Carbon Reduction through Building Matrix Design for Sustainable Development

Chapter

Carbon Reduction through Building Matrix Design for Sustainable Development

Bin Li, Luca Caneparo, Yuqing Zhang and Weihong Guo

Abstract

Under the influence of planet problems such as global warming and the energy crisis, carbon reduction has become one of the goals for sustainable development. This chapter focuses on residential buildings as research objects for achieving carbon reduction based on architectural design. After analyzing three design principles from the life cycle of the building, macro, medium and micro design scales, and passive-active design, the authors initially established an open-source matrix design method. Then, an architectural competition plan that won only first prize from 92 proposals was taken to explain further the connotation of carbon reduction to achieve sustainable development through the matrix design method. The results show that the vicious circle exists between global warming and the energy crisis. Residential buildings contain more potential than other buildings for solving these problems. The matrix design method is established based on the three design principles. From a qualitative perspective, according to the case application, this research helps achieve carbon reduction for sustainable development.

Keywords: matrix design, carbon reduction, sustainable development, residential building, architectural design, life cycle, passive design, renewable energy

1. Introduction

1.1 Background

At least from the nineteenth century, scientists began to recognize the role of carbon dioxide in global warming [1]. Using the NASA global temperature data from 1880 to 2022 [2], 'Tableau Public' (https://www.tableau.com/products/public) software was used to analyze and display the data. **Figure 1** shows the change in global surface temperature compared to the long-term average from 1951 to 1980. It can be clearly seen that the global land-ocean temperature index has been increasing in the past 150 years. On March 19, 2023, the Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change, published the Synthesis Report of the IPCC Sixth Assessment Report (AR6), which

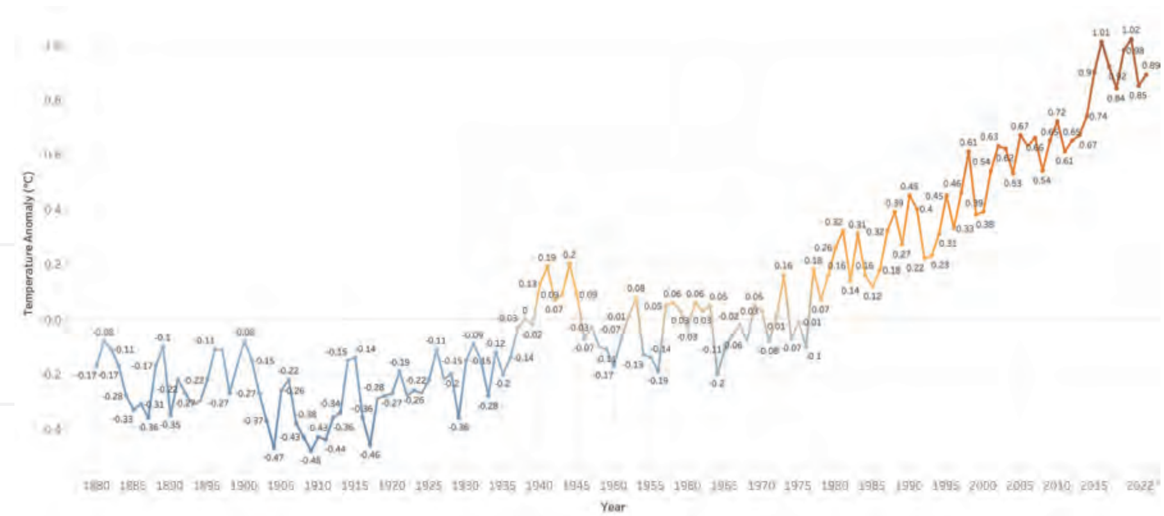

Figure 1.
Global land-ocean temperature index (the data come from Ref. [2], and the image was created by the authors).

indicates the global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020 [3]. Global warming is intensifying and a problem that needs to be solved.

On the other hand, energy crises from fossil energy sources happen now and then. For non-renewable reasons, the more fossil energy is used, the less is left. Using the data downloaded from Our World in Data [4], **Figure 2** is generated by Tableau Public software to show global fossil fuel consumption. By 2021, especially since the Industrial Revolution, the consumption is increasing dramatically daily. Correspondingly, the remaining global fossil energy up to 2021 is shown in **Figure 3**. Although these values can change with time based on the discovery of new reserves and changes in annual production, the remaining years from 2020 of global coal, gas and oil are

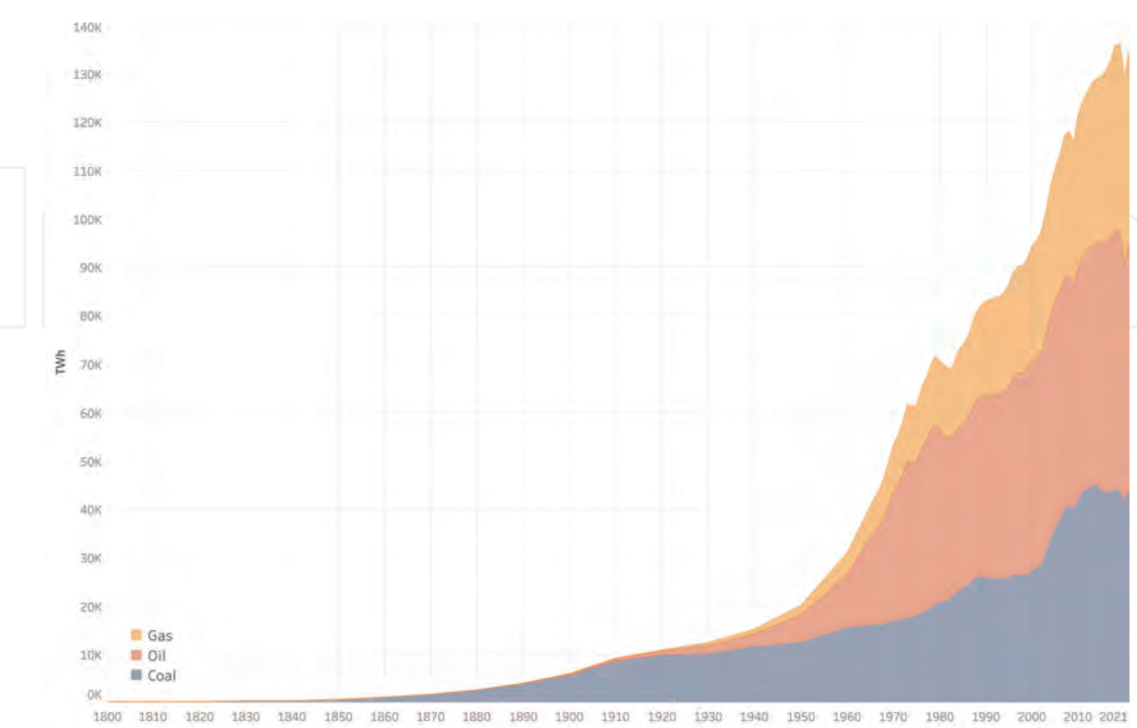

Figure 2.
Global fossil fuel consumption (the data come from Ref. [4], and the image was created by the authors).

