure 57. Case study. Static traffic analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

In order to rationalize the static traffic arrangement, the following points were designed:

- The parking index is calculated as one car per unit, and the community parking in the general plan design adopts a combination of underground and above-ground, with underground parking as the main and above-ground parking as the auxiliary mode, which can park a total of 26,000 vehicles.

- An appropriate amount of parking lots are planned and set up near elementary school and kindergartens to facilitate parents to park their children without affecting the city roads when picking up or dropping off.
- On-street parking is set up along the feeder roads to provide night and temporary parking.
- The proportion of parking allocation for non-motorized vehicles is appropriately increased, and bicycle centralized storage of appropriate size is arranged in combination with to interchange points and around major public facilities.

Analysis of planning elements

The analysis of planning elements is closely linked to the database, which can be classified and displayed according to various indicators, such as the nature of land use, building height, nature, and floor area ratio, and one can then intuitively analyze the current situation and planning elements of the designated area.

➢ **Building height control analysis** (Figure 58)

Figure 58. Case study. Building height control analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

- According to the analysis of the simulated three-dimensional model of the site, the urban design plan is to take the two public construction belts in the core area as the main body in the urban design plan to form the main tone.
- The north-south skyline is designed to be low in the middle part, rising on both sides, ending in a 300-meter super high-rise building group on the north side.
- Residential building layout points, board combination, and treatment of the interface along the elevated line along the river, the height is staggered, and the point type is dominant. The building height of the entire project is low in the middle and high on the sides, making the entire landscape belt more open, and therefore the landscape sight of the residential area has a better relationship with the urban green environment.
- The lower buildings are arranged on the south side of the project site to avoid excessive building density and blocking the buildings' sunlight. The flexible opening and closing of the space enrich the high-level relationship of the city.

Figure 59. Case study. 3D simulation model and visibility analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

- **3D simulation model and building height control analysis and visibility analysis** (Figure 59)

To analyze the landscape sightline and building height of the entire urban design project, the building height control analysis is shown in Figure 59. Different colors represent different building heights, showing whether the scale of the building is properly designed.

By analyzing the project's three-dimensional simulation model and setting the line-of-sight point analysis of different positions, one can analyze the visible range of each landscape point.

- **Greening landscape and open space 3D model analysis** (Figure 60)

The green space system is mainly composed of the following aspects:

- Beihu Recreation Area. The open space is composed of cultural, ecological, tourism, entertainment, shopping, catering, hotel, and other multi-format urban entertainment destinations, green space, and performance beach. The lake's open space is fully integrated to provide a place for citizens to relax and entertain. The landscape layout of the amusement park area revolves around the Haier Brothers adventure storyline, and the setting of each theme area landscape expresses its own content and scenes. While creating thematic and characteristic landscapes, reasonable arrangement of tourist routes, service outlets, and other functional facilities, the layout has accurately captured the leisure tourism park's landscape atmosphere.
- Yunjie riverside open space. A linear open space road and water system interchanges form a sequence of spatial nodes, combined with the treatment of bridges and culverts. It also provides a wealth of sightseeing spots for cruise ships. The "North-South Sight Corridor" is designed for key greening landscapes, forming a green landscape walking system, and becoming the most important ecological green vein in the north-south direction.
- The green space inside the cluster provides a place for residents to rest and communicate with each other, based on their daily activities. Through strict control of building delimitation, the site ensures the street space's continuity and forms an open space on the ground. The plot's interior forms several half-spread public activity space nodes through the building's enclosure, which relates to the park and square space in the middle to connect the landscape.

Street greening open space and the basic greening of the core area. To reflect the core area's road landscape characteristics, the design considers that the main road should be designed with double-row road trees as much as possible, and the secondary roads and branch roads pass through single-row road trees. Each season the flower bed combination reflects different styles.

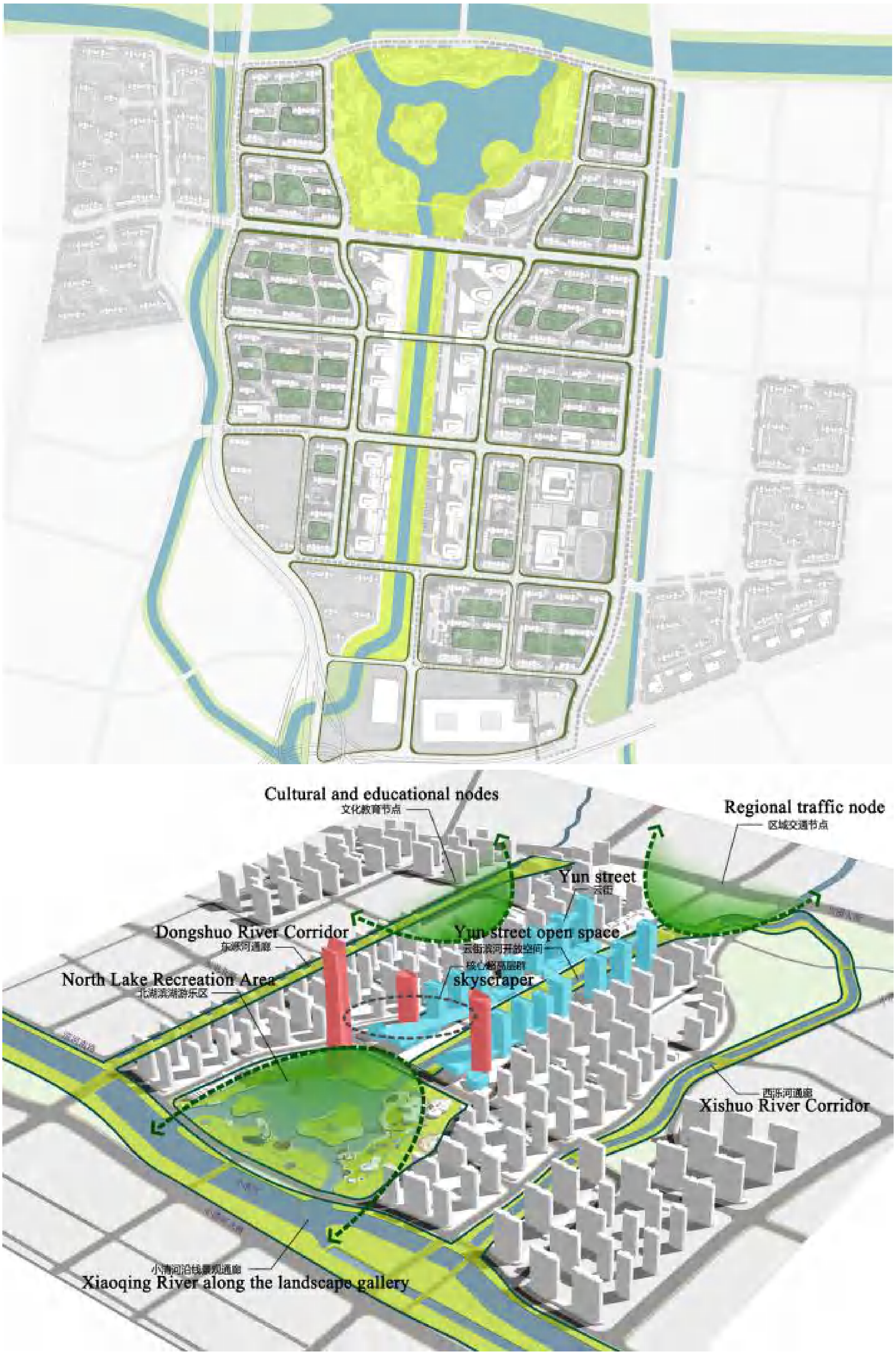


Figure 60. Case study. Greening Landscape and Open Space 3D model analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

➢ **Functional distribution analysis** (Figure 61)

Figure 61. Case study. Functional distribution analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

The commercial distribution is composed of four levels: centralized commercial complex, Haier cloud street commercial support, lakefront commercial entertainment and residential ground floor.

There are two kindergartens, one elementary school and one junior high school in the community. The elementary school and junior high school are located in the southeast of the site, in the middle of the whole project, with a reasonable service radius, which is convenient for parents to pick up and drop off. The kindergarten is set in the middle of the east and west, with a reasonable service radius, designed to meet the requirements of sunlight and ventilation, and equipped with activity venues and supporting facilities, which can not only meet the needs of students on weekdays, but also meet the exercise and fitness needs of the surrounding residents.

➢ **Line-of-sight analysis** (Figure 62, 63, 64)

Simulate the effect of the urban design plan from different angles (pedestrian, vehicle, air), and analyze the effect of the plan's building height, building volume, building color, etc., in the urban landscape.

Figures 62, 63, and 64 show the analysis of sight lines from different angles.

Figure 62. Case study. The internal landscape of the commercial pedestrian street. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Figure 63. Case study. Perspective view of the low point in the northwest corner. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Figure 64. Case study. The southeast perspective view of the landscape gallery. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

- **Density analysis and Floor area ratio analysis** (Figure 65)

Figure 65. Case study. Density analysis and Floor area ratio analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Data calculation and analysis in the 3D model of BIM can quickly and accurately calculate the density and floor area ratio of the entire urban design project, and can be adjusted accordingly to meet the needs.

- **Sunshine simulation analysis** (Figure 66)

Real-time simulation of the sunlight conditions of the building in different solar terms and different time periods, together with continuous playback, can intuitively observe the impact of the shadow of the building on the surrounding buildings. Through sunshine simulation analysis, it can be seen from Figure 66, on the shortest day of the year, what length of the full window sunshine time that the bottommost window of each building can get, in order to determine whether the sunshine interval between buildings meets the requirements. At the same time, different building functions have different requirements for full window sunshine time. For example, functional buildings such as buildings for elderly people and kindergartens require windows offering longer sunshine hours. Through the analysis results, it will be necessary to adjust the height of each building in the design project to meet the sunshine requirements.

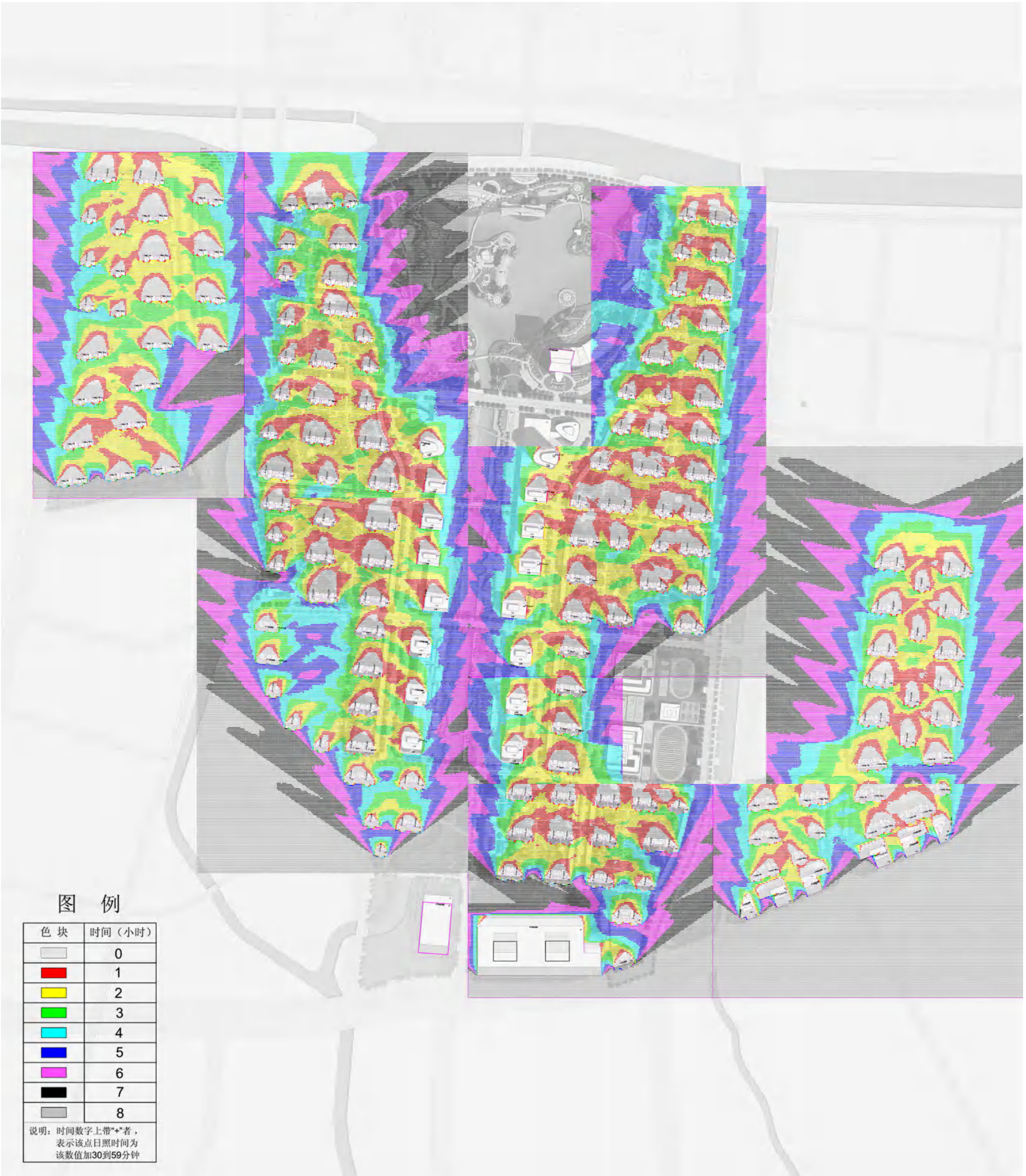
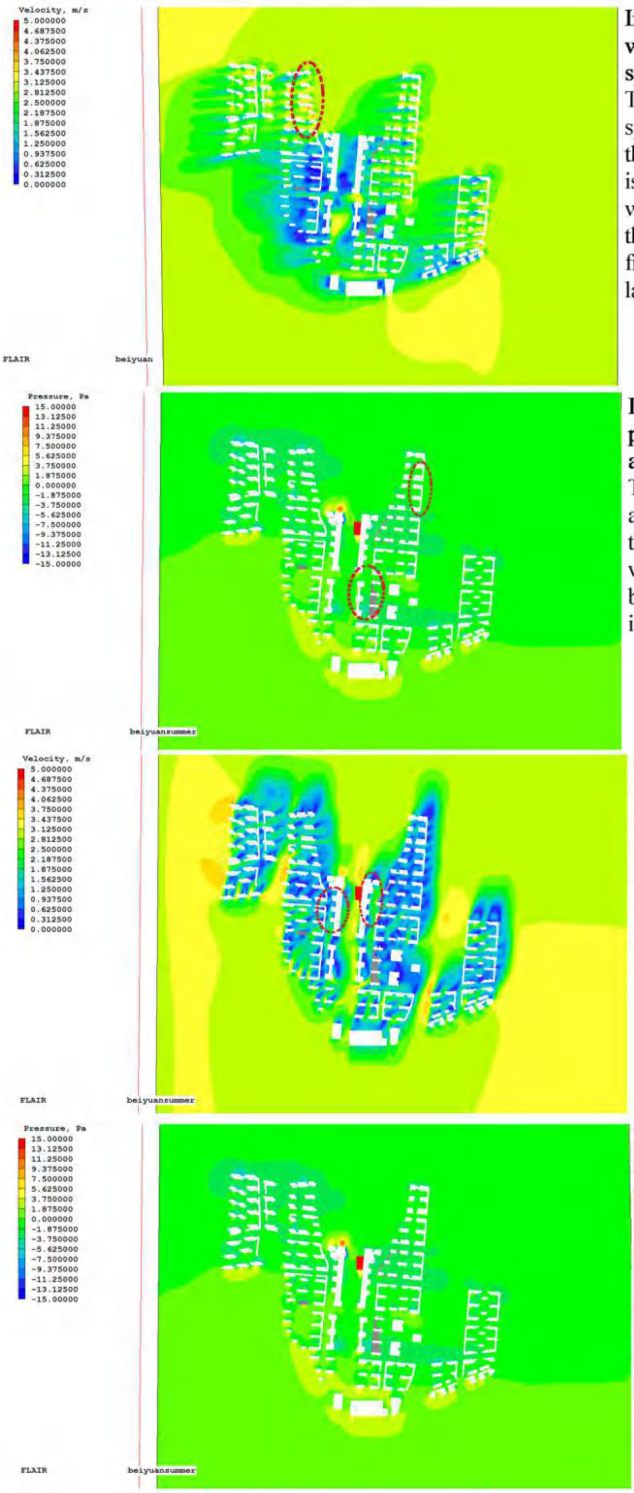


Figure 66. Case study. Sunshine simulation analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

- **Analysis of the micro-environment airflow and wind environment of the design project** (Figure 67)

With the process of urbanization, the density and height of mid-and high-rise buildings in the city are getting greater and greater, and the wind-environment interaction between various buildings has become more and more complicated.



