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RESEARCH ARTICLE

Design method based on modularization and customization for rural dwellings: A case study in Nanjing, China



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Abstract Rural dwelling is a significant part of rural architecture, serving not only as a place for residents to live and conduct a variety of activities, such as agricultural work and gathering, but also as a representation of local history and culture. However, rural residents usually lack professional guidance when constructing houses, and their requirements for dwellings are not fully consistent with local policies. In this paper, a systematic design method based on modularization and customization was proposed, which can satisfy the residential needs within the constraints of the policy, and protect the continuity of the architectural culture while enhancing the living comfort. With the current situation of the settlement analyzed and the residents being researched, the modularization and customization designing approach was adopted to develop a flexible atlas of house types that can fulfill various demands of the residents. This method was initially applied to the Longchi area in Nanjing, China, which was highly recognized by local residents, providing a new strategy for future rural settlement planning and dwelling design.

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1. Introduction

Different from urban dwellings, rural dwellings are not only places for families to live, but also centers of agricultural operations. Rural dwellings from a specific time period reflect the lifestyles of the residents while also being intimately tied to the climate, history, and cultural heritage of the region (Ríos-Vizcarra et al., 2025). The evolution of rural dwellings provides an invaluable material for the research of regional history and culture. With the development of society, the production and lifestyle of rural residents have changed a lot, while traditional buildings built over time no longer satisfy current living standard (Rashid and Ara, 2015; Zhang et al., 2022). On the other hand, the planning for the countryside from the local government is not entirely consistent with the spontaneous residential construction of the residents. The problem that how to balance the overall planning with the expectations of the dwellings, while maintaining the architectural and cultural continuity, is urgent to be solved. Therefore, various researches on rural dwellings have been conducted.

Rural dwelling, which is an essential part of rural architecture, is also a symbol of regional culture. Researches have been conducted on the architectural continuity of rural settlements in different regions over the world. While most of them have been conducted in developing countries in the Eastern Hemisphere. The reason was, with the expansion of urban boundaries in developing countries, villages were gradually being incorporated into urban areas and traditional dwellings were experiencing problems of preservation and development (Chen et al., 2011; Dong et al., 2022; Gocer et al., 2021; Li et al., 2022; Wang et al., 2023). The architectural continuity of rural dwellings was analyzed by Olczak et al. (2022), who quantified the methods and variables used to assess the continuity of the dwellings, helping to inherit regional characteristics and maintain the diversity of architectural culture.

In the process of rural residential evolution, the constraints and guidance of local policies have had a significant impact (Donovan and Gkartzios, 2014; Erickson and Roberts, 1997; Katapidi, 2021; Sullivan and Ward, 2012; Ward et al., 2011). Six typical cases in the Irish region were selected to investigate the interaction between the development policies and residential planning policies in the countryside (Gkartzios and Scott, 2010, 2013). Based on the status quo of hollowing out of the countryside, and using the rural areas of Henan Province in China as an example, discussed the two typical homestead consolidation and allocation schemes in rural China were discussed, with a development mechanism involving villagers should be formed proposed (Li et al., 2014). The research on rural planning policy provides suggestions for rural land resource management and helps to realize the effective integration of land use, environmental protection and economic benefits in rural areas.

During the fieldwork in southwestern China, it was recognized that rural residents had little contact with architectural experts, so when they decided to redesign their homes, they were often left with only broad guidelines, which may even be misinterpreted (Pitts et al., 2019). This

phenomenon is widespread and therefore more specialized guidance is necessary. Considerable analysis has also been carried out on the planning and design of dwellings in different rural settlements, and locally adapted solutions have been proposed. A case study of a large-scale settlement in Turkey with traditional characteristics was present in terms of both the structure of the settlement as a whole and the organization of the internal spaces of the dwellings (Bekleyen and Koekmaz, 2013). While Erem et al. (2016), on the other hand, pointed out the mismatch between the original pattern of Turkish villages and the present lifestyle in response to the phenomenon of the demise of local architecture associated with social development. A parametric shape grammar method is proposed to enable residential design to adapt to the current environment and to ensure the continuity of residential building culture. By studying rural dwellings in four settlements, the problems in land planning and housing patterns were analyzed, and corresponding measures were proposed (Polat and Olgun, 2004). With the traditional rural dwellings in Cyprus with typical dwellings published by the local government, a design method was proposed that considered the natural environmental conditions, the mode of production, the experience of living in the dwellings, and architectural and cultural sustainability (Günçe et al., 2008). These studies have provided new ideas for bridging the gap between local architecture and globalized contemporary architecture. Bański and Wesolowska (2010), in turn, investigated the impact of residential construction on rural settlements. Obtained information about the impact of newly built residences on the living conditions of rural inhabitants, summarized the typical appearance and aesthetic characteristics of residences, and also studied the factors that influence the diversity of the number of residences and their structures. It shows the development direction of residential construction. Typical appearance and aesthetic characteristics of dwellings were summarized, and factors affecting the number and structural diversity of dwellings were investigated. These extensive studies have indicated the direction of development of residential construction.

Furthermore, with the development of science and technology, more techniques used to improve building performance and enhance living comfort have been used in rural dwellings. Among them, passive design strategies have been frequently applied in research to reduce building energy consumption (Asadi et al., 2016; Wang et al., 2023; Zhang et al., 2022). Based on the local climate, targeted design methods have been introduced in different regions to improve the built environment. Taking a rural settlement in Egyptian as an example, the characteristics and typical types were analyzed, and three envelope retrofit measures were compared (Abouaiana, 2021). It was found that the optimal one of the retrofit solutions could reduce energy consumption and carbon emissions by about 40%. Bioclimatic analysis was also a useful method to help better design, that local land and water resources, renewable energy sources, and ecological regeneration were taken into consideration when passive design was performed (Bera and Nag, 2022; Bera et al., 2023; Shi et al., 2012).