DOI: http://dx.doi.org/10.5772/intechopen.1004867

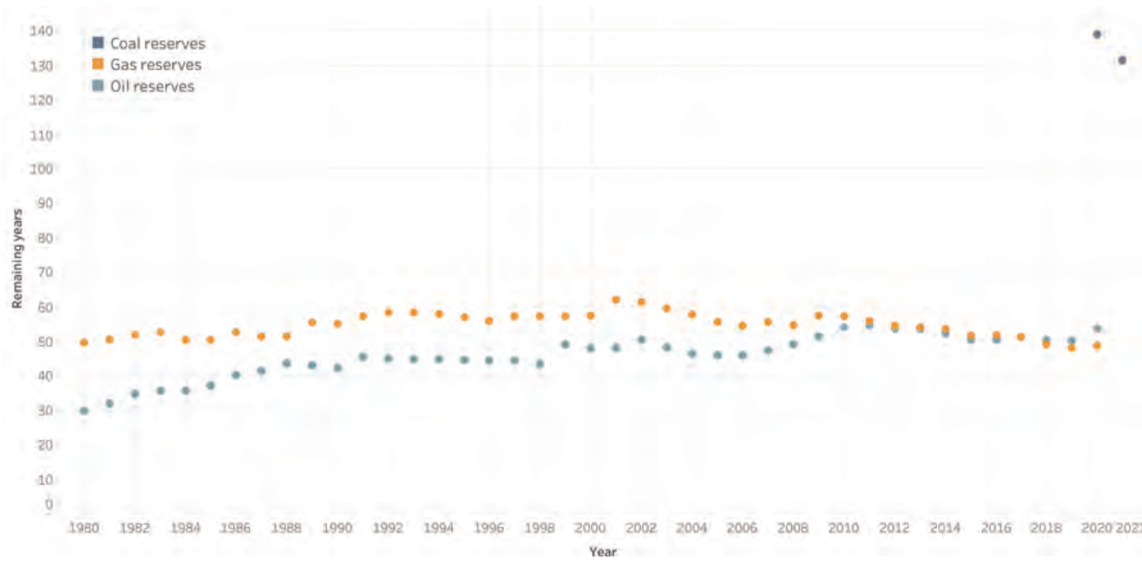

Figure 3.
Years of fossil fuel reserves left (the data come from Ref. [5], and the image was created by the authors).

only 139, 49 and 57, respectively [5]. Fossil energy consumption causes energy crisis and carbon emissions to exacerbate global warming [6]. A vicious circle is formed between global warming and the energy crisis. So, carbon reduction is essential to solving these problems for sustainable development.

1.2 Research objective

The 2022 Global Status Report for Buildings and Construction, published by the UN Environment Programme (UNEP), indicates that the buildings and construction sector accounted for around 37% of energy-and process-related CO_2 emissions and over 34% of energy demand globally in 2021. The building sector's operational energy-related CO_2 emissions reached an all-time high of around 10 $GtCO_2$, and operational energy demand in buildings reached an all-time high of 135EJ [7]. Moreover, residential buildings accounted for 17% of operational and process CO_2 emissions globally compared with 11% of non-residential buildings. The final energy demand for residential buildings is 21%, more than twice the proportion used in non-residential buildings (9%) [8]. So, energy saving, even producing renewable energy on residential buildings, is necessary and more effective for solving the energy crisis and global warming problems to some extent [9].

In this research, residential buildings are focused as research objects, especially from the building design aspects for achieving sustainable development by carbon reduction.

2. Design principles

The typical building design principles include the life cycle of the building in the time dimension, the macro, medium and micro design scales in the space dimension, and passive-active design in the technology dimension. These three design principles support each other to form the final buildings. The relationship between them is shown in **Figure 4**.

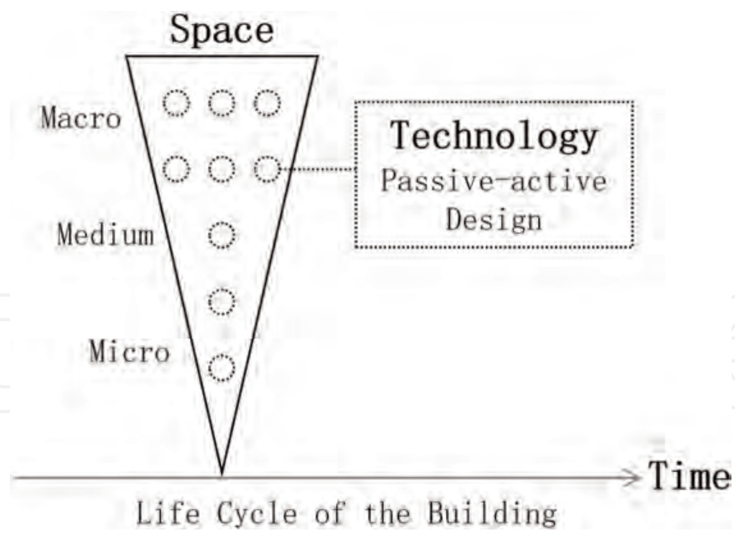

Figure 4.
The relationship of the three design principles.

2.1 Life cycle of the building

The life cycle of the building can be defined as five stages: design, construction, operation, renewal, and demolition [10]. The design and renewal, the construction and demolition, can be seen as similar and reversible stages, respectively, but they face different conditions (**Figure 5**).

The design stage is the point at which the most basic decisions regarding sustainable development, including carbon reduction, are taken [11]. It plays a critical role in determining the sustainability, the life cycle environmental impact and the efficiency of the buildings [12]. The construction stage can also take the role of carbon reduction but more from the construction practices, craft techniques and building materials which play a major role in the building's carbon footprint. The operation stage accounts for the most significant proportion of energy consumption in the building life cycle [13]. However, the user behavior and the energy efficiency of devices have a huge impact on that. The renewal stage can be regarded as redesign. Although it is not a design from scratch, optimizing the existing conditions with a better design is generally more sustainable [14]. The demolition stage can be seen as the inverse of the construction stage, especially if all the components can be reused.

All the stages can contribute to sustainable development with carbon reduction. However, the design and renewal stages play the leading role.

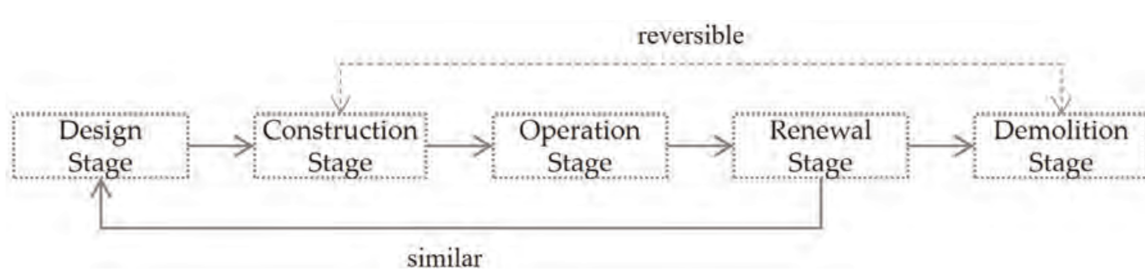

Figure 5.
The analysis of the life cycle of the building.

2.2 Macro, medium and micro design scales

In addition to the diachronic life cycle of the building, the different levels of synchronicity in the residential building are also essential design principles that should be paid attention to. The different levels of residential design can be divided into macro, medium and micro, matching community planning, building design and detail design [15], which makes up the second design principle.

Different levels of residential design focus on different scales. For example, the community planning of different residential buildings in Lingnan focuses mainly on site selection, layout models and related aspects for sustainable development (**Figure 6**).

1. Typical layout in Guangfu residential community.

2. Typical layout in Chaoshan residential community.

3. Typical layout in Hakka residential community.

As for the building design, it focuses more on space design. **Figure 7** shows an example of a typical residential building design in Lingnan, highlighting the natural ventilation, to achieve carbon reduction. The design contents are different from the community planning.