In winter, the prevailing wind direction and wind speed are the distribution map of wind speed at pedestrian height.
This case meets the requirement that the wind speed at the height of 1.5M in the area around the building is less than 5M/S. Because the north is relatively open, areas with higher wind speeds will be formed in winter (the position marked by the red circle in the figure), and strong wind blowing from these parts will reduce outdoor comfort. The latter can be improved by planting trees and shrubs.

Distribution map of pedestrian height wind pressure in winter with prevailing wind direction and wind speed.
The position marked in the red circle in the figure has a large pressure difference between the windward and the winding surface, and the penetration of cold wind will be relatively large. The heating load in winter will be relatively large. In the later stage, it can solve by improving the insulation method.

Distribution map of pedestrian height wind speed under the prevailing wind direction in summer.
The red circle in the picture is due to dense high-rise buildings. As a result of insufficient ventilation, the wind speed on the leeward side is mostly below 1M/S, producing a stuffy feeling. Later, it can be improved by establishing a sinking square and vegetation quotation marks.

Pedestrian height and air pressure distribution map under the predominant wind direction in summer.
The pressure difference between the front and rear of most buildings in the scheme is greater than 1.5Pa, which can meet natural ventilation requirements in summer. Ensure a good ventilation rate, and make full use of natural ventilation to cool down in summer

Figure 67. Case study. Wind environment analysis chart. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

By analyzing the wind environment of BIM, the microenvironment of urban design projects can be analyzed intuitively, and the design of the scheme can be adjusted in time according to the conclusions of the analysis and evaluation system. The wind environment analysis diagram of this project is shown in Figure 67.

- **Noise analysis (**Figure 68)

When using the BIM virtual model for noise analysis, it is necessary to analyze the mutual influence of the surrounding environment of the design project on the noise. One can then adjust the layout of each building according to the analysis results, avoid noise sources, and apply noise treatment on the required facades.

Figure 68. Case study. Noise analysis. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Figure 69. Case study. A street view of the project. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

Figure 70. Case study. A landscape view of the project. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

- **Visualization analysis** (Figure 69, Figure 70)

In the real and accurate urban project space, objectively demonstrate the effect of the urban design plan and demonstrate the feasibility of the construction project plan. Through the simulation analysis, before and after the completion of the project, the large deviation between the actual completion effect and the design plan can be reduced or even eliminated, and an accurate and reliable basis can be established for project decision-making.

- **Comparing urban design schemes through BIM virtual models** (Figure 71)

In the initial stage of the design, a comparative analysis of multiple schemes was carried out, and the urban design schemes were reviewed simultaneously from different angles and directions. Compare the impact of different schemes on the city's landscape and surrounding buildings, evaluate the advantages and disadvantages of each scheme intuitively, and adjust the height and volume of the scheme in real-time.

Figure 71 shows two different design schemes of this design project. It can be seen that the building height and location in the residential area are different, and the building height and building form of the commercial building are also different. By comparing the two schemes, the effect of actual construction can be simulated. Through the data analysis of BIM, it is concluded that the design of scheme one is more reasonable.

Figure 71. Case study. Comparison of two urban design schemes. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

5.5.4 The case study conclusion

Figure 72. Case study. A bird ‘eye view of the project. (Author: Xiaolei Wang, Shandong Tongyuan Digital Technology Co., Ltd.)

The presented example shows that BIM (Building Information Modeling) is an effective tool for urban design.

A city consists of many urban design projects of different sizes. The simulation design analysis of urban design predicts the city’s future development, and it is essential for the realization of future results. BIM’s virtual digital model system can intuitively and comprehensively express the spatial state in urban design and the relationship between the city and its surrounding environment. As the population continues to increase, cities are constantly changing. It is essential to have dynamic adjustment and management of urban development and changes. The virtual analysis capability of BIM solves the problem of the city’s dynamic development and creates an information model based on three-dimensional digital technology. It integrates various relevant information of urban design projects through digital information simulation to provide information for personnel in all aspects related to construction. It provides a scientific collaboration platform of “Simulation and analysis”. It uses the three-dimensional digital model to assist in the whole life cycle of project design, construction, and operation management.

5.6 BIM evaluation

5.6.1 Introduction of BIM evaluation

Global warming caused by greenhouse gas, especially CO2 emissions (carbon emissions), constantly endangers the presence of human and biological conditions and has caused a number of worldwide concerns, for example, rising ocean levels, ozone depletion, crop failures, desertification. The building industry is at present anticipated to contribute 35% of carbon discharges to add up to worldwide outflows, and 52% by 2050[108]. In Europe, the building and construction industry represent more than 40% of total energy consumption [109] and contributes almost half of the carbon emissions discharged into the climate. During the life cycle of a building, the embodied energy and construction-related energy may take up in the vicinity of 10% and 60% of total energy utilized [110]. In the United States (U.S.A), development exercises oversee 40% of carbon emanations of non-transportation portable sources [111], and discharges from development hardware and plants represent over half of most sorts of outflows. In the United Kingdom, development division related exercises represent an expected 47% of aggregate CO2 emanations [112] and transmitted 42.6 Mega huge amounts of CO2e (MtCO2e) in 2011, among which inexact 10 MtCO2e related with development operational exercises and 22 MtCO2e credited to material generation [113]. The carbon emission of buildings in cities has become an important evaluation element for the urban environment's quality control and energy conservation. [114] Building effectiveness speaks to one of the simplest, quickest, and most savvy approaches to decrease carbon emissions. BIM technology provides the best answers for evaluating urban design projects and minimizing carbon emissions and energy savings. This chapter presents strategies and innovations for coordinating actual plan surveys with Building Information Modeling (BIM).

[108] I.P.C.C. Mitigation, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 521, Cambridge University Press, Cambridge, UK, 2011, p. 2

[109] Casals, X.G., 2006. Analysis of building energy regulation and certification in Europe: Their role, limitations and differences. Energy and buildings, 38(5), pp.381-392.

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5.6.2 Green BIM application

The construction industry is increasingly being challenged to consider more environmentally friendly building methods. One of the important parameters of ecological issues is the use of energy and the emission of carbon dioxide and other greenhouse gases due to energy demand. To address the ecological issues, different approaches and ideas have been created in the recent decades. With the development of green BIM systems, a coordinated assessment system is now an important step in advancing green building standards and improving sustainable buildings and infrastructure. Both public authorities and private developers are demanding more sustainable approaches in developing naturally ecological urban projects and reducing energy bills. The BIM technology can take on a key part of this change through green building evaluation systems that are more convincingly collaborative, framework reconciled and streamlined. Green BIM aligns project stakeholders' goals and decision-making processes to be more effective and efficient.[115].

5.6.3 Case study of BIM evaluation

How can the evaluation of BIM technology reduce the carbon emissions of urban design? This dissertation investigates the use of BIM performance evaluation as a tool for building performance analysis (BPA) based on the geological and climatic conditions of urban design projects.

In the design of a large volume urban project, in addition to the simulation analysis of the project, it is necessary to evaluate the sustainability of several aspects of the design. Especially in the case of industrial plants with other functional buildings located in adjacent areas, it is very important to evaluate the overall traffic organization, sunlight, noise, etc. during the design process.

The Modernization of the Machinery Industry Factory SKF project is a rolling bearing plant of the Swedish capital group SKF in Poznań, in the Greater Poland province, where SKF's International Shared Services Finance Center is located. It is one of seven such centers established worldwide and is providing services to almost all SKF Group entities.[116]

Project overview:

- Project name: Modernization of the Machinery Industry Factory SKF
- Chief Architect: Wojciech Bonenberg
- Site Area: 91.500 sq. m.
- Floor Area: 18.500 sq. m.

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[115] Azhar, S., Brown, J. and Farooqui, R., 2009, April. BIM-based sustainability analysis: An evaluation of building performance analysis software. In Proceedings of the 45th ASC annual conference (Vol. 1, No. 4, pp. 276-292).

[116] https://investmap.pl/szwedzki-koncern-skf-otworzy-w-poznaniu-finansowe-centrum-uslug-wspolnych.a147179(Accessed on 25 June 2020)

- Height: 18 m
- Financing: SKF SA Poznan
- Location: Poznan, Poland

Figure 73. Case study. Financial Shared Services Center in Poznań. Source: https://investmap.pl/szwedzki-koncern-skf-otworzy-w-poznaniu-finansowe-centrum-uslug-wspolnych.a147179

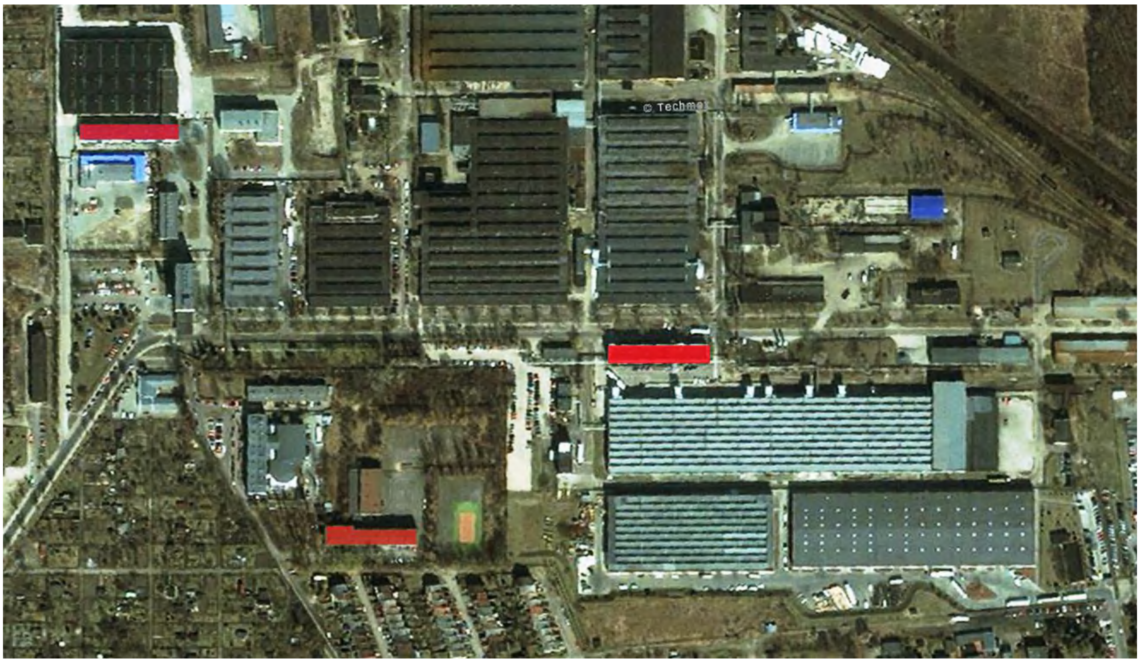


Figure 74. Case study.The Satellite image of location of The Modernization of the Machinery Industry Factory SKF project. (Google earth)