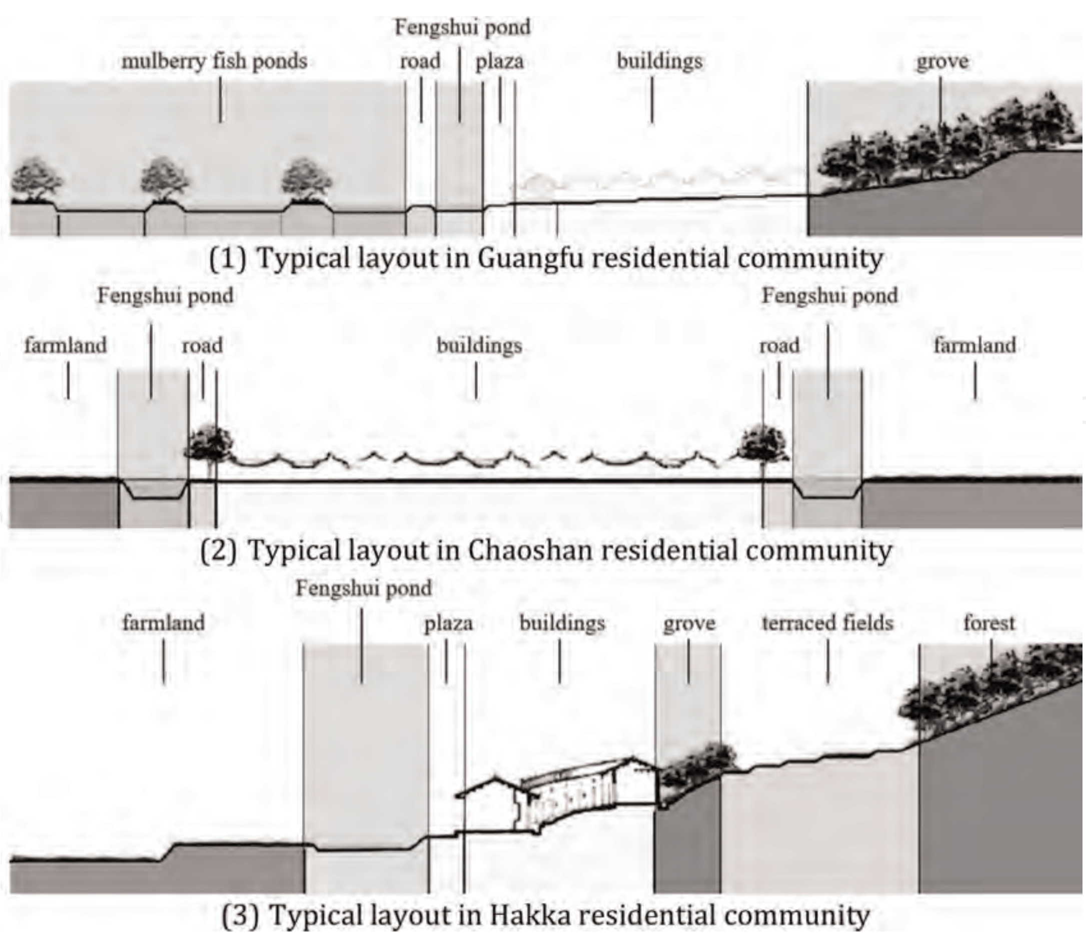

Figure 6.
Different community planning in Lingnan residential buildings.

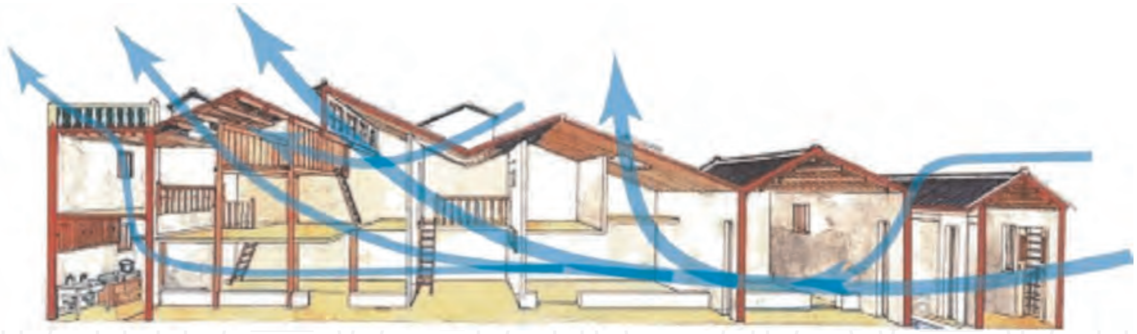

Figure 7.
Space design in Lingnan for natural ventilation.

At micro scale, detail design focuses more on the technologies that help to achieve community planning and building design. For example, the building technologies of the Oyster wall [16], different wall masonry methods and so on all support the implementation of residential buildings in Lingnan with different roles (**Figure 8**). These also contribute to achieving sustainable development.

2.3 Passive-active design

Generally, passive design in building is the leading way to reduce energy demand based on high performance. Active design can achieve carbon reduction by improving energy efficiency, such as using high-efficiency equipment. Even though some research indicates that active strategies include generating renewable energy, such as using solar panels [17], other scholars classified passive, active and renewable strategies as three factors for carbon reduction in buildings [18]. This research acknowledges active and passive classification methods. However, reducing energy demand, improving energy efficiency and generating renewable energy are different ways to reduce carbon.

Based on a 3rd Solar Decathlon China case study, 35 types of technologies are sorted out from the 15 competition residential buildings (**Figure 9**). It is clear that passive and active technologies, including reducing energy demand, improving energy efficiency, and generating renewable energy, are three aspects. These technologies are helpful for carbon reduction to achieve sustainable development.

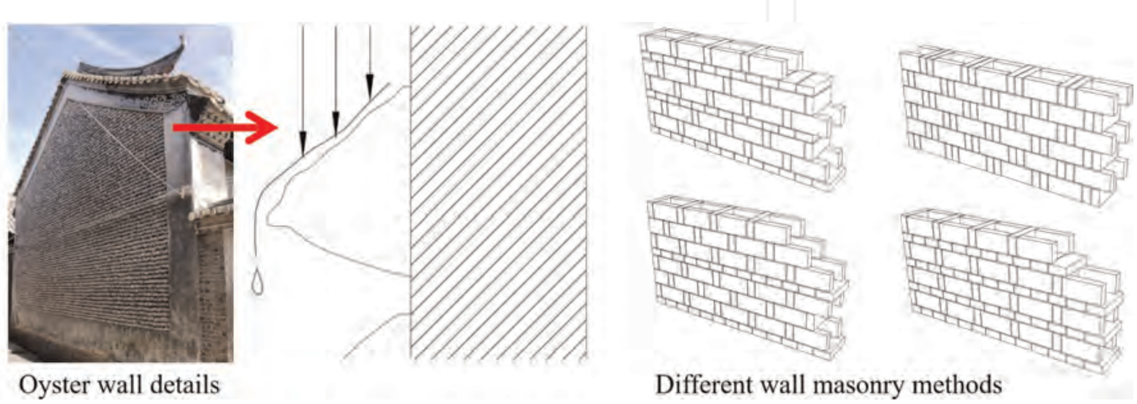

Figure 8.
Windows, doors and construction implementations in Lingnan.

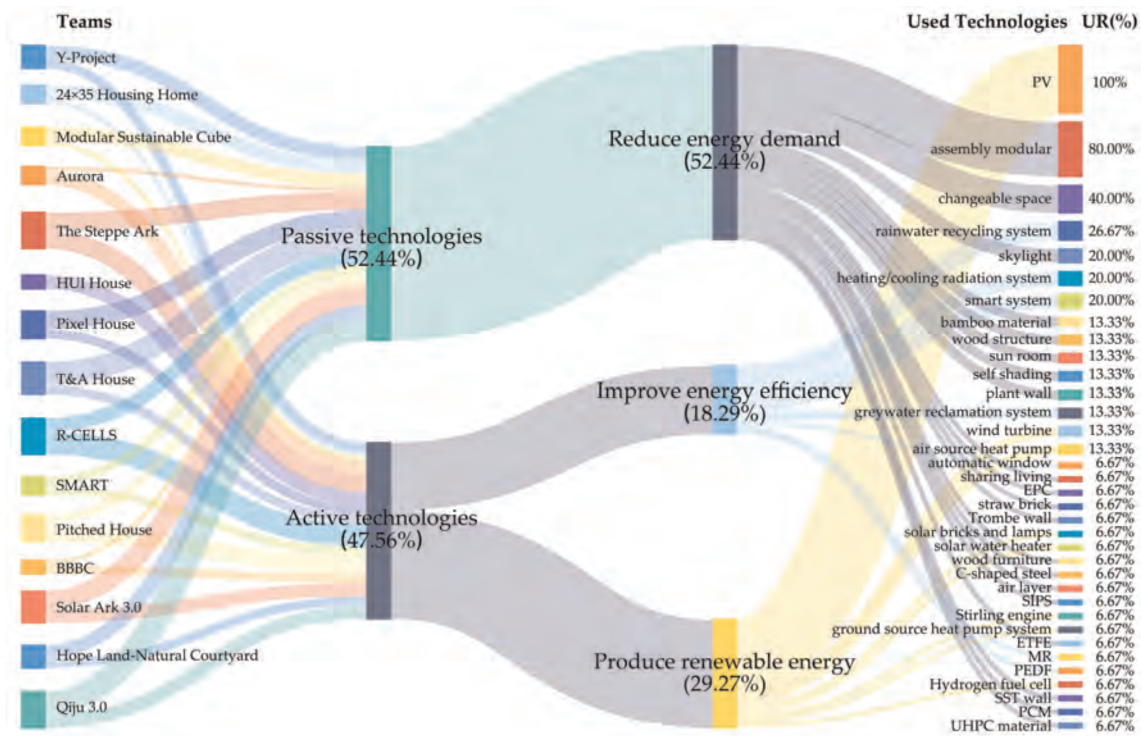

Figure 9.
Technologies used in the 3rd solar decathlon China (the data come from Ref. [19], and the image was created by the authors).

3. Matrix design method

3.1 Matrix design establishment

The matrix design method is grounded in three design principles. Although some methods exist to guide further design, these methods usually only follow some of these three design principles.

For example, the Life Cycle Assessment (LCA) method analyzes and quantifies the environmental consequences of buildings during their whole life cycle, from the extraction of raw materials, through production, use phase and end-of-life. This method is used to quantitatively assess the material used, energy flows and environmental impacts of products [20]. However, this method is more from the product point of view rather than architectural design. Moreover, a systematic literature review demonstrated that LCA continues to face barriers in both methods and practice, preventing its ability to guide early-stage design decisions and greatly impacting the environmental performance of buildings [21].

As for the design scales, these have split into different disciplines, such as urban design, architectural design, building construction and so forth. However, carbon reduction for sustainable development also needs knowledge of building technology, building services engineering (BSE) and further ones. This knowledge should be comprehensively applied to specific situations to achieve sustainable development [22].

Moreover, some research focus on the passive-active design. Aparicio-Ruiz et al. [23] did the research in Spain and tried to get the integrated optimization result for residential building design. The passive optimization design mainly considered the materials based on the best Energy Efficiency Index (EEI) and the lowest Life Cycle Cost (LCC). The annual energy demand for cooling and heating was calculated to define the energy rating. Generating renewable energy by solar panels was calculated to cover the energy consumption. Moreover, the active systems HVAC (heating, ventilation, and air conditioning) were also considered to maintain comfortable environments. However, these methods are complex and only consider carbon reduction from the passive-active design principle for sustainable development.

The matrix design method tries to find the key points for sustainable design based on the three design principles. A matrix diagram has supported the analysis. The matrix diagram is a project management and planning tool for displaying and analyzing the relationships between two or more data sets, also known as matrix charts. Matrix diagrams provide a valuable visual aid to intuitively understanding complex information that might otherwise be difficult to understand. Different types of matrix diagrams have been explored, such as L-shaped matrix diagram, Y-shaped, C-shaped, T-shaped and X-shaped.

3.2 Background on matrix design

Matrix design methods are rooted in "architecture, the age-old question of the quantification of quality, that is, of the measurability of the levels of satisfaction of the needs of living, answered by the performance approach. The demand-performance approach expresses the exceeding of the practice of associating specific 'objects' with specific 'needs' and shifts theoretical reflection and the possibilities of improving living conditions to the satisfaction of the latter. As a result, unlike traditional experiential approaches based on the rule of art, it is committed in 'what to get,' not 'how to get it'" [24].

Rational design theories started to be widely deployed in the mid-sixties as paradigms to ground design practices on "scientific methods" [25]. Christopher Alexander advanced demand-performance scientific methodologies, for instance, outlining design issues by means of detailed requirements and misfit variables [26]. Alexander is committed to bridging the gap between design practices and scientific methods: "This conflict, which has not yet been mended, has been repeatedly resumed, such as in the debate on the contrast between the two cultures, the humanistic and the scientific one, highlighted by Charles Snow, or in symmetric oppositions between world of ideas and world of practice. In architecture, in the wake of these dichotomies, there is still a contrast between a 'world of forms' and a 'world of techniques'" [27].

On the use of methodologies and techniques in design, Alexander [26] states "A design problem is not an optimization problem. In other words, it is not a problem of meeting any one requirement or any function of a number of requirements in the best possible way (though we may sometimes speak loosely as though it were, and may actually try to optimize one or two things like cost or construction time). For most requirements, it is important only to satisfy them at a level which suffices to prevent misfit between the form and the context, and to do this in the least arbitrary manner possible."

Giuseppe Ciribini outlines the methodology to represent the requirements in matrix form: the "Performance requirements (occurrences to be met through the production of a good) are translated into requirements:

- Environmental, issues or requests to the environment to fulfill suitable conditions for well-being, safety, etc.;

- Technological, or quality levels are required to technological objects or bodies to achieve the desired environmental quality.

A requirement (and the associated performance) can be expressed by one or more functions such as:

f (a, b, c, …),
where a, b, c, … are the characterizing variables. […]

Their correlation in the system starts with filling a matrix with the correspondences between requirements, paired two by two" [28].

The Performance Based Building (PeBBu) Thematic Network has addressed a systematic approach for applying building industry and user requirements to the building process. Among the support toolkits, Design Structure Matrix (DSM) has been selected and trialed. DSM is described as "a compact and clear representation of complex system and capturing method for the interactions between system elements. Visual relationship matrix reveals key information flows and sets simultaneously targets to process analysis and re-engineering. It is used for finding the optimal order of tasks, defining product architecture (modularity and interfaces) and forming teams in large organisations. In case the problem exists it helps also to solve inconsistencies. There are many commercial applications available for DSM" [29].

3.3 Proposed matrix design methodology

Here, the L-shaped matrix diagram is used for analyzing three data sets. It is the intersection of the life cycle of the building data set with design scales, and passive-active design data set, respectively (**Table 1**).

3.4 Matrix design analysis

The life cycle of the building includes five stages. The interaction relationship between the life cycle of the building and design scales shows that only four stages

		Life cycle of the building				
		Design stage	**Construction stage**	**Operation stage**	**Renewal stage**	**Demolition stage**
Design scales	**Community planning**	√	√	×	√	√
	Building design	√	√	×	√	√
	Detail design	√	√	×	√	√
Passive-active design	**Reduce energy demand**	√	×	√	√	×
	Improve energy efficiency	√	×	√	√	×
	Generate renewable energy	√	×	√	√	×

Note: √ stands for relationship; and × stands for no relationship.

Table 1.
Matrix analysis for three design principles.

have relationships with community planning, building design and detail design. Even the operation stage can be considered at different scales, macro, intermediate, and micro (namely, the design scales: community planning, building design and detail design), the space was constructed before the operation stage. So, the operation stage depends more on user behavior and device energy efficiency, which are somewhat outside the building design. As for the construction and demolition stages, even though they are interactive with design scales, they point more to the construction modes, craft techniques and building materials on a broad design level.

As for the relationship between the life cycle of the building and passive-active design, there is no relationship between the construction and demolition stages because the passive, active and renewable aspects do not apply to the construction process. However, the passive, active and renewable aspects are important during the operation stage. As for their relationship in the design and renewal stages, these three aspects are essential to being involved in carbon reduction for sustainable development.

It can be found that design scales and passive-active design all take roles in the design and renewal stages. Referring to the Matrice d'impacts croisés multiplication appliquée à un classement (MICMAC) method, a cross-impact matrix multiplication [30], and the transitivity principle [31], the relationship between them can be established as a matrix method to sort out the key points for sustainable development.

3.5 Matrix design focus

The L-shaped matrix diagram is applied again, as **Table 2** shows. The intersecting sections show different key points for sustainable development in the design and renewal stages. Even though it is hard to sort out all the key points for matrix design, especially in the context of the continuous development of the times, new ideas and technologies will emerge. However, the intersection points of these three design principles were finally found through matrix analysis. These points are used to guide carbon reduction for sustainable development.

Community planning interacts with the three aspects of passive-active design, generating the layout, orientation, terrain, water, plant … , pipe gallery, lighting, power, gas, water supply and drainage … and energy station, biogas digester … , respectively. Building design interacts with the three aspects of passive-active design,

		Passive-active design		
		Reduce energy demand	**Improve energy efficiency**	**Generate renewable energy**
Design scales	**Community planning**	Layout, orientation, terrain, water, plant …	Pipe gallery, lighting, power, gas, water supply and drainage …	Energy station, biogas digester …
	Building design	Shape, space, color, window-to-wall ratio …	HVAC, power, lighting, plumbing, smart control …	PV, wind turbine, heat pump …
	Detail design	Material, insulation, window, door, construction …	Auto shading, sensor, craft …	System, orientation, angle …

Table 2.
Matrix design method.

generating the shape, space, color, window-to-wall ratio … , HVAC, power, lighting, plumbing, smart control … and PV, wind turbine, heat pump … , respectively. Detail design interacts with the three aspects of passive-active design, generating the material, insulation, window, door, construction … , auto shading, sensor, craft … and system, orientation, angle … , respectively. Some of them, such as improving energy efficiency in community planning and building design, generated similar results but different application scales. On the one hand, there may be only so many existing design points. On the other hand, some points may be repeated in different parts but face different problems.