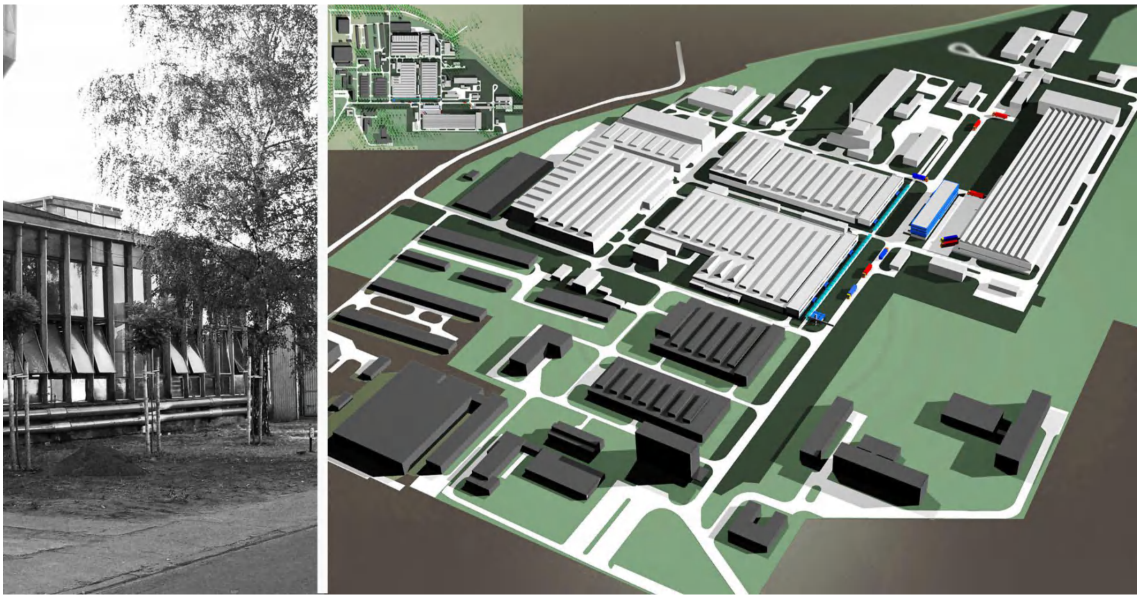
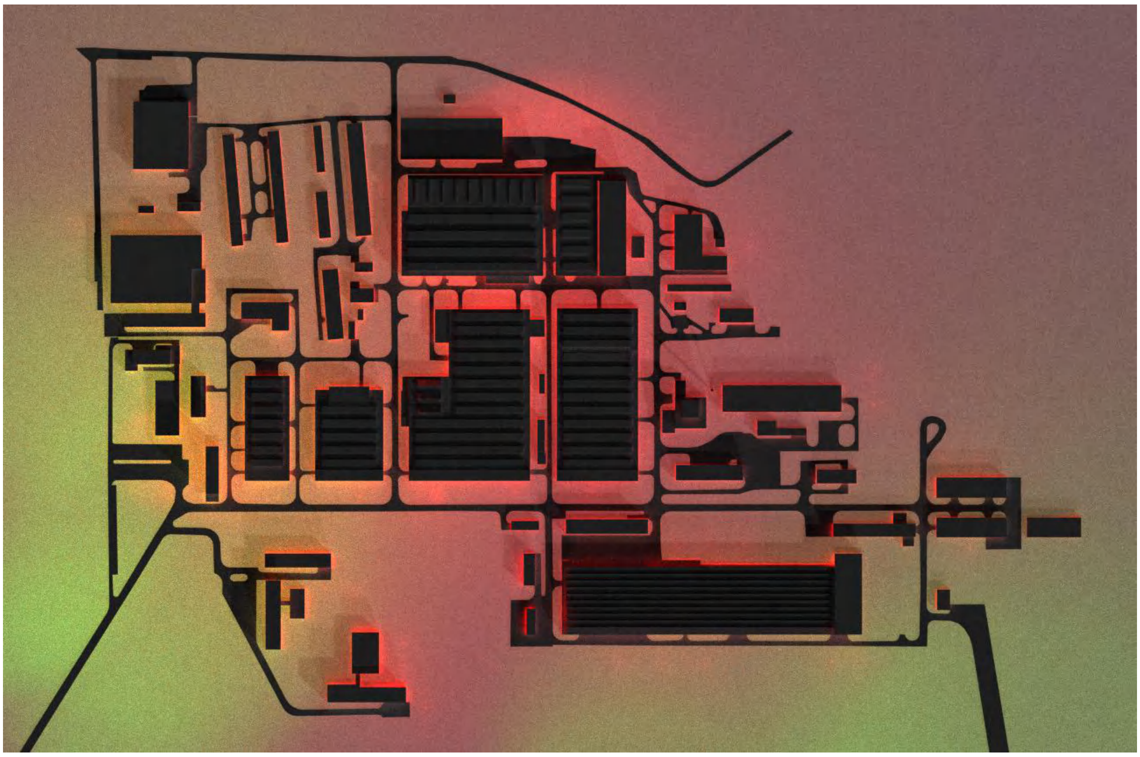


Figure 75. Case study. The Satellite image of location of The Modernization of the Machinery Industry Factory SKF project. (Author: Wojciech Bonenberg)

Figure 76. Case study. The Satellite image of location of The Modernization of the Machinery Industry Factory SKF project. (Author: Wojciech Bonenberg)

In this case, and in the overall planning and design of the project, it is very important to use the digital model of BIM to carry out visual analysis and noise analysis of the whole project. In the 3D BIM model in Figure 75, the traffic organization design of the project, the scale relationship between buildings, etc. can be clearly analyzed. The 3D model simulation analysis in Figure 76 allows clients who are not construction professionals to visualize the project.

The eastern side of the project is the plant construction area and the western side is the office area, including the former Faculty of Architecture of Poznan University of Technology.



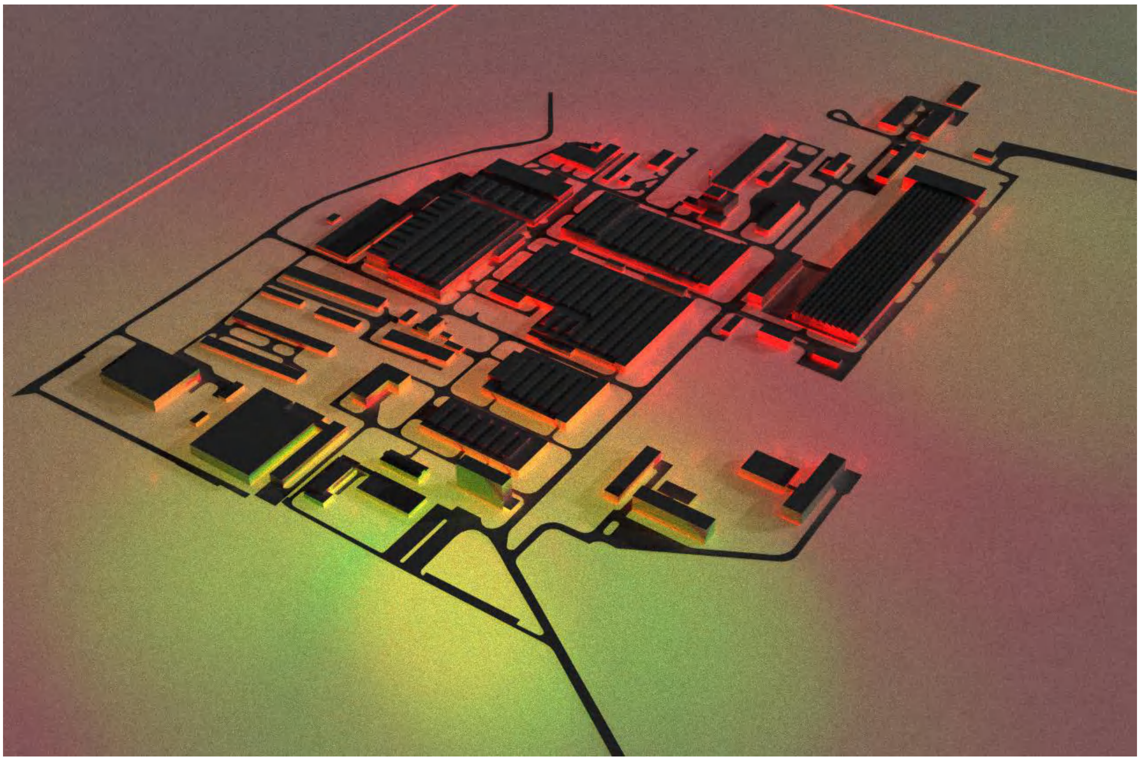


Figure 77. Case study. The noise analysis of The Modernization of the Machinery Industry Factory SKF project. (Author: Wojciech Bonenberg)

Noise is an extremely influential factor in the design of buildings for integrated functional urban design projects where there are various buildings with different functions in close proximity. Figure 77 shows the noise analysis graph. It shows that the plant building noise is the highest in the eastern plant area, the heavier red color indicating the greater noise level. On the other hand, in the office building area on the west side of the project, the green color means that the building is the least affected by noise.

After the overall plan of the project is determined, in order to make an assessment of the energy consumption analysis of the whole project, the energy performance of individual buildings needs to be analyzed and evaluated with the help of BIM. The environmental and financial impacts of the various options are then evaluated, compared and decisions are made. With a more comprehensive understanding of each building's performance, it is possible to prioritize and propose a holistic building design plan that focuses on the detailed design and construction of the highest impact projects. Regardless of the function of the building to be evaluated, Green BIM's evaluation capabilities are a practical and valuable tool.

As a case study, the following is a description of the building energy evaluation process for a single building - the former Faculty of Architecture office building at Poznan University.

The evaluation and analysis of BIM is similar to the simulation process, in which a BIM information model is created by collecting the basic data of the building. This information model contains the dimensions and material information of building components such as windows, doors, walls, floors, and roofs. The energy consumption and carbon footprint of the building is evaluated in conjunction with the project's geographic and climate data, and sustainable green designs that reduce resource consumption are identified. For example, BIM analysis tools are used to analyze and calculate the heating demand and energy consumption of a single building and the lighting demand of a building, and to calculate the energy consumption of a single building based on the size and material of windows and doors, and even the number of layers of glass, so as to select the size and material of building components that can reduce energy consumption.[117]

The design concept was to produce a shallow imprint on the site, taking into account the annual energy consumption and CO2 emissions. Basic model energy calculations estimated that the building would produce more energy from non-renewable sources. There was inventive utilization of available sources, testing the low energy potential of highly insulated, sustainable, and locally sourced materials.[118] The project speaks to a chance to embrace a look into two key territories, monitoring building performance regarding energy consumption and embodied carbon.

The analysis model of BIM (Figure 80) consists of the construction drawing design and equipment design of the building, etc. (Figure 78, Figure 79)

[117] Autodesk,. BIM 在政府建筑性能分析中的优势. Source: http://images.autodesk.com/apac_grtrchina_main/files/bim_government_whitepaper_cn.pdf (Accessed on 25 June 2020)

[118] Ceranic, B., Latham, D. and Dean, A., 2015. Sustainable design and building information modelling: case study of energy plus house, Hieron's Wood, Derbyshire UK. Energy Procedia, 83, pp.434-443.

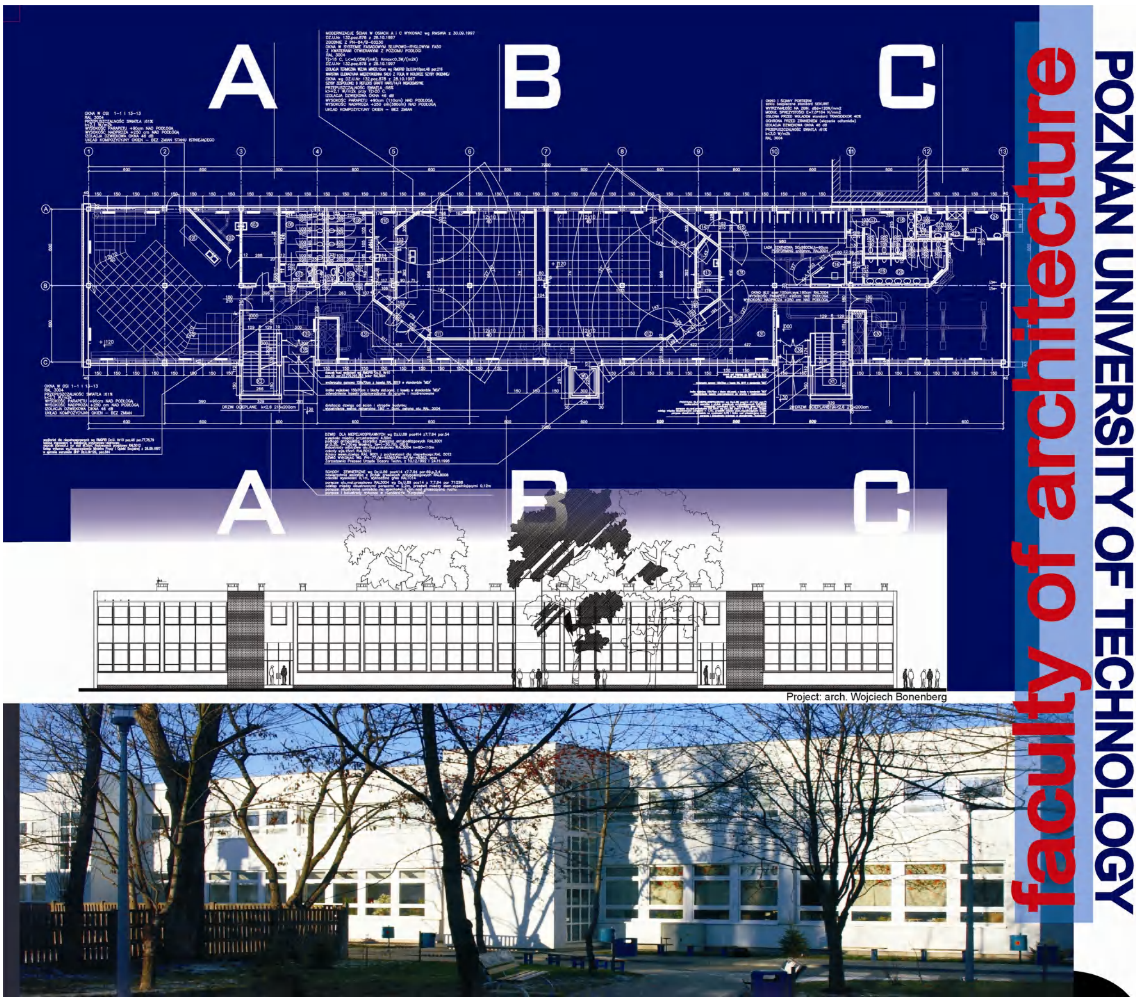


Figure 78. Case study. The construction design drawing. (Author: Wojciech Bonenberg)

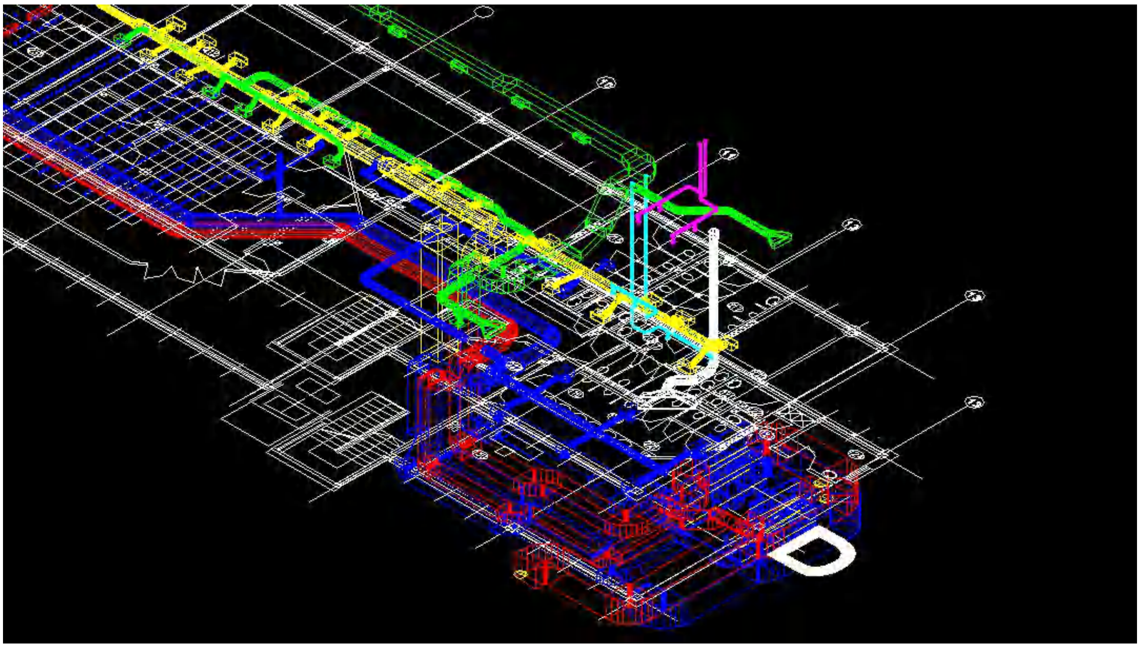


Figure 79. Case study. The construction equipment design. (Author: Wojciech Bonenberg)