Establishing the building matrix design method should be applied according to the specific conditions and developing with time as an open-source method. This method considers as many design points as possible from different design principles. Due to user's insufficient information, these may not be perfect enough. However, this can be regarded as a reorganization of the Architectural Practice System Theory for sustainable development [32]. Every design principle points to a system; its superposition is still a system but with different boundaries. Although the outline of the matrix design appears unsystematic and even fragmented, it can lead to problem-oriented outcomes and multi-objective solutions.

4. Case application

4.1 Introduction

Based on the background issues, the matrix design method is established after analyzing three design principles. The oriental courtyard design, designed by Bin Li et al. and which won first place out of 92 submitted designs [33], is taken as the case application of the building matrix design method for carbon reduction in residential buildings.

This competition requires the design of a residential building no more than 25 m in length and 18 m in width, a construction area of 240 $m^2 \pm 15$, a building height of less than 12 m, and not more than 3 floors. The building site should be in the Lingnan area [34]. The carbon reduction for sustainable development is one of the aims of this competition. It also encourages participants to learn from oriental architecture wisdom, traditional Chinese architectural culture, and then innovate to meet contemporary needs.

4.2 Design concept

The design site is chosen in Yongqingfang, Guangzhou city, where the density of bamboo barrel houses is high [35]. However, due to high density and long-term disrepair, the houses are dilapidated, resulting in huge energy demand that is not conducive to sustainable development. The residential buildings in Yongqingfang need to be renovated, even though there has now been a national renovation demonstration (**Figure 10**).

The design concept is based on building matrix design to figure out the renewal content. This project mainly focused on the building and detail design at the design scales. The passive-active design was applied together to reduce energy demand, improve energy efficiency and generate renewable energy. Therefore, the design points are mainly figured out in **Figure 11**. Moreover, the traditional Chinese

Figure 10.
Renovated Yongqingfang.

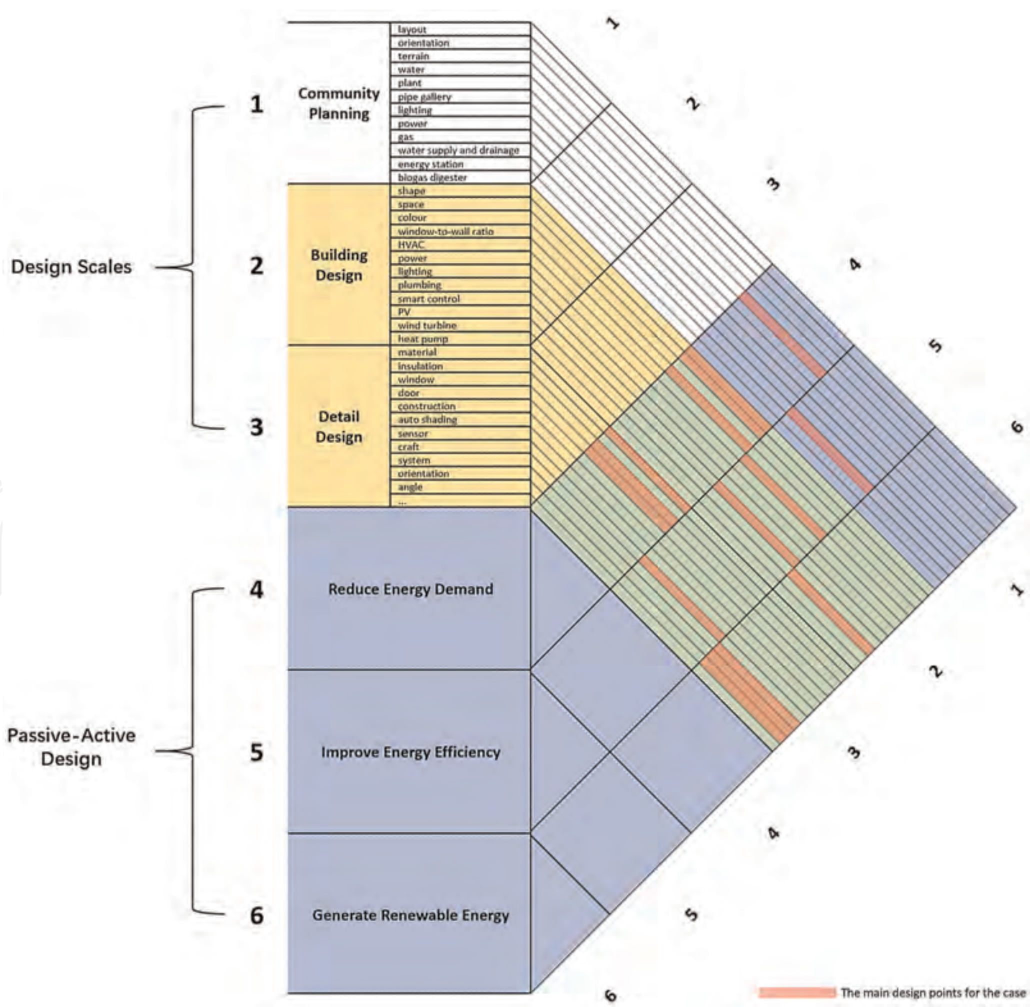

Figure 11.
The main design points of the renovation case (the figure was created by the authors).

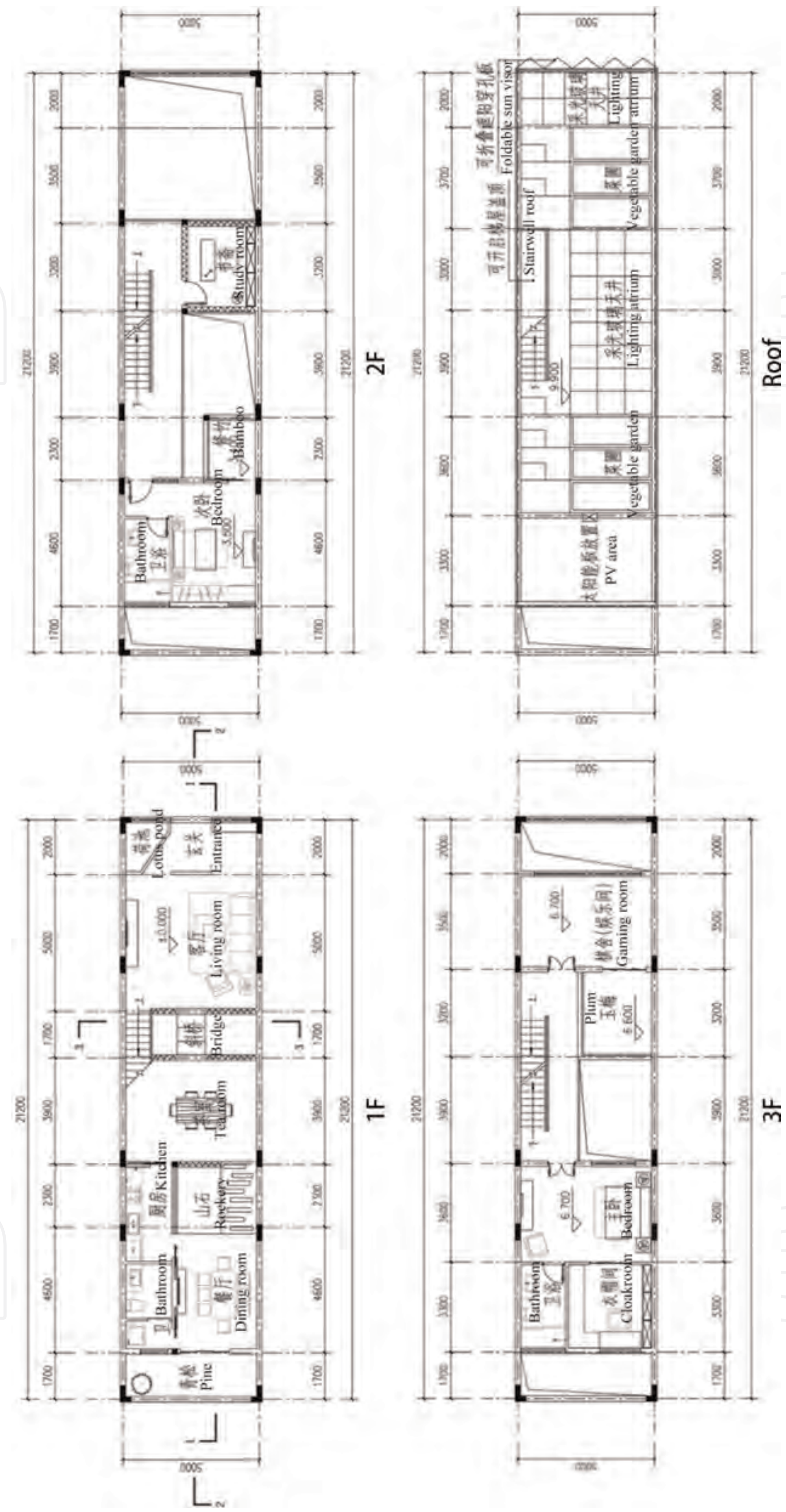

Figure 12.
Floor plan.

architectural culture is also considered according to the competition goals based on the open-source matrix design method. Yuyinshanfang, a traditional Lingnan Garden, was an attempt to learn for this design. The traditional passive technologies on the buildings and the greening measures were referenced.

4.3 Design results

The design-based bamboo barrel house is redesigned with three floors, including an accessible roof (**Figure 12**). The building function is shown on each floor. The sections indicate the building functions and the heights (**Figure 13**).

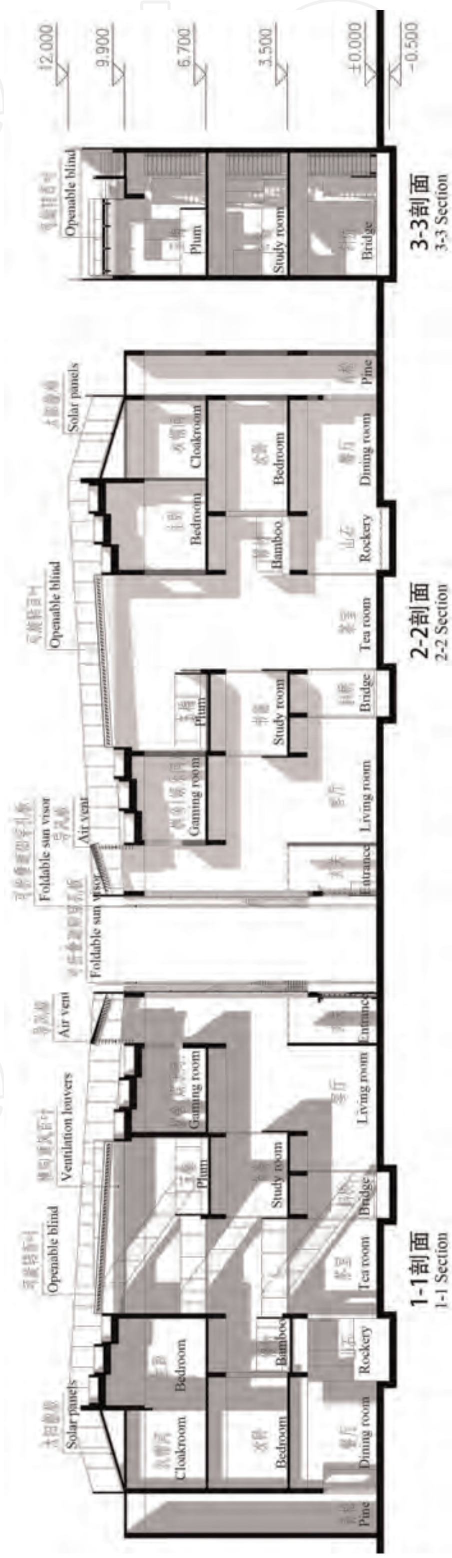

Figure 13.
Building section.

DOI: http://dx.doi.org/10.5772/intechopen.1004867

Traditional indoor split-level spaces are used for this design, which helps achieve wind-driven and buoyancy-driven ventilation (**Figure 14**). Phoenics software simulated the natural ventilation of this design (**Figure 15**) [36]. When the wind comes from the building entrance, the ventilation effect improves as floors rise. The wind flows out mainly from the central atrium and the rear courtyard, which are helpful to achieve a comfortable indoor environment without fossil energy consumption in the hot summer and warm winter Lingnan area and conducive to the discharge of the kitchen and bathroom smell. This helps to achieve carbon reduction by the passive building design for good indoor ventilation. The lighting environment is simulated by Ecotect (**Figure 16**). The results show that the overall indoor lighting is bright under the effect of atriums. However, in some places on the third floor, the lighting factor exceeds 7%, which may cause glare problems. Manual openable blinds can solve this without energy consumption. Passive lighting design helps conserve energy to reduce carbon emissions. The landscape elements and the plants used in the building for carbon reduction are shown in **Figure 17**. The above design points are passive design,

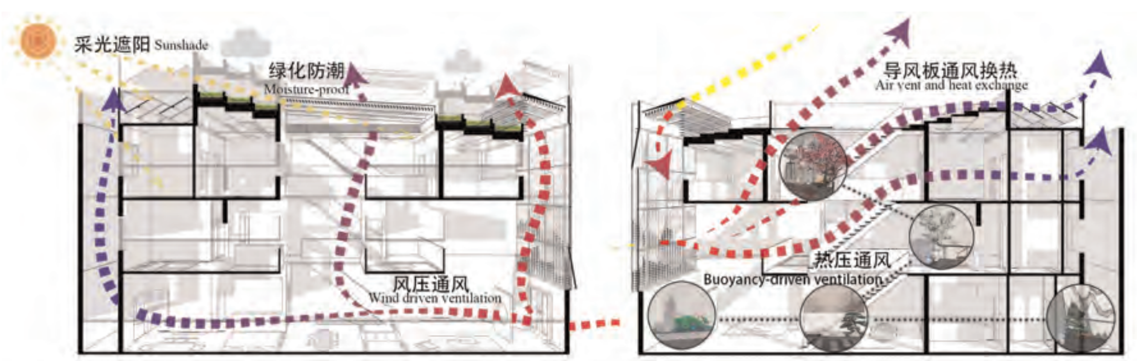

Figure 14.
Indoor ventilation.

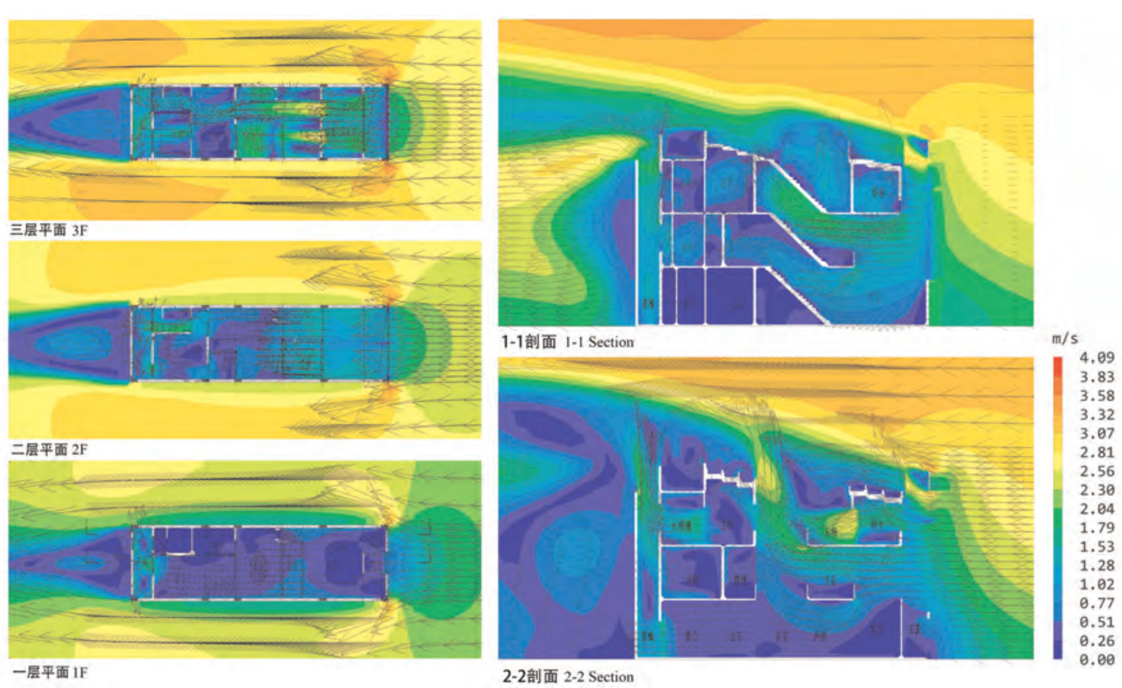

Figure 15.
Natural ventilation simulation.