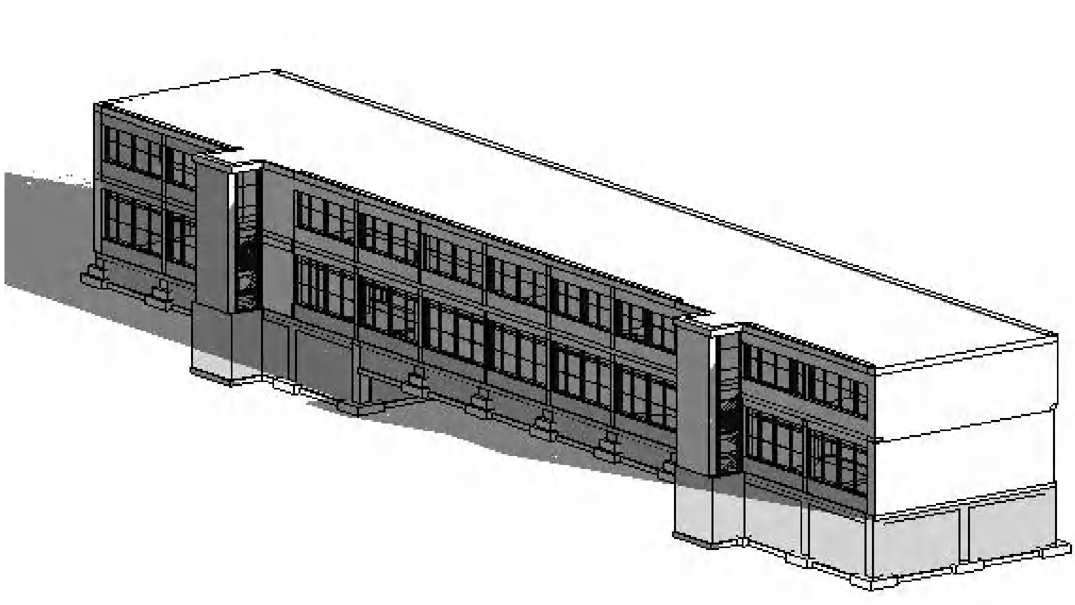


Figure 80. Case study. The BIM models（Revit model). (Author research)

Here, from figure 81, are five possible ways to save energy for the proposed research undertaken. The first three are considered in this project.

- More or better roof insulation

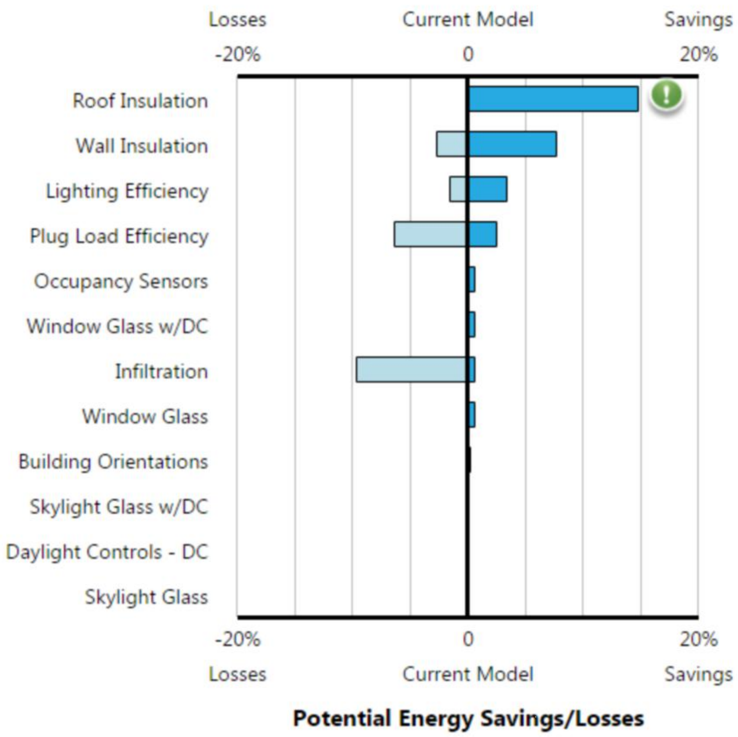


Figure 81. Case study. The potential energy saving/losses analysis (Green Building Studio). (Author research)

- More or better walls insulation
- Better windows glazing or frame material
- Using photovoltaic cells

- Using more solar energy
- Reducing the resource consumption need

Some of the factors affecting the potential energy savings or losses are explained in Figure 81. The BIM evaluation report clearly shows that the design solution will achieve an energy saving of approximately fifteen percent by improving the insulation of the roof. Further improvements to the insulation of the walls and the lighting system allow the building to achieve even greater building energy savings through passive energy saving measures.

The coordination of BIM and sustainable design, as well as an evaluation of the supporting urban design, is necessary. During the design process, the building materials in the urban design were evaluated for their energy saving impact on the building and the utilisation of low carbon materials, through the link between BIM and sustainable design, using the evaluation software available in BIM application technologies such as Autodesk © Revit, Green Building Studio and Vasari to provide conceptual design to between conceptual design and construction drawing design to improve the design. Below is a comparison between the basic model and the concept model, with material checks and details specified below. (Table 17, Table 18)

Table 17. Analysis report for basic model and concept model.

Basic model:	**Concept model:**
1. Windows: a) Single glazing • Heat transfer coefficient (U): 3, 69 W/ (m2*K) • Thermal resistance (R): 0, 27 (m2*K)/W b) Frame profile • Aluminum: 5x10 cm • Thermal Conductivity: 230 W/ (m*K)	1. Windows: a) Triple glazing • Heat transfer coefficient (U): 1, 45 W/ (m2*K) • Thermal resistance (R): 0, 69 (m2*K)/W b) Frame profile • Stainless steel: 5x10 cm • Thermal Conductivity: 16, 2 W/ (m*K)
2. Walls [Resistance: 5, 12 (m2*K)/W] a) Structure layer • Brick: 38 cm • Thermal Conductivity: 0, 54 W/ (m*K) b) Thermal layer • Rock wool: 25 cm • Thermal Conductivity: 0,034 W/ (m*K) 3. Roof [Resistance: 2, 77 (m2*K)/W]	2. Walls [Resistance: 9, 16 (m2*K)/W] a) Structure layer • Brick: 38 cm • Thermal Conductivity: 0, 54 W/ (m*K) b) Thermal layer • Rock wool: 25 cm • Thermal Conductivity: 0,034 W/ (m*K)

a) Structure layer • concrete: 24 cm • Thermal Conductivity: 1,046 W/ (m*K) b) Thermal layer • Rock wool: 7 cm • Thermal Conductivity: 0,034 W/ (m*K)	
3. Roof [Resistance: 2, 77 (m2*K)/W] a) Structure layer • concrete: 24 cm • Thermal Conductivity: 1,046 W/ (m*K) b) Thermal layer • Rock wool: 7 cm • Thermal Conductivity: 0,034 W/ (m*K)	3. Roof [Resistance: 9, 20 (m2*K)/W] a) Structure layer • Concrete: 24 cm • Thermal Conductivity: 1,046 W/ (m*K) b) Thermal layer • Rock wool: 25 cm • Thermal Conductivity: 0,034 W/ (m*K)

Table 18. Summary for energy, carbon and cost.

	Analysis report for basic model:	**Analysis report for concept model:**
Energy, Carbon and Cost Summary		
Annual Energy Cost	42,392 zł	41,757 zł
Lifecycle Cost	577,385 zł	568,724 zł
Annual CO2 Emissions		
Electric	93.3 Mg	87.1 Mg
Onsite Fuel	89.2 Mg	82.6 Mg
Large SUV Equivalent	18.3 SUVs / Year	18.0 SUVs / Year
Annual Energy		
Energy Use Intensity (EUI)	1,463 MJ / m² / year	1,458 MJ / m² / year
Electric	199,645 kWh	197,150 kWh

Fuel	1,789,213 MJ	1,756,588 MJ
Annual Peak Demand	66.3 kW	65.1 kW
Lifecycle Energy		
Electric	5,989,356 kW	5,914,494 kW
Fuel	53,676,390 MJ	52,697,640 MJ

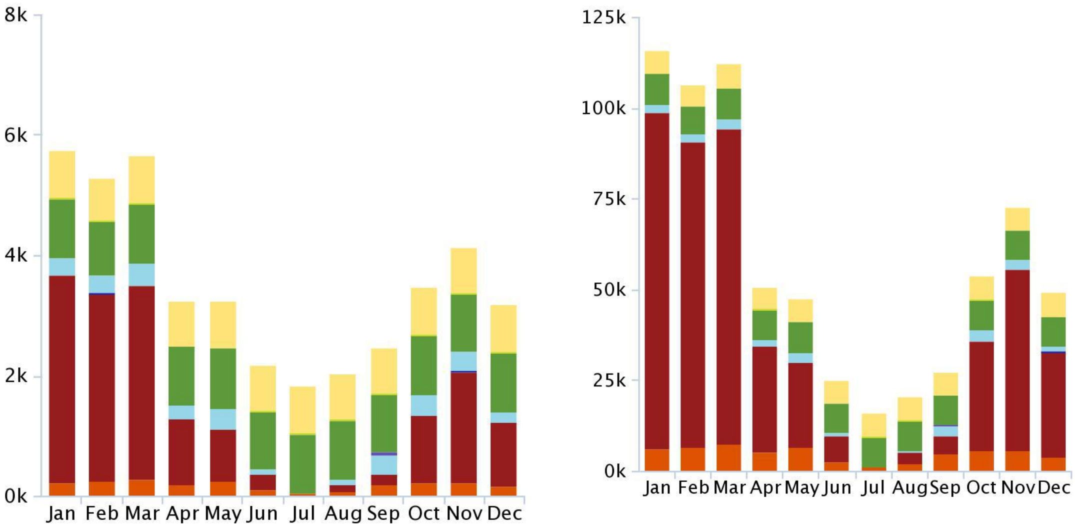


Figure 82. Case study. Cost total energy (Basic model). (Author research)

Cost total energy (Basic model Figure 82, Concept model Figure 83)

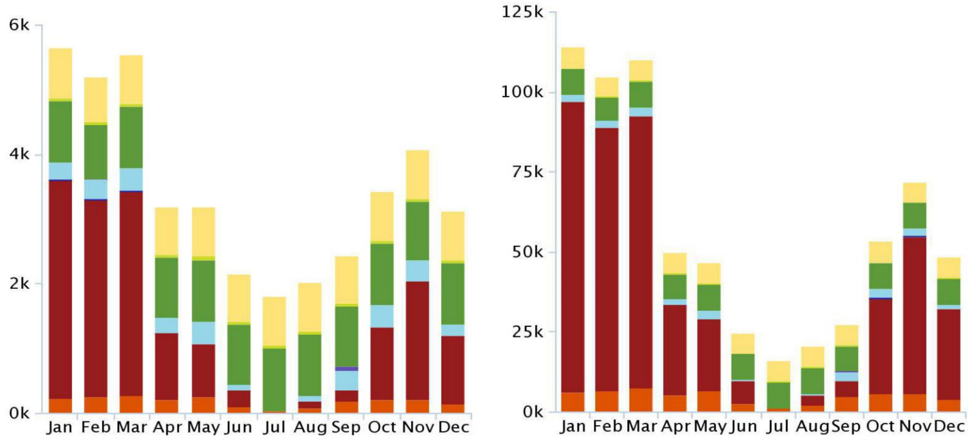


Figure 83. Case study. Cost total energy (Concept model). (Author research).

5.6.4 Discussion and Conclusions

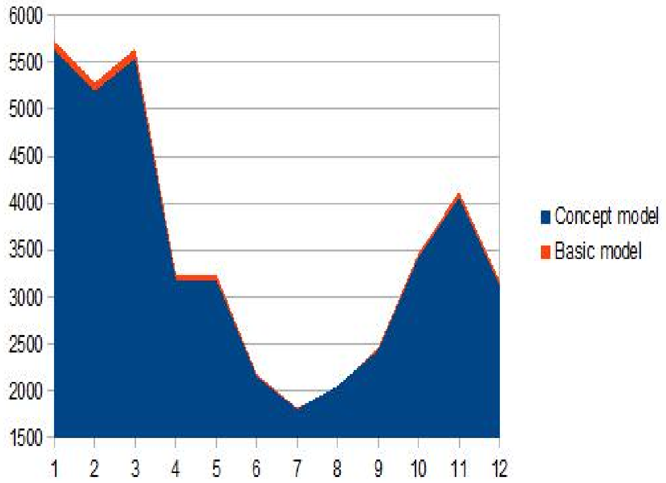


Figure 84. Case study. The comparison of total energy cost monthly data. (Author research)

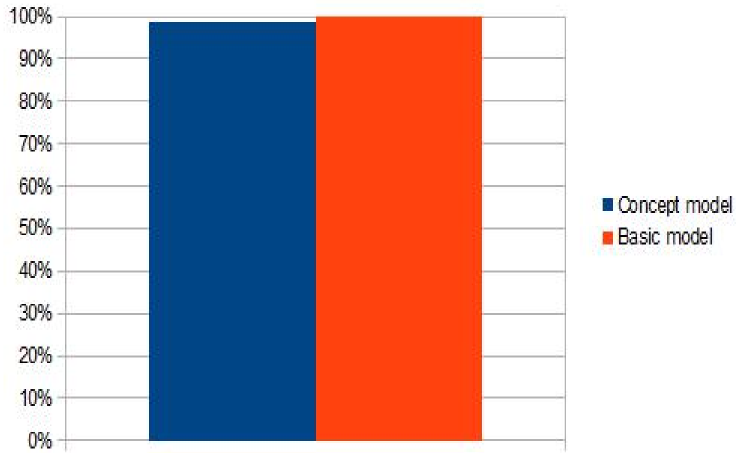


Figure 85. Case study. The comparison of total cost in one year rates summary. (Author research)

According to the analysis (Figure 84, Figure 85), the result is the following.
Carbon footprint (annual CO_2 emissions):
Basic model: 182,5 Mg
Concept model: 169,7 Mg
This contextual analysis-based study presents techniques and innovations that combine sustainable design analysis with BIM evaluation. Carbon emissions, thermal analysis and energy were created using calculations from Autodesk Green Building Studio and Vasari, taking advantage of the specificity of building development and considering the generation of building energy calculations without the sense of responsibility for precise decisions regarding structural components. The method requires a low LOD [LOD:100 to LOD:300], which in most cases reduces the amount of calculations. In addition, the final investigation of the conceptual model's carbon emissions and energy estimates

was resolved. The results presume a reduction in annual carbon emissions from 182.5 Mg to 169.7 Mg. This demonstrates the advantages of using BIM for sustainable design. At the early stages of the project, the cost of design changes is minimal, yet represents the most noteworthy opportunity to affect the general task costs. This option reduces as the outline advances while the cost of changes increment. Thus, the capacity to control costs and the exertion required to roll out improvements is most advantageous at the early design and construction stages.