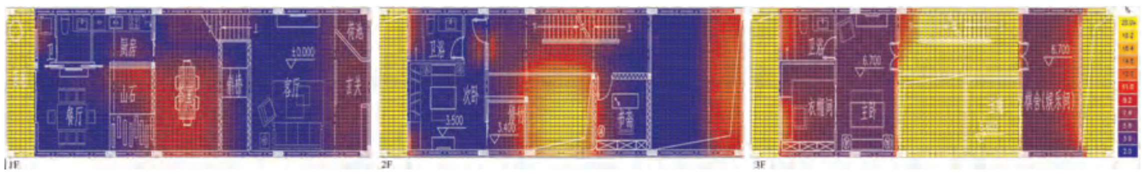

Figure 16.
Lighting environment simulation.

Figure 17.
Landscape in the building.

which avoids using energy through reasonable architectural design and achieves carbon reduction from the source. As for the active technologies, except for the smart control system for improving energy efficiency, the solar panels on the roof generate renewable energy to cover the building's energy consumption.

These key technologies include passive and active, as shown in **Figure 18**. Moreover, some interior renderings are shown in **Figure 19**. The design methods of matrix design and traditional Chinese architectural culture were applied to this project. The oriental courtyard spirit is inherited and innovated to meet the contemporary needs for carbon reduction to sustainable development.

5. Discussion and conclusions

This research starts from the global warming and energy crisis background problems to focus on the research object, residential buildings, for carbon reduction to achieve sustainable development. This problem-oriented research approach supports previous research results [37]. Based on the three design principles, the life cycle of the building, the macro, medium and micro design scales, and passive-active design, the relationship between them is figured out. That is, the integration of time, space

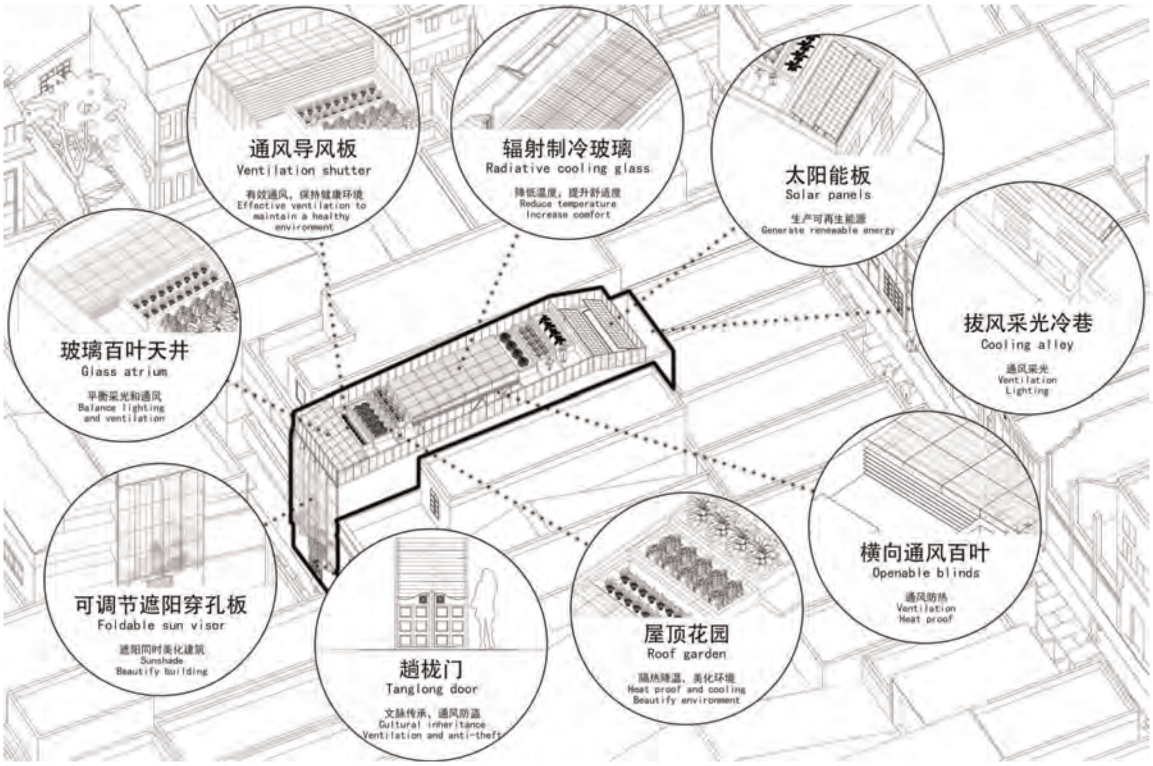

Figure 18.
Key technologies.

Figure 19.
Interior renderings.

and technology. The building matrix design method was originally established based on the design principles, which is an open-source design method that should be applied integrally according to the specific situation. Importantly, this method expands the architectural research ways [38, 39]. Then, the first prize of an architectural competition plan applied the matrix design method to show how to achieve carbon reduction in residential buildings for sustainable development.

Even though the building matrix design is established and applied in the competition plan, some limitations still need to be overcome. Due to the matrix design being an open-source method, it should be improved further. Moreover, the contributions of carbon reduction to sustainable development are hard to quantify for evaluation in this research, even though the direction helps achieve sustainable development [40]. This research mainly focuses on the original method established and applied for a case in a qualitative aspect. Further research from a quantitative aspect will be done in the future.

In summary, (1) the vicious circle relationship of background problems, global warming and energy crisis, is figured out. (2) Based on the problem-oriented, the most carbon reduction potential object for sustainable development in building, residential building, is identified. (3) The three design principles in architecture are analyzed, and the relationship is clarified. (4) A building matrix design method is originally advanced based on the design principles. This is an open-source method that expands the tools for architectural research. (5) Applying the matrix design method to a first-prize architectural competition plan illustrates how to reduce carbon in residential buildings for sustainable development.

Future research will focus on this direction to contribute more to sustainable development.

Acknowledgements

This research is supported by the Guangdong Basic and Applied Basic Research Foundation (Grant No. 2023A1515011137 and Grant No. 2024A1515012129); the 2022 Guangdong Philosophy and Social Science Foundation (Grant No. GD22XGL02); the Guangzhou Philosophy and Social Science Planning 2022 Annual Project (Grant No. 2022GZQN14); the Fundamental Research Funds for the Central Universities (Grant No. QNMS202211); the Guangzhou Basic and Applied Basic Research Foundation (Grant No. 2024A04J9930). Thanks to the MAECI Scholarship (Prot. N. 2793) for financial support. It is also partly supported by the China Scholarship Council (CSC) scholarship under the CSC Grant Nos. 202106150080 and 202006150053, and the Unite! Seed Fund project (Unite! Poster Contest on Architectural Energy for Sustainable Development).

Conflict of interest

The authors declare no conflict of interest.