Although a lot of building-related carbon emission calculation and data information have been produced, most of them still stay in the measuring by two-dimensional drawings and then applying the calculation formula, which is very simple and easy to grasp. However, the work efficiency is not high and it is easy to make calculation errors, plus these data basically stay in the building materials, which leads to little discussion in the construction aspect. Another point is that energy analysis is too simple, still stuck in the traditional manual calculation method. This is quite time-consuming and laborious for buildings with large volume and high complexity. The object-oriented parametric design of BIM building information model, which can make model changes and estimate quantities in time, establishes relevant building information, and improves the efficiency of design operations and quantity estimation.

One important point is that carbon emissions are larger during the construction phase. BIM technology can apply the established BIM model to calculate carbon emissions, using its own unique object-oriented features and building information database to combine the 3D model of the building and construction-related information, carbon emissions of building materials and other data in the software, using the concept of cost estimation to calculate carbon emissions. BIM 's technology applied to urban early intervention of design and using its evaluation performance to propose energy-saving and low-carbon solutions will enable sustainable urban design with energy saving and low emission at the beginning of design. Under the threat of global warming, how to use BIM technology to minimize carbon emissions in construction and achieve truly green urban buildings will become an important factor for sustainable urban design.

5.7 Chapter summary

From this chapter, we can summarize the following points:

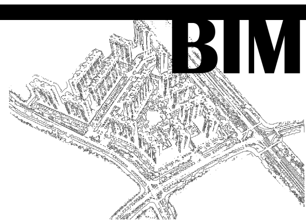
- Urban design is an important link in the development of urban planning. Urban design has always been one of the most demanding areas for visualization technology due to its complexity and high forecasting requirements. To correct the mistakes and deviations in urban design, reduce planning errors, and promote the planning process, urban design needs effective methods to achieve predictable simulation of the project's future results and to facilitate dynamic adjustment and management. Using the technical characteristics and nature of BIM, we can completely achieve this requirement.

- The simulation design of BIM technology for urban design projects can express the space of urban design intuitively and richly and fully demonstrate the relationship between various urban entities.
- Using digital information, BIM is based on a three-dimensional digital model to simulate and integrate various related information in construction projects and to provide a simulation and analysis collaboration platform for professionals in various construction-related industries.
- BIM can evaluate the advantages and disadvantages of urban design projects by analyzing digital simulation and drawing analysis conclusions. It can use various schemes in data and visualization to assist in evaluating urban design projects in the design stage.

The “green contribution” of BIM evaluation technology to sustainable design is summarized as follows:

- By evaluating the BIM model of urban design with the physical environment data, such as geographic information and climate parameters of the project site, and, based on the analysis results, improving the design deficiencies, avoiding design errors, and achieving the best design solution for the base.
- Energy evaluation of each building unit in the urban design project, effective energy saving calculation and carbon emission evaluation in the operation phase, plus feedback correction, can achieve the optimal design of energy saving solutions.
- Using the visualization and simulation capabilities of BIM technology to enable rapid and effective communication of design decisions can rationalize the schematic design process and enhance life-cycle energy efficiency.

In short, BIM technology is an effective tool with strong computing and performance capabilities. The three-dimensional simulation and evaluation capabilities in BIM technology can visualize the urban design and contribute to its refined development.



6 The Impact of BIM Technology on Traditional Urban Design Methods

6.1 Introduction

It can be concluded from the previous chapters that the application of BIM technology in urban design can improve work efficiency and save time and energy. Faced with the emergence of this new technology, what influence and reaction will the traditional design system have? After comparing BIM with traditional design methods, author summarized the design advantages and design development potential of BIM and found a direction for future BIM research, and, at the same time, sought to find out the reasons for the lack of BIM application in non-developed countries. As a revolution in the design industry, CAD brought immeasurable design advantages to designers and the construction industry, so the emergence of BIM is destined to be another major step forward for the construction industry. We may ask, will BIM be as irreplaceable, as is CAD today, in the design field in the future? Even as CAD is a necessary skill that practitioners must master, author fear that no one can yet give a clear answer. This dissertation will invite urban design experts from various countries to make a questionnaire survey on this issue, fully understand BIM problems in urban design, and explore a solution.[119]

6.2 Comparison of BIM and traditional urban design methods

[119] Wei, X., Bonenberg, W., Zhou, M. and Wang, J., 2021, July. The Impact of Building Information Modeling Design System on Traditional Urban Design Methods. In International Conference on Applied Human Factors and Ergonomics (pp. 302-309). Springer, Cham.

6.2.1 The difference between BIM compared with traditional urban design methods.

- **BIM has a full life cycle effect on urban design.**

The concept proposed by BIM (Building Information Model) includes the design of the building space and the operation of the construction project, and the "BIM model" refers to the description of the design process and the simulation of the construction work, because the BIM model can be used in urban design. From the initial stage of project design to the entire life cycle of building demolition, it can be said that BIM is a set of information models that describe the process of building construction life cycle.[120][121]

It can give, for example, the design details (such as the size, material, construction process, manufacturer, etc.) of a certain window. In urban design projects, the working principle of BIM is mainly to assign the name of the building element to the graphic object without attributes so that it has the same characteristics as the actual building. Simulate the architectural components of the entire design project, use this simulation model to analyze and calculate the entire project and make a reasonable evaluation of the design plan. The main difference between BIM and traditional computer-aided drawing design systems is that traditional computer-aided drawing design systems are mainly based on drawing geometric information. They cannot directly obtain meaningful information from these output geometrical figures, such as building components. The two-dimensional construction drawings of the traditional design system must be interpreted by the designer or construction staff to turn them into useful information. In contrast, the "BIM system" can directly obtain the required information from the information model.[122]

- **Comparison of the traditional design process and BIM design process.**

In the traditional design engineering process.

Designers in various professional fields establish their own design models. For example, in the process, the structural designer refers to the architectural design drawings and the materials handed by the mechanical and electrical professional to establish a structural analysis and design model. He or she conducts structural internal force analysis and component design in the structural design software, then feeds back the results to the architectural designer; the architectural designer adjusts the architectural design, and then feeds it back to the structural designer for modification and adjustment, knowing that the design requirements are met; finally, the structural construction drawing is produced according to the structural design result, delivered and archived.

[120] Smith, D.K. and Tardif, M., 2009. Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. John Wiley & Sons.

[121] Wei, X., Bonenberg, W., Zhou, M. and Wang, J., 2021, July. The Impact of Building Information Modeling Design System on Traditional Urban Design Methods. In International Conference on Applied Human Factors and Ergonomics (pp. 302-309). Springer, Cham.

[122] Arayici, Y., Khosrowshahi, F., Ponting, A.M. and Mihindu, S.A., 2009, May. Towards implementation of building information modelling in the construction industry. In Proceedings of the fifth international conference on construction in the 21st century: Collaboration and integration in engineering, management and technology (pp. 1342-1351).

Although with the gradual maturity of CAD technology application development, some identification technologies can automatically import part of the building's component information into the building structural analysis model, a large amount of structural calculation and analysis model information still needs to be manually reconstructed. In producing structural construction drawings, some CAD systems have the function of automatically generating two-dimensional drawings. Nonetheless, these drawings do not have the completeness and relevance of the information, and it is not easy to ensure the consistency of the information.

The design process of BIM.

BIM-based structural design is different from traditional structural design in the design process, weakening the design preparation link in the traditional design process, resulting in a model-based comprehensive coordination link and a new two-dimensional view generation link.

BIM-based structural design can directly extract the structural model from the BIM model, import it into the structural software for analysis and calculation, adjust and modify the model to meet the design requirements, and link back to the BIM model. The BIM model only needs to be updated according to the structural design, and the models of the architectural and electromechanical major parts will be updated simultaneously. The design process of this sharing and co-writing is completely different from the traditional design process.

Through the above analysis, the differences between the two processes can be drawn.

In the traditional plan design stage, the process always starts from constructing the structure for the electromechanical profession. In the plan design stage, subsequent professions usually do not participate.

Based on BIM, all professions can intervene in advance from the very beginning of urban design to establish their own professional BIM models and can participate in the whole subsequent design and construction process. The process of establishing 3D digital information models of BIM models completely replaces the traditional 2D drawings, and designers only need to focus on establishing BIM models and coordinating the whole design project process. The same BIM model contains all the information involved in the project and is constantly improved and updated throughout the life cycle of urban design, avoiding design errors and design conflicts and allowing for timely and reasonable adjustments.

6.2.2 The advantages of BIM over traditional architectural design are as follows.

- **In urban design, BIM's three-dimensional model system expression is more accurate than two-dimensional drawings.** Two-dimensional drawing design and BIM technology also have a big difference in the way of expression. Traditional design schemes adopt the method of stacking lines, use the projection method to project and describe the building components, and use the ruler to transfer various data. Labeling to ensure the accuracy of various data is relatively complicated. The BIM technology only needs to use the system to calculate accurate data and build a three-dimensional model and an overall model of building components based on the data to provide a more convenient way for designers, later construction personnel, and management personnel. It also greatly saves design and construction time. In addition, BIM technology can also display the designed model and basic structure more intuitively and make the details more specific to ensure rationality.

- **Combining BIM's simulation analysis and calculation functions to improve the benefits of urban design.** BIM's simulation analysis and calculation functions can more accurately calculate the data of urban design projects, such as buildings, structures, and electromechanics, and obtain more accurate and useful design results. Traditional CAD two-dimensional drawings cannot achieve this.
- **Data integration of 3D models and evaluation of urban design projects.** The digital model of BIM is an integrated parametric database, and the parametric modeling method can unify and coordinate all parties involved in an urban design project. This parametric data model can be applied to the entire life cycle of urban design projects, and it will continue to be improved and upgraded over time. The application in the design stage can evaluate the rationality of different design schemes and is conducive to making reasonable adjustments and decisions regarding them.

6.3 Questionnaire

BIM is different from the earlier 2D drawings. It uses computer object-oriented concepts to store and exchange important information generated by various related disciplines in the building life cycle[123]. It forms a new architectural collaboration model, which can effectively reduce the various stages of the building process. Unnecessary operating procedures and waste of resources, when applied to the maintenance and management stage, can also improve the quality and operational efficiency of the building and reduce the impact on the global environment[124].

BIM has created an international trend that cannot be ignored, but the current promotion strategies of various countries are not the same, depending upon national conditions. Consider United States as an example. Given basic technical capabilities, information standards are proposed. Many necessary core standards for information exchange have been developed and formulated, such as NBIMS-USV3 (the third edition of the American National BIM Standard), which has also influenced the development direction of BIM in many countries in Asia in recent years. The United Kingdom has

[123] Singh, V., Gu, N. and Wang, X., 2011. A theoretical framework of a BIM-based multi-disciplinary collaboration platform. Automation in construction, 20(2), pp.134-144.

[124] Omer, A.M., 2008. Energy, environment and sustainable development. Renewable and sustainable energy reviews, 12(9), pp.2265-2300.

taken the lead in the world in the development and application of BIM after learning from the development achievements of the United States in recent years. The use of BIM in the United Kingdom is led by the government, which promotes BIM from top to bottom throughout the construction industry. Similarly, the UK's investment also affects other countries in Europe.

So, what influence and effect will BIM have on traditional urban design methods? Will BIM's digital parametric design completely replace the traditional two-dimensional-aided design method? This chapter will use the questionnaire survey method to conduct research by sending questionnaire surveys to specific major designer groups, including Polish and Chinese architects. The survey received 165 questionnaire results one month later, and some research conclusions were drawn through statistics and analysis of the questionnaire results. The entire questionnaire survey is divided into three parts, the first part of which is the identity survey of the respondents.

Questionnaire section one, about the respondents

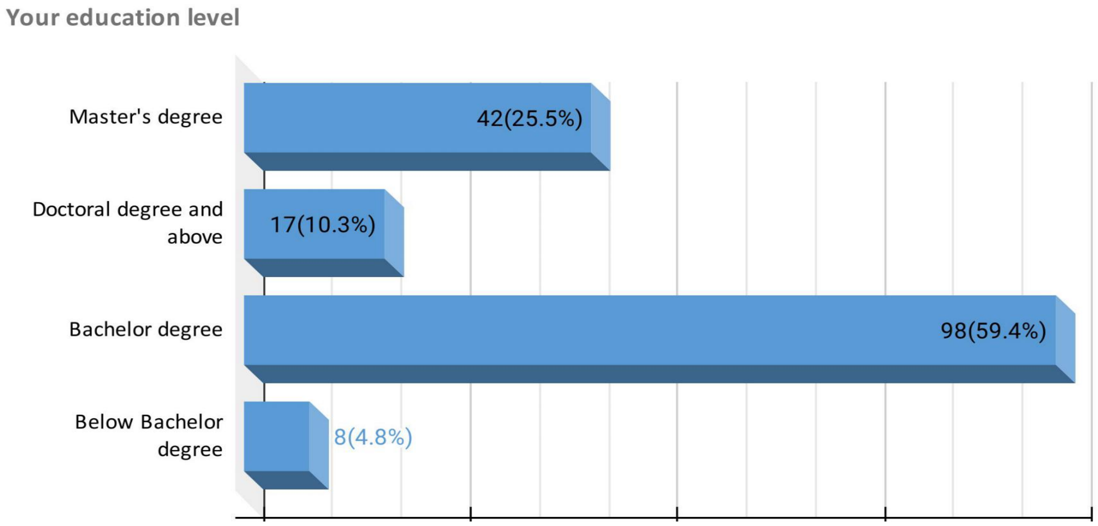


Figure 86. Respondents' education level. (Author research)

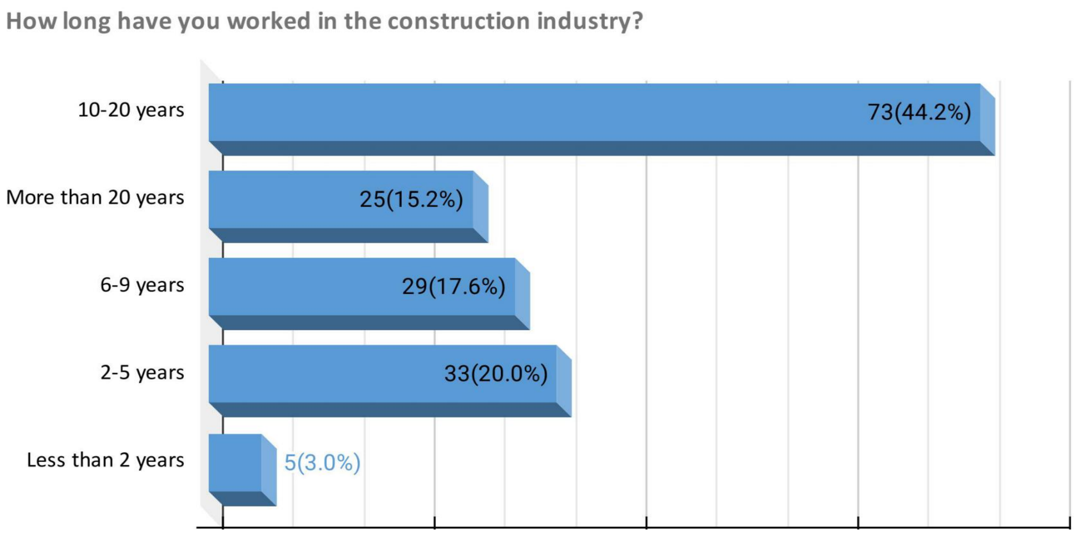


Figure 87. Respondents' education work time in the construction industry. (Author research)

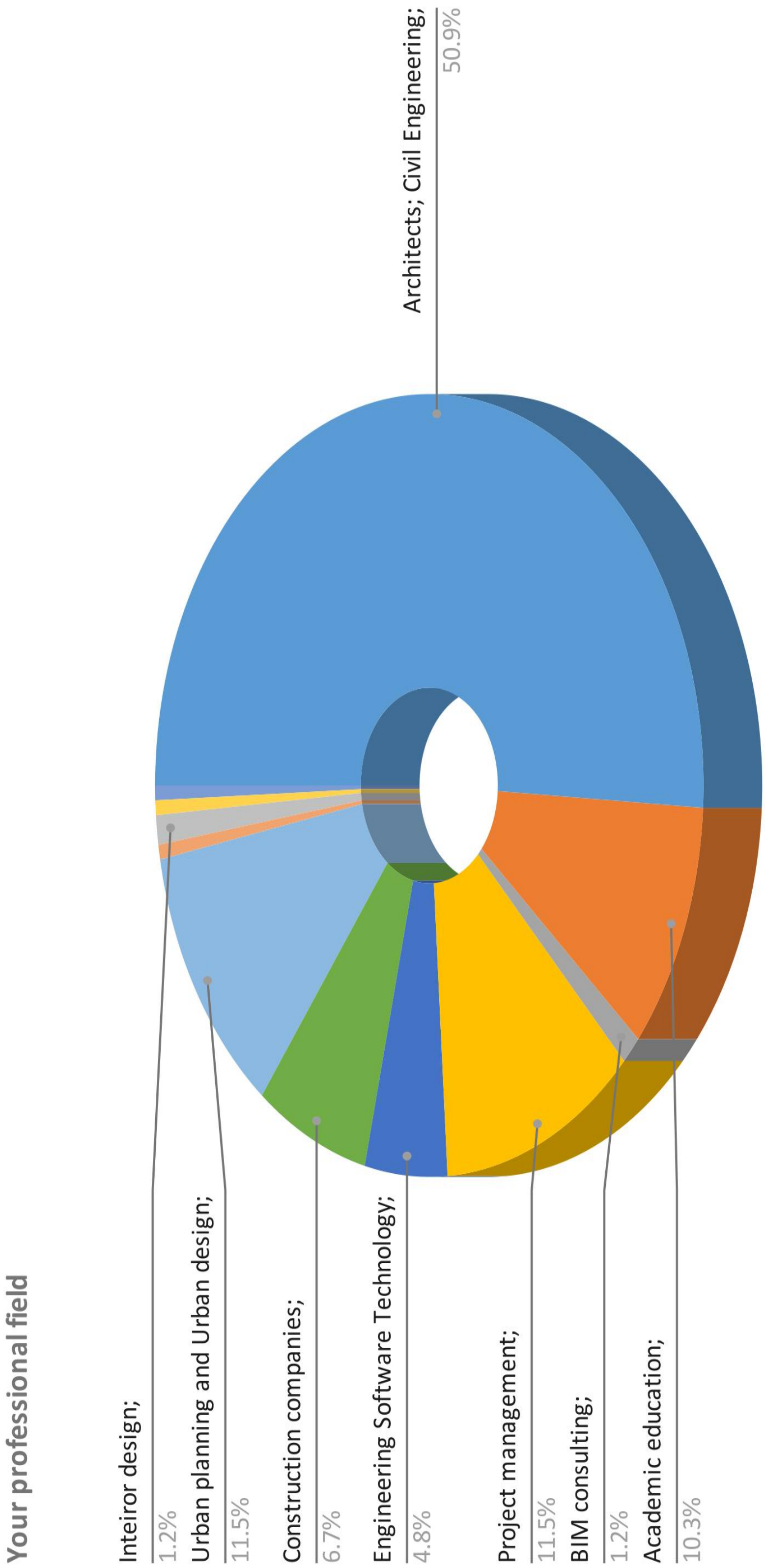


Figure 88. The professional fields of the respondents. (Author research)

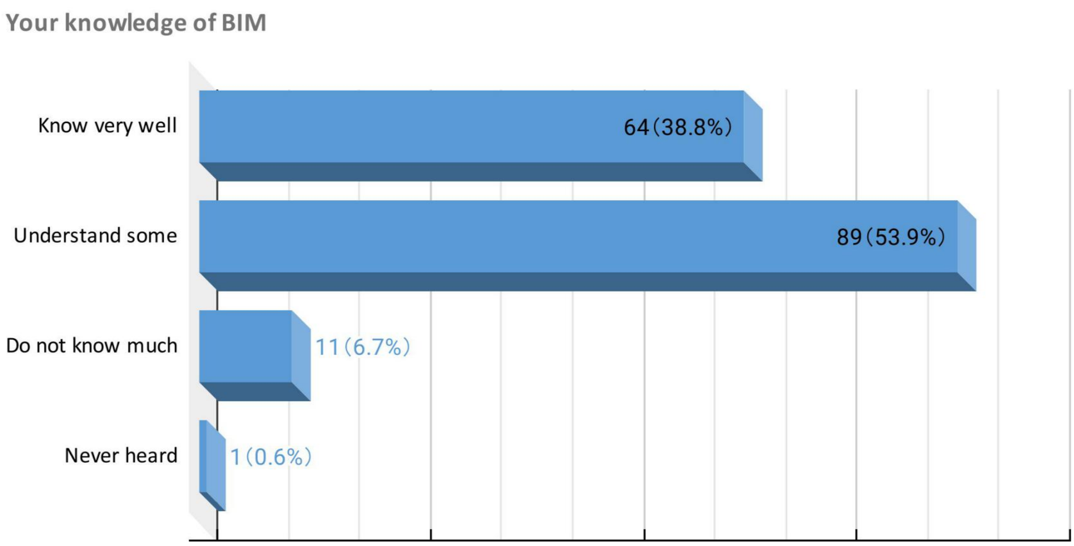


Figure 89. The respondent's knowledge of BIM. (Author research)

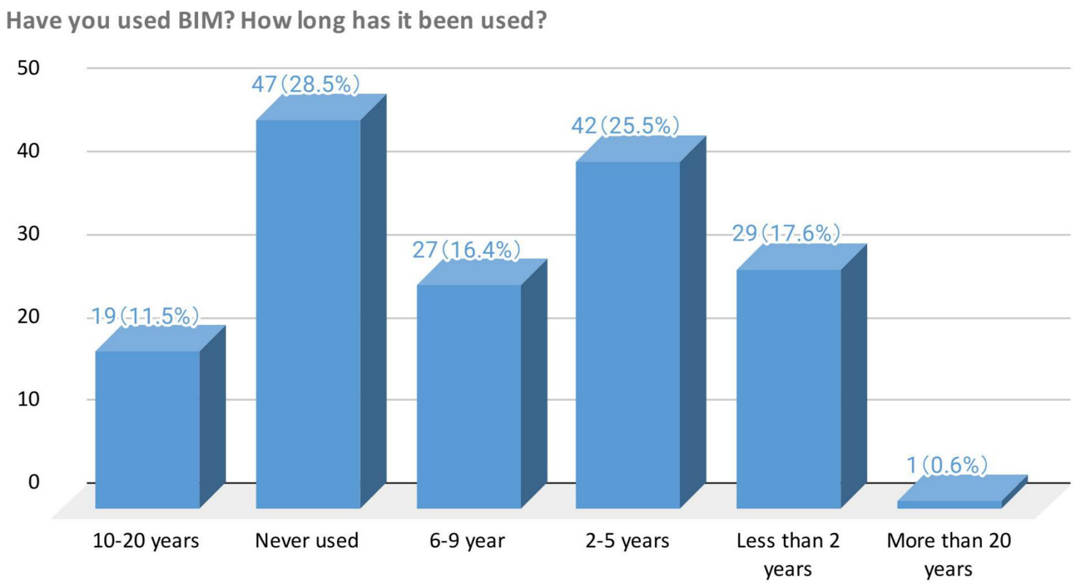


Figure 90. The respondent's work time on BIM. (Author research)

It can be seen from Figures 86 and 87 that only a minimal number of respondents have a lower education level than a bachelor's degree, and 45.8% of the respondents have a bachelor's degree or above.

The survey results in Figure 88 show that architects and structural engineers were the largest respondents, with 10.3% of the respondents coming from academic education.

Figures 89 and 90 show the survey respondents' knowledge level and work time on BIM. It can be seen that most of the respondents know of the existence of BIM, but 28.5% of the respondents have not used BIM.

Questionnaire section two, about respondent's opinions

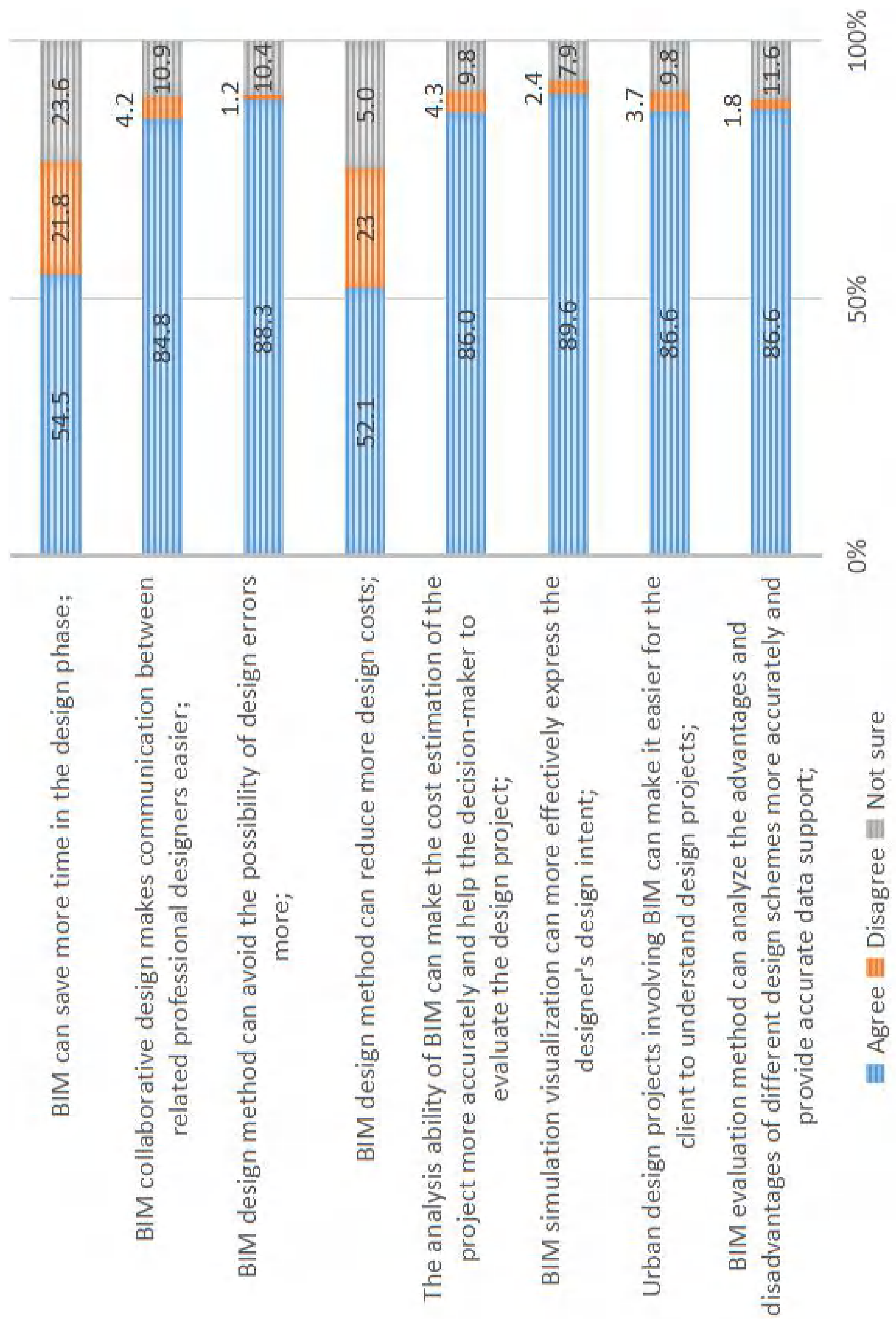


Figure 91. Comparison of BIM and traditional two-dimensional design methods, comments from respondents. (Author research)

In the second part of the survey results, it can be seen that most of the interviewees agree that BIM's design system has advantages in many respects compared with traditional urban design methods. Figure 91.

Questionnaire section three. The impact of BIM on traditional two-dimensional design methods, comments from respondents.

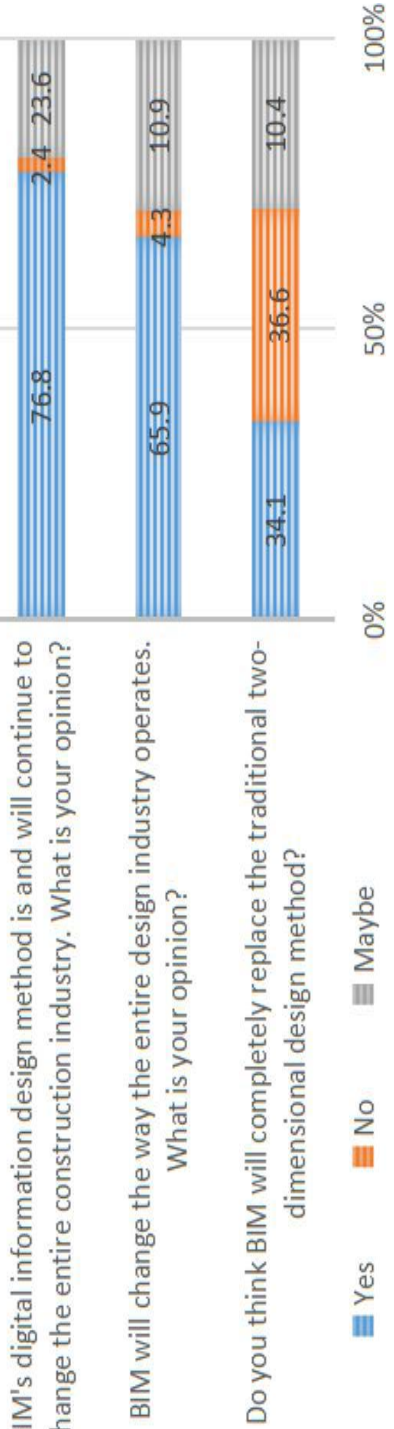
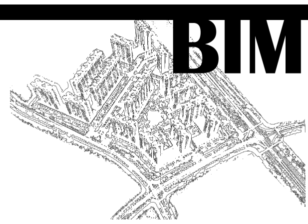


Figure 92. The comparison of total cost in one year rates summary.   (Author research)

The results in Figure 92 show that 76.8% of respondents believe that BIM is changing and will continue to change the way the entire construction industry works. 10.4% of the respondents believe that BIM may completely replace the traditional urban design method, whereas 36.6% believe that this will not happen.