Author details

Bin Li[1,2,3,4,5], Luca Caneparo[2*], Yuqing Zhang[1,2,5] and Weihong Guo[1,3,4,5]

1 School of Architecture, South China University of Technology, Guangzhou, China

2 Department of Architecture and Design, Politecnico di Torino, Turin, Italy

3 Energy Saving Technology Research Institute, South China University of Technology, Guangzhou, China

4 Architectural Design and Research Institute Co., Ltd., South China University of Technology, Guangzhou, China

5 State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, China

*Address all correspondence to: luca.caneparo@polito.it

References

[1] Bonneuil C, Choquet P-L, Franta B. Early warnings and emerging accountability: Total's responses to global warming, 1971–2021. Global Environmental Change. 2021;**71**:102386

[2] NASA. Vital Signs [Internet]. 2023. Available from: https://climate.nasa.gov/vital-signs/global-temperature/ [Accessed: December 26, 2023]

[3] IPCC. Synthesis Report of the IPCC Sixth Assessment Report (AR6) [Internet]. 2023. Available from: https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_SPM.pdf [Accessed: December 26, 2023]

[4] Our World in Data. Fossil fuels [Internet]. 2023. Available from: https://ourworldindata.org/fossil-fuels#global-fossil-fuel-consumption [Accessed: December 26, 2023]

[5] Our World in Data. Years of fossil fuel reserves left, 2020 [Internet]. 2023. Available from: https://ourworldindata.org/grapher/years-of-fossil-fuel-reserves-left [Accessed: December 26, 2023]

[6] Dai H, Mamkhezri J, Arshed N, Javaid A, Salem S, Khan YA. Role of energy mix in determining climate change vulnerability in G7 countries. Sustainability. 2022;**14**(4):2161

[7] United Nations Environment Programme. 2022 Global Status Report for Buildings and Construction: Towards a Zero - emission, Efficient and Resilient Buildings and Construction Sector [Internet]. 2023. Available from: https://wedocs.unep.org/bitstream/handle/20.500.11822/41133/Building_Construction_2022.pdf?sequence=3&isAllowed=y [Accessed: December 26, 2023]

[8] United Nations Environment Programme. Tracking Progress [Internet]. 2023. Available from: https://globalabc.org/our-work/tracking-progress-global-status-report [Accessed: December 26, 2023]

[9] Papoyan A, Zhan C, Han X, Li G. Energy saving strategy for residential buildings: Case study in Armenia. International Journal of Low-Carbon Technologies. 2021;**16**(3):987-997

[10] Wong JKW, Zhou J. Enhancing environmental sustainability over building life cycles through green BIM: A review. Automation in Construction. 2015;**57**:156-165

[11] Azhar S, Carlton WA, Olsen D, Ahmad I. Building information modeling for sustainable design and LEED® rating analysis. Automation in Construction. 2011;**20**(2):217-224

[12] Kovacic I, Zoller V. Building life cycle optimization tools for early design phases. Energy. 2015;**92**:409-419

[13] Morsi DMA, Ismaeel WSE, Ehab A, Othman AAE. BIM-based life cycle assessment for different structural system scenarios of a residential building. Ain Shams Engineering Journal. 2022;**13**(6):9-13

[14] Zheng B, Masrabaye F, Guiradoumngué GM, Zheng J, Liu L. Progress in research on sustainable urban renewal since 2000: Library and visual analyses. Sustainability. 2021;**13**(8):1-4

[15] Zheng Y, Sun Y, Wang Z, Liang F. Developing green–building design strategies in the Yangtze River delta, China through a coupling relationship

between geomorphology and climate. Land. 2023;**12**(1):6

[16] Shuo W, Jian T, Shaobin W, Chenchen W, editors. Study on the unsteady thermal insulation performance of subtropical oyster shell wall constructions. In: Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023). Dordrecht, The Netherlands: Atlantis Press; 2023

[17] Vahidinasab V, Ardalan C, Mohammadi-Ivatloo B, Giaouris D, Walker SL. Active building as an energy system: Concept, challenges, and outlook. IEEE. 2021;**9**:58009-58024

[18] Kim C-H, Park M-K, Kang W-H. Energy saving quantitative analysis of passive, active, and renewable technologies in different climate zones. Applied Sciences. 2021;**11**(15):1-4

[19] Li B, Guo W, Liu X, Zhang Y, Caneparo L. The third Solar Decathlon China buildings for achieving carbon neutrality. Buildings. 2022;**12**(8):7-20

[20] Blengini GA, Di Carlo T. The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. Energy and Buildings. 2010;**42**(6):869-880

[21] Roberts M, Allen S, Coley D. Life cycle assessment in the building design process – A systematic literature review. Building and Environment. 2020;**185**: 107274

[22] Leoto R, Lizarralde G. Challenges in evaluating strategies for reducing a building's environmental impact through integrated design. Building and Environment. 2019;**155**:34-46

[23] Aparicio-Ruiz P, Guadix-Martín J, Barbadilla-Martín E, Muñuzuri-Sanz J. Applying renewable energy technologies in an integrated optimization method for residential building's design. Applied Sciences. 2019;**9**(3):1-10

[24] Laurìa, A. Approccio esigenziale-prestazionale e qualità dell'abitare. Claudi de Saint Mihiel, A.(ed.) Tecnologia e progetto per la ricerca in Architettura, Napoli: Clean Edizioni; 2014; 54.

[25] Blachère G, Bâtir S. Habitabilité, durabilité, économie des bâtiments, Eyrolles. Paris: Eyrolles; 1965

[26] Alexander C. Notes of the Synthesis of Form. Cambridge, MA: Harvard University Press; 1964

[27] Losasso M. Between theories and practices: Culture, technology. TECHNE-Journal of Technology for Architecture and Environment. 2017; **13**:9

[28] Ciribini G. Tecnologia e progetto: argomenti di cultura tecnologica della progettazione. Turin: Celid; 1984

[29] Porkka J, Huovila P. Decision Support Toolkit (DST) – A step towards an Integrated Platform for Performance Based Building (PBB). In: Huovila P, editor. Combining Forces - Advancing Facilities Management & Construction through Innovation Series: Performance Based Building. Vol. V. Helsinki, Finland: VTT Technical Research Centre of Finland; 2005. pp. 81-93

[30] Ahmad M, Tang X-W, Qiu J-N, Ahmad F. Interpretive structural modeling and MICMAC analysis for identifying and benchmarking significant factors of seismic soil liquefaction. Applied Sciences. 2019;**9**(2):1-13

[31] Dubey R, Ali SS. Identification of flexible manufacturing system

dimensions and their interrelationship using total interpretive structural modelling and fuzzy MICMAC analysis. Global Journal of Flexible Systems Management. 2014;**15**(2):131-143

[32] Guo W. Architectural Practice System Theory. Guangzhou: South China University of Technology Press; 2016

[33] 筑岸设计. "东方人居杯"方圆东方的院子建筑设计竞赛入围作品 [Internet]. 2023. Available from: https://mp.weixin.qq.com/s/fJPUF7dkuy3NOIYi2vuoYA [Accessed: December 31, 2023]

[34] 南方建筑. 东方人居杯 [Internet]. 2023. Available from: https://mp.weixin.qq.com/s/QYl3UCvyqfHmp0RCyCUgWg [Accessed: December 31, 2023]

[35] RIBA. Bamboo Barrel House Museum in Guangzhou [Internet]. 2023. Available from: http://www.presidentsmedals.com/Entry-13671 [Accessed: December 31, 2023]

[36] Li B, Guo W, Schnabel MA, Moleta T. Feng-shui and computational fluid dynamics (CFD): Analyzing natural ventilation and human comfort. In: 25th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2020, August 5, 2020–August 6, 2020. Bangkok, Thailand: The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA); 2020

[37] Li B, Guo W, Liu X, Zhang Y, Russell PJ, Schnabel MA. Sustainable passive design for building performance of healthy built environment in the Lingnan area. Sustainability. 2021;**13**(16):1-3

[38] Zhang Y, Li B, Caneparo L, Meng Q, Guo W, Liu X. Physical environment study on social housing stock in Italian western Alps for healthy and sustainable communities. Land. 2023;**12**(7):11-24

[39] Zhang Y, Liu X, Meng Q, Li B, Caneparo L. Physical environment research of the family ward for a healthy residential environment. Frontiers in Public Health. 2022,**10**

[40] Li B, Zhang Y, Caneparo L, Guo W, Meng Q. Energy use in residential buildings for sustainable development: The fifth Solar Decathlon Europe revelations. Heliyon. 2024;**e30701**:30-34. DOI: 10.1016/j.heliyon.2024.e30701