6.4 Chapter Conclusion

BIM's parametric design has a huge impact on urban design projects, has a great impact on the entire construction market, and presents a challenge to designers' industry capabilities and choices. The advantages of BIM also subtly influence the future development and direction of the construction industry. At present, the construction industry worldwide has begun to pay attention to the development and application of BIM technology. With the active advocacy of the government and the establishment of industry standards, it can be seen that the construction industries of all countries in the world have realized the inevitable trend of BIM technology in the future. BIM has a positive impact on traditional design methods, and, at the same time, brings good technical application effects to urban design.



7 Synthesis of the Research Material

Referring to the main objective in the title of the dissertation “Application Research of Simulation and Evaluation Based on BIM Technology in Urban Design”, the following points can be mentioned.

7.1 BIM as a coordination tool in urban design

BIM in urban application acts as an instrument for coordinating spatial policy by standardizing the graphic record and linking it to databases. BIM ensures the compatibility of planning records of individual urban units, which makes it possible to compare the effectiveness of different design solutions and to monitor them on an ongoing basis.

BIM (similarly to GIS) gives the possibility to link graphical information with the terrain information system. Data represented graphically on an urban design drawing can be archived, systematized, processed and updated.

Imaging techniques are of interest to many scientific disciplines. They are used for strategic visualization, including ecophysiography, remote sensing, logistics, economics. Medicine uses imaging as an important diagnostic tool.

Imaging in urban planning has an established tradition. BIM technology makes it possible to combine two-dimensional planning studies with databases about space, and then imaging in three dimensions and combining the result with virtual reality (e.g., a virtual walk through a future residential area).

In this context, BIM is an instrument for coordinating decisions in the urban planning and design process. BIM makes it possible to coordinate the most important components of an urban design project, including environmental parameters, social conditions, infrastructural equipment. It then helps to determine the investment absorption of the land, transport links, optimize investment costs, etc. All these diagnostic factors - thanks to BIM technology - have become available directly to designers, planners, local authorities, investors and inhabitants. They facilitate spatial decisions, supported by objectivized measures.

In this context, BIM plays an important role as a tool for coordinating social, economic, community and environmental phenomena in urban design. It enables the assignment of logical semantic formulae to a plan drawing. Capturing these relationships enables the analysis of complex inter-factor relationships in urban design.

Examples include:

- Maximum and minimum building intensity;
- Indication of biologically active surface;
- Building height;
- Location of height dominants
- Maximum and minimum number of parking spaces;
- Building lines;
- Technical infrastructure;
- Routes of communication.

BIM facilitates the coordination of spatial development with regard to building design, environmental protection, nature and landscape, which together have a crucial impact on sustainable urban design.

7.2 BIM as a quality factor in urban design

BIM technology can be regarded as an important quality factor in urban design and land planning.

In the last decade, new methods of planning and land management have been intensively introduced in Europe, Japan and the USA. The tools used in this field are defined by the term Total Quality Management (TQL). The standards resulting from this approach describe the systems and documents necessary to achieve stable, high-quality outcomes in planning, management, implementation and monitoring. An important element of this approach is the standardization of the coding system for spatial information. This is intended to produce decision-making data with a high degree of reliability that can be easily compared with.

Modern quality management systems emphasize the final efficiency in terms of cost and time of performing urban planning studies, emphasize the impact of graphical representation of data on reducing costs and accelerating the planning process.

From this point of view, BIM can be regarded as an important quality factor in urban design. BIM gives the possibility to continuously improve the design process, taking into account emerging ideas, initiatives, and above all, the local specifics resulting from the technical level, economic opportunities and cultural conditions.

It is worth noting that BIM covers all the components of the planning procedure, which consists of:

- Diagnosis;
- Measurement;
- Analysis;
- Implementation;
- Control.

BIM technology allows one to link the code of graphic designations on urban plans to the basic elements of urban design, such as:

A. demarcation lines and boundaries of areas:

- With different designation of use or different development principles;
- Requiring real estate consolidation and division;
- Revitalization of existing buildings and technical infrastructure;
- Requiring transformation or reclamation;
- Objects included in the cultural heritage and their protection zones;
- Areas of outstanding landscape values and natural monuments;
- Public investments of a supra-local importance;
- Recreation and leisure areas as well as areas for the organization of mass events;
- On which equipment generating energy from renewable sources may be placed, as well as their protection zones associated with restrictions on development and the use of the area.

B. development and land use conditions, including:

- Control of the dimensions, geometry and method of shaping of buildings and land development;
- Control of building area to plot ratio for individual properties and their complexes;
- Ratios of biologically active surface to the plot area for individual properties and their complexes, and the structure of green areas;
- Parameters and requirements for building plots;
- Course and parameters of roads and linear technical infrastructure facilities;
- Water management, including rainwater storage in housing estates,

C. BIM technology allows for clear definition and control of basic standards in terms of:

- Energy efficiency of individual buildings in an urban project;
- Obtaining energy from renewable sources;
- Provision of communication services;
- Provision of technical infrastructure;
- Provision of basic social infrastructure within walking distance.

BIM technology allows the formulation of planned relations between the number of inhabitants and the level of supply of the above-mentioned public services. This way of urban design prevents the creation of incomplete fragments of cities or settlements, deprived of basic transport, commercial, educational, cultural and health services.

7.3 BIM improves the possibility of public participation in the urban design process

Public participation means the participation of citizens in the management of the area where they live. It is a process of cooperation between citizens or social groups at the stage of designing and implementing local spatial policy. Its characteristic feature is the active participation of all stakeholders involved in the consultation process. Social participation gives a sense of co-determination in the appearance of the space that is a place of everyday use. Participation contributes to a sense of belonging to a given place. It leads to the creation of social bonds and local community.

In Polish law, the provisions relating to public participation can be found in the Act of 27 March 2003 on spatial planning and development. The Act defines the requirements concerning public participation in planning procedures. These procedures concern the drawing up of a draft study of the conditions and directions for development of the municipality and the local spatial development plan.

Public participation in European countries is a basic element in the process of planning and implementation of an urban planning project, and it is widely used. It usually includes the following activities:

- a. submission of proposals concerning the urban project at the beginning of the procedure of its drafting,
- b. familiarizing oneself with the urban design project (and its variants) after the completion of the preliminary design phase, taking note of opinions and the arrangements for public viewing of the project, as well as participation in the public discussion on the solutions adopted in the project
- c. filing of possible comments and protests by the stakeholders concerning the urban design.

BIM significantly improves the possibility of public participation in the urban design process. With easy visualization in three dimensions, urban design projects can be more understandable by ordinary people who are not urban planning specialists. In addition:

- BIM simulation makes it possible to visualize the essential provisions of an urban plan in a clear way and presents the planned reality from the perception level of an ordinary resident,
- BIM simulation ensures universal, public digital accessibility to all materials, opinions, analyses, reports,
- BIM simulation provides an easy way to present variant assumptions of urban design for public discussion in the initial phases of project execution. This enables public discussion of economic, social and environmental consequences,
- BIM simulation makes it possible to publicly consider proposed alternatives and, if they are not accepted, to justify the rejection of the proposal.

7.4 BIM enable the inclusion of the fourth dimension (time) in urban design

This can be implemented using Gantt charts and urban design roadmaps. Both tools present information related to the implementation of an urban design project. These tools also set temporal milestones for different elements of an urban design project.
A roadmap produced with the help of BIM defines the strategic plan and implementation goals of an urban design project. The basic elements of roadmaps are:

- Defining the strategic objectives of the urban design project;
- Focusing on high-level activities (not details).

A roadmap facilitates the presentation of planning strategies in stakeholder consultations. A roadmap can be an effective tool for periodically checking the implementation of urban plans.
Gantt diagrams produced using BIM are more detailed in nature. They provide a mapping of each project element in the time relationships of its execution in relation to other elements. Gantt charts represent a cascading approach to the execution of an urban design project; they facilitate the division of a project into phases, stages and detailed tasks based on time. With this approach, we can avoid the situation where the construction of residential houses overtakes the construction of sewage systems, water systems and access roads to the apartments.
BIM can be used as a tool to identify time conflicts and spatial clashes in urban design. Time management technologies have evolved beyond simple Gantt charts to include sophisticated operational research systems, of which queueing analysis is widely used. Many organizations such telecommunication companies and police departments routinely use time models to help manage and allocate spatial resources in a timely and cost-effective manner. Queuing analysis is also a useful tool for estimating capacity requirements and managing demand for any system where the demand time for services is random. In urban design, such systems include transportation systems and stormwater management systems. In this regard, BIM technology, combined with an algorithmic parameterization of requirements, provides an opportunity to build innovative spatial resource allocation models.

7.5 Urban design requires more details, which is provided by BIM technology

In rapid economic development, the urban population is increasing, and urban design issues play an essential role in future urban development. With the growing needs of urban residents for a better living environment, urban and architectural planning has put forward new requirements. Urban design is a comprehensive deployment of various facilities in the city. It is an essential part of urban management and plays a vital role in urban construction, urban planning, and operation. Urban design plays a significant role in the city's economic and social development goals. It can be used to study the direction of the city's development, size, and nature.

a. **Before AutoCAD**. Prior to the advent of AutoCAD and other drawing software, engineering drawings for architectural and urban design were drawn on paper using a drawing board. This drawing method requires multiple equipment types to complete a given drawing, such as a drawing board, different thickness pens, T-squares, triangle feet, and the like. Designers needed to spend a lot of time and effort on drawing, and the final engineering drawings often had a lot of errors. Designers had to modify repeatedly. This approach led to inefficiencies, and it was difficult for designers in various industries to achieve uniformity and coordination. See Figure 84 for how the Architects Engineer work before AutoCAD.
b. **Traditional urban design method AutoCAD.** CAD technology is one of the most successful engineering techniques of the 20th century and is widely used in various fields, such as machinery, electronics, and construction. CAD has initially been designed to liberate designers from complicated and time-consuming hand-drawing and innovation in traditional technology. Two-dimensional computer graphics can accurately and quickly depict the various views of the designed 3D product. With the development of technology, CAD technology has been transformed from the original technology-assisted drawing into the current computer-aided design. Among many kinds of drawing software, AutoCAD software occupies most of the market. The three-dimensional object's traditional two-dimensional expression cannot meet the designer's requirements, because in some complex, large-scale engineering design projects, the two-dimensional method cannot express the design clearly, and the designers also have great difficulty in communicating with customers.
c. **3D.** With the development of drawing technology, 3D technology has emerged, and the three-dimensional expression makes people's overall design of the project noticeably clearer. The CAD (Computer-Aided Design) has had more than forty years of development, and its technology and products are updated continuously, which significantly promotes the development of social productivity. After entering the 21st century, integration, intelligence, and collaboration are the academic community's broad consensus on the development direction of CAD technology. Intelligence means that the breakthrough of the traditional CAD system can only carry out engineering calculations and geometric expression of products. With the help of related technologies in the computer field, CAD gradually infiltrated into the creative design work activities. The research focus of intelligent direction lies in: intelligent design and intelligent engineering based on knowledge, acquisition, and utilization of product knowledge, model expression of knowledge-intensive products, simulation of product design, and optimization of engineering methods or engineering analysis. Advances in computer technology and related theories have

greatly facilitated the development of computer-aided auxiliary design techniques. Various intelligent design methods simulate human design behavior from different angles. They provide a basic design framework for the intelligentization of computer-aided design technology, which is of considerable significance for intelligent design development. However, the expression of materials, functions, and other attributes still cannot meet designers' needs.

Based on the comparative analysis of traditional two-dimensional design and three-dimensional digital information design, the urban design must meet the standards of a digital information model, and some technical problems need to be resolved, as shown in the following Table 19[125]:

Table 19. Technical problems need to be resolved in Urban design.

Many planning digital information requires multidisciplinary collaboration.
Design projects should be easy to adjust and manage.
Need a more intuitive, visible process analysis file.
Predictable simulation of future results.
Future use and maintenance require cost forecasting and control.

Because of the above problems in CAD's architectural design, the solution of BIM technology was born. BIM provides all the processes and techniques in the project construction cycle and uses digital methods to express the construction project's parameters. As a new concept and practical tool, BIM has designed an information model that covers all the technical information in the construction project's process. Both physical properties and statistical calculations are represented in the model. Experts and scholars in the industry have valued the rapid development of BIM. It is known as the second technological revolution following the CAD technology revolution (See Figure 93. BIM is the second revolution in design).

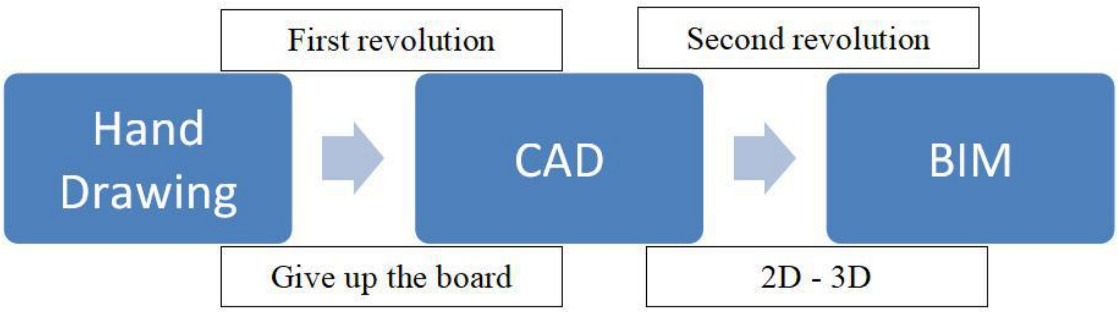


Figure 93. BIM is the second revolution in design. (Author research)

BIM has completed the transformation of drawing technology from 2D to 3D, and in addition to the basic 2D drawing, it provides support for the dynamic display of 3D

[125] Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

objects and the roaming experience. The designer's control over the design renderings has also changed from a traditional imaginary space to a real experience. In addition, the building model's material information can be obtained through the analysis and calculation of BIM.

Table 20. Common application diagrams of BIM technology.

Plan	Design	Construct	Operate
Existing Conditions Modeling			
Cost Estimation			
Phase Planning			
Programming			
Site Analysis			
Design Review			
	Energy Analysis		
	Design Authoring		
	Structural Analysis		
	Lighting Analysis		
	Mechanical Analysis		
	Other Engineering		
	LEED Evaluation		
	3D Coordination		
		Site Utilization Planning	
		Construction System Design	
		Digital Fabrication	
		3D Control and Planning	
		Record Model	
			Maintenance Scheduling
			Building System Analysis
			Asset Management
			Space Management/ Tracking
			Disaster Planning
Main Application		Secondary Application	

BIM can always keep track of the model's editing, maintaining a high degree of consistency throughout the model system, which can therefore effectively avoid engineering problems caused by unsynchronized modifications. These advantages are not possible in two-dimensional CAD technology computer-aided design. The role of BIM is far more than that. In the second edition of the BIM Project Implementation Plan Guide, written by the Computer Integration Construction Research Group of Pennsylvania State University in 2010, published twenty-five common application diagrams of BIM technology", which runs through the entire life cycle of the construction project. The emergence of BIM technology solves many shortcomings in 2D CAD architectural design, breaking through traditional architectural design performance limitations and opening broader design space for architects. BIM is an integration of all building information throughout the life cycle of a building, from early concept design to demolition, and can be used effectively in all phases of design, construction, management, and maintenance in the field of construction engineering. BIM's information model is at the heart of BIM's application technology, integrating a wide range of architectural engineering information in buildings.

In the process of urban design, most construction project decision-makers are not professional architects or engineers, and it is challenging for them to understand and recognize two-dimensional architectural work drawings. For those who do not belong to professional design, the three-dimensional architectural performance drawing will be easier to understand. If designers can only use two-dimensional design drawings to communicate with customers, such a design process wastes time. It cannot achieve good communication effects, which greatly affects the control of design quality.

7.6 Urban design can be smarter with BIM technology

With the development of digital information technology, the application of information technology in urban design has improved, and smart cities have emerged. Smart cities are a way to achieve sustainable urban development. By creating smart cities, combining all aspects, so the city's energy is saved. OGC[126] explained that data from various sources needs to be integrated into the urban model in the design of future cities. As the global urban population grows, cities need to find an active management approach. There is a need to effectively integrate social and natural digital systems and provide management methods and tools for this digital system so that cities can be more prosperous and sustainable, thus allowing residents of the city to live comfortably.[127] (See Figure 94. Smart cities are driving the integration of BIM & geospatial).

[126] The Open Geospatial Consortium (OGC) is an international non-profit organization associating with over 450 companies, government agencies, and universities. They cooperate on the development and implementation of open standards for spatial data and services, geographical information systems (GIS), for the purposes of data processing and sharing.

[127] Smart cities are driving the integration of BIM & geospatial.
Source: https://www.geospatialworld.net/article/future-cities-pilot-ogc-standards/ (Accessed on 18 July 2020)

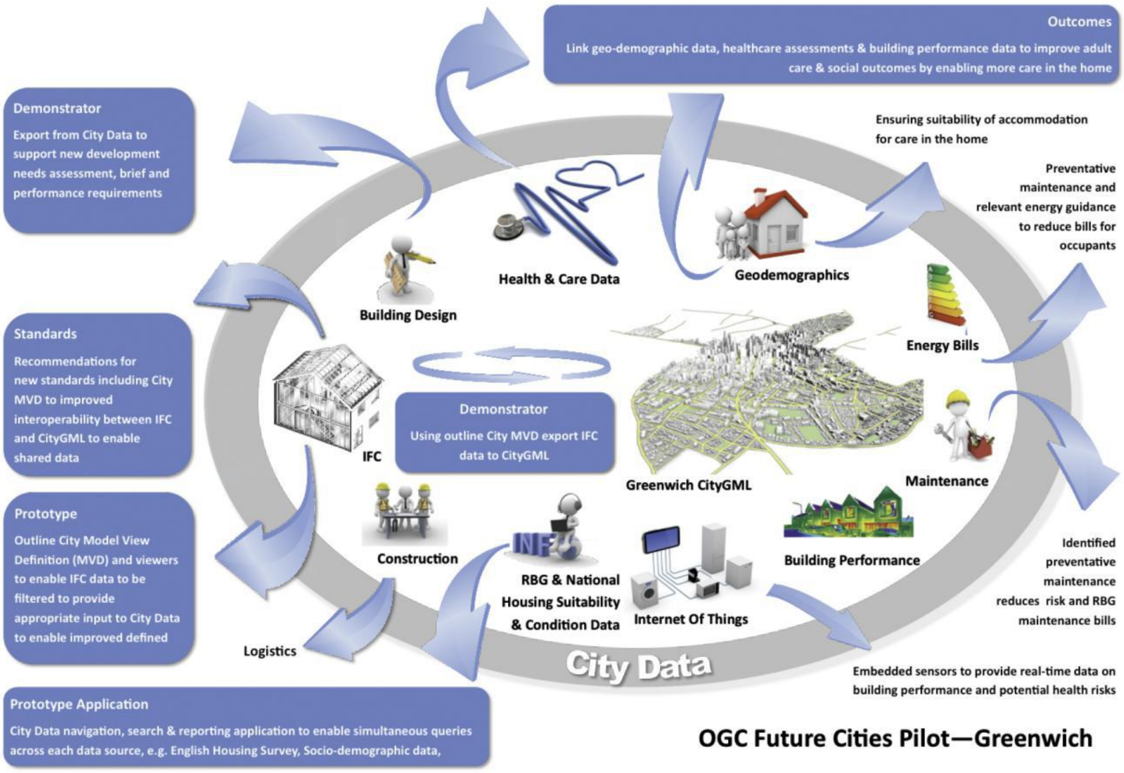


Figure 94. Smart cities are driving the integration of BIM & geospatial. Source: https://www.geospatialworld.net/article/future-cities-pilot-ogc-standards/

a. **Building a smart city is the way to achieve sustainable urban development.** For example, after entering the 21st century, China has accelerated the development of urbanization. Every year, thousands of rural people enter the cities. As the urban population continues to grow, more and more problems have emerged in urban construction and management, such as resource shortages, environmental pollution, traffic congestion, and safety risks, and even education and living resources are uneven.[128] In order to solve these increasingly serious problems in China, smart cities have begun to develop. Because smart cities use new information technologies such as the IoT technology (The Internet of things describes the network of physical objects — a.k.a. "things" — that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet. [129]), and cloud computing technology (Cloud computing is the on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. [130]), they can effectively solve the problem of "urban diseases". The application of these technologies makes it easier to perceive cities and more fully integrate urban resources. Based on these emerging sciences and

[128] Toli, A.M. and Murtagh, N., 2020. The concept of sustainability in smart city definitions. Frontiers in Built Environment, 6, p.77.
[129] Rouse, M., 2019. Definition-Internet of Things (IoT). techtarget. com, para. 1.
[130] https://en.wikipedia.org/wiki/Cloud_computing (Accessed on 18 July 2020)

technologies, digital technology has made urban design more refined and smarter. These smart designs and smart management can effectively reduce resource consumption, reduce environmental pollution, and ultimately achieve sustainable urban development.

b. **Building a smart city is a need for the development of information technology.** Today's global informatization is developing rapidly, and the degree of informatization has become a decisive factor in the degree of economic development of a country. The smart city is just such a necessary concept that uses information technology to design and manage cities. Currently, most developed countries are carrying out smart city development planning and design, which complement each other, and which information technology helps to develop.[131]

BIM puts the entire urban design in an urban data model, which contains not only the data of buildings but also geography, traffic organization, climate conditions, living environment, perceived information, etc. Through simulation analysis and evaluation, it can be involved in managing and updating not only in the design and construction phase but also in the whole development phase of the city.

[131] Yamamura, S., Fan, L. and Suzuki, Y., 2017. Assessment of urban energy performance through integration of BIM and GIS for smart city planning. Procedia engineering, 180, pp.1462-1472.

8 Summary and Conclusions

The research carried out allowed us to find answers to the research questions posed at the beginning of the doctoral dissertation.

A. Referring to the first of them: “What are the research trends in the use of BIM in urban design?”, based on the analyses conducted, it can be concluded that over the past ten years, Building Information Modeling (BIM) has found wide application in engineering design. Most of the current research focuses on the application of BIM in management, green building, and infrastructure.
However, there are relatively few examples of the application of BIM in urban design.
The second chapter of the dissertation analyzes the state of application and direction of BIM development research in urban design over the last ten years.
The research led to the conclusion that, compared to the application of BIM in architectural and engineering design, the application of BIM in urban design is still in its infancy, but there is a clear upward trend.

B. To answer the question, “Can BIM technology be useful in urban design as it is in architectural design?”, it should be noted that BIM has been spectacularly successful in applications to individual buildings.
The BIM digital information model has played an important role in building design and has been widely used in many architectural projects.
In theory, for urban design projects, multiple independent digital BIM models can be considered and merged into a complete model with more content and information.
From this perspective, the application of BIM technology in urban design is fully possible.

However, it should be noted that a new approach to BIM is required to achieve advanced urban design. The new approach must rely on the synergistic integration of BIM with other digital platforms such as GIS, CIM, and LoT. Then BIM in urban planning will play the same or even greater role compared to BIM in architectural design. In particular, BIM technology can be useful in the early stages of urban design. The application of BIM in urbanism will contribute to the building of sustainable urban units.

C. Moving on to the third main research question, “In what elements of urban planning BIM can be used effectively”, the results of the research led to the conclusion that BIM technology allows the transformation from a “top-down” approach to a “bottom-up” approach in urban design.

The traditional “top-down” planning approach means that major design decisions originate at the highest planning levels and are passed down to lower levels, and eventually down to the level of the ordinary resident. The ordinary resident actually has little influence on the shape of the space in which he lives.

The “bottom-up” approach draws attention to how the space is assessed by ordinary residents, and their opinions constitute the basis for making planning decisions at higher levels.

The "bottom-up" approach requires that a real design contact be established with the ordinary users of the space, for whom specialized urban planning provisions may be incomprehensible or too abstract. In this respect, the BIM technology gives a direct possibility to visualize the design arrangements and even to use virtual reality (VR) to "invite" the inhabitants to walk around the designed space. The possibilities of 3D simulation and imaging of the basic provisions of an urban plan in BIM technology can contribute to a more sophisticated and sustainable urban design.

With simulation capabilities, BIM technology can transform design drawings from two-dimensional to three-dimensional, achieving the design of real space. Designers can clarify the problems of spatial positioning and the overlapping of complex surfaces by building three-dimensional models. The three-dimensional BIM model clearly and reliably shows the details of urban planning.

From the point of the view of evaluation ability, designers can calculate the relevant urban design data using the BIM information model to adjust the design plan in a targeted way to ensure the rationality of the urban plan.

From the point of view of the development of informatization, BIM technology can support the expression and transmission of differentiated data, facilitate the exchange of information related to urban design, and contribute to the development of urban design informatization. BIM can effectively improve project coordination and identify spatial collisions and social conflicts.

From the perspective of scientific development, BIM technology can be used in conjunction with GIS, GPS, and other technologies to collect urban meteorological and geographical data. BIM provides reliable data for urban design and improves the quality of urban plans.

D. In response to the research question, “Will this new design technology completely replace traditional methods of urban design?” it can be concluded that the conducted research did not allow for the formulation of a definite answer.

Design as the initial stage of the rational shaping of the built environment plays a key role in the entire life cycle of an investment. The application of BIM technology has transformed the design of the built environment from two-dimensional to multidimensional. This transformation has improved work efficiency and cost savings, affecting sustainable development. The advent of BIM technology has had a significant impact on traditional design methods and systems, but BIM will probably not soon completely replace traditional urban design methods. Contrary to architecture, in which BIM is very commonly used, in urban planning BIM still requires development work toward greater integration of geographic information systems about the area with systems of technical information about buildings and technical infrastructure. Already, a strength of BIM in urban planning is the ability to visualize three-dimensionally and to introduce time as the fourth dimension of urban studies.

The BIM model uses various relevant information data from urban construction projects as the basis of the model for building model objects and simulating accurate information about city buildings through digital information simulation. BIM integrates relevant information from different projects using a parameter model, makes it available, and transmits it throughout the project planning, operation, and maintenance lifecycle.

All stakeholders, including ordinary space users, have a unified platform for cooperation, which plays a fundamental role in improving efficiency, saving costs, and shortening the time of project execution. In this regard, BIM in urban planning has features of coordination and optimization of the design process.

E. Extending the summary and conclusions of this dissertation, it can be concluded that, compared to traditional methods of urban design, the BIM digital design system builds a digital city based on a sustainable development system, so that all aspects of the city can be coordinated and a synergistic symbiosis can occur.

The BIM model is a virtual representation of the real system on the computer. All elements of urban design are saved in digital form. With the development and maturity of BIM, the building information model, based on three-dimensional digital technology, the established urban design simulation model, and the two-dimensional drawings in traditional designs, are all integrated and visualized, and the drawing design is optimized.

Technical exchange can be more convenient to achieve the goal of comprehensive optimization of an urban design.

With 3D BIM simulation platform in city design, multi-dimensional applications can ultimately perform design analysis that the current system's 3D simulation cannot recognize. Especially in the performance analysis of urban design schemas, digital BIM information evaluation analysis can solve intangible problems in traditional urban design, such as comfort index, air volume, noise profile, insolation intensity, etc. The use of BIM simulation and evaluation can combine traditional urban design with data models to positively influence knowledge-based urban design and sustainable development.

The implementation of BIM in urban design provides opportunities for spatial management and design of former land, data management, and data integration in the future, and the application of future intelligence.

Facing the future, Internet of Things (IoT) data sensing is especially important. With the seamless reach of IoT, data on the natural environment, social environment, and behavior patterns will be effectively aggregated so that the future portrait of a city can be drawn through data management. It also monitors and evaluates the performance of urban development.

Using GIS, BIM, IoT, and other systems, the three levels of a city, community, and family can come together to build a complex giant digital city system. All analyses, and even future deductions and judgments, are based on data.

The author predicts that, in the next step, the use of BIM in urban design will focus more on the simulation of planning schemes. With the help of three-dimensional planning condition formation links, will be created a cross-professional database, which connects the overall urban planning with the independent architectural design. It also seamlessly connects geology, transportation, energy, water supply, environmental protection, and other related special planning and urban design plans and establishes data synergy between various disciplines.

At the same time, model testing and simulation, including traffic, space, water, and climate models, will become auxiliary tools to optimize urban design schemes.

For urban operation and maintenance, more emphasis is placed on urban perception and the interconnection of everything. Through the city's market-oriented operation, real-time collection of the use of energy, transportation, and public facilities by different types of buildings and different types of the population to promote real-time monitoring, early warning, and evaluation of the city, and regular feedback for big data analysis for the next step. The planning, design, construction, and operation of the project to improve the space governance capabilities.

For the BIM platform itself, the collaboration between different technical modules is particularly important. The first step is big-data spatial analysis, which includes both descriptive analysis and predictive analysis. The second is the urban systemic model, including the construction of transportation systems, energy systems, environmental sanitation systems, water systems, etc., which depend largely on the establishment of professional knowledge maps.

The digital city based on the BIM platform will eventually improve and reshape our human perception, cognition, experience, and decision-making capabilities for the city of the future. BIM will nurture more innovative and exciting scenarios and will explore more developmental dimensions for the future. It will give birth to more creative ideas and ultimately accelerate the future development of the physical city and, indeed, of society’s evolution.

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