Research on several aspects of rural dwellings has contributed to improve the planning and design of rural

settlements. However, the majority of published studies simply give generic recommendations, which failed to guide residents effectively in their construction. While some targeted design solutions typically picked only one or a few dwellings in a rural settlement, which was limited and did not adequately address the demands of local residents. Moreover, when providing guidance for the construction of dwellings, there was a difficulty with resident engagement and the construction program was not flexible enough to be adapted to rural dwellings with different geographical characteristics. Consequently, a systematic method for planning and designing rural dwellings was proposed in this paper to fill this gap by incorporating local legislation, architectural culture continuity and demand of residents.

In this paper, Longchi area was taken as a case study to investigate the evolutionary of planning and design methods in rural China. The paper began with a policy analysis that summarizes the characteristics of rural dwellings construction in different periods, including their respective benefits and drawbacks. In the next section, basic information about Longchi area was presented, followed by the introduction of a new approach for planning and designing rural dwellings, which incorporated local policy, maintained architectural culture continuity, and met the needs of residents. Next, the process of applying this method to Longchi area was described in detail; field research was conducted, the local architectural culture was studied, and the distribution of the settlement as well as the characteristics of the local traditional dwellings were summarized and presented. In addition, the structure of residents was obtained through interviews and questionnaires, and requirements of the residents were carefully considered to optimize the design. It is worth mentioning that the modularization of function rooms contributed to promoting the utilization and flexibility of space, and together with a menu-based customization approach on structure components, increasing the participation of residents in design process. And through this method, the experience and guidance of the experts can also be translated into an intuitive form that is more easily understood and practiced by the rural residents. In the last section, some typical house types designed for Longchi area derived from this new method were discussed. However, they are only the sample, as more design solutions can be quickly realized according to specific demand, and this method can be applied to different regions to provide effective guidance for rural dwellings construction.

2. Policies for rural dwellings construction in China

Since the economic reforms of 1978, rural areas in China have undergone transformative changes in both socio-economic conditions and land use patterns, and urbanization has led to the migration of large numbers of rural population into cities (Ding and Ma, 2020; Qi et al., 2021). The decline of rural communities as a result of out-migration is a global phenomenon, and rural areas in the developed countries have also experienced declines in rural populations (Hoggart and Paniagua, 2001; Loblely and Potter, 2004; Nelson, 2001; Smith, 2025; Woods, 2005). The urbanization

rate of China increased from 17.9% to 63.08% (Hu et al., 2023), during which the main focus of construction has been placed on cities, with very little investment in rural buildings and village renewal. The main direction of infrastructure investment in rural China is residential construction. In 2023, rural dwellings investment accounted for 41.3% of the fixed assets investment of rural residents (Luo et al., 2025). Comparison of the area of completed buildings and completed dwellings in rural China in recent years revealed that dwellings have always accounted for more than 90% of rural construction, occupying an absolutely dominant position (Gao et al., 2022; Liu et al., 2025; Long et al., 2016). The long-term urban-rural dual structure and economic backwardness have caused rural construction to lag far behind that of urban areas. Wide distribution, large construction volume, low economic level, deterioration of ecological environment, lack of infrastructure, weak construction management, and serious waste of land are the most prominent and urgent problems facing rural construction in China (Tan and Li, 2013).

After liberation, as farmers' productivity increased, the construction of self-built dwellings in rural areas entered a boom. Craftsmen with local or blood ties and experience in construction were invited by residents, sometimes even constructing by themselves. Unlike traditional rural buildings, new materials and structures such as concrete and hollow bricks were commonly used, but the whole construction was in an unorganized state, and the dwellings built were of various forms.

Under this construction method, the location of homestead was usually random and decentralized to facilitate the daily production and living of the residents, resulting in an obvious waste of land use. Due to the low professionalism of the craftsmen or construction teams, the quality of the built dwellings also suffered to varying degrees. In addition, due to the independent construction, coupled with the lack of facade design regulation, the style of each dwelling was different, which was detrimental to the overall appearance of the settlement and was not conducive to maintaining the continuity of regional architectural culture. Despite these problems, residents were generally keen to build houses on their own, which was not only because they were more familiar with traditional construction procedures, without paying for the information, as well as the agreement on the payment of labor was low-cost and easy to reach in the verbal contract form; but also because the blood and geographic ties made it easier for residents to communicate with craftsmen to express their needs.

Since the 21st century, governments have become more involved in the construction of rural dwellings, mainly through the integration of development, design and construction. Policies, funds, personnel and technical support were provided by the government, and the builder was entrusted with the construction of the dwellings. Professional institutions were organized to carry out unified planning for rural settlements, the homestead area was controlled strictly with the principles of protecting arable land and intensifying land use. This regulation method was conducive to the intensive use and management of rural land, and also contributed to reducing the cost of public facilities with the concentrated dwellings. Compared to the self-built method, the participation of government in

organizing and coordinating the all parties in the entire process greatly reduced the burden of residents, and problems such as poor quality can be solved. However, the excessive pursuit of uniform design styles usually resulted in the lack of regional characteristics, and even destroying the texture of the rural area, disrupting the continuity of local architectural culture. Moreover, residents were often in a passive participation position, difficult to express their personal needs.

A more common and advanced management approach is the development of universal design atlas to regulate the rural dwelling construction. Residents can select construction plans from the atlas and then apply for government permits, which reduces irregularities during the construction and the quality of dwelling is improved. However, there are usually few options to choose from, failed to meet individual demands, and the house types given were not flexible enough to accommodate possible changes in room function in the future. Moreover, the lack of follow-up systematic guidance and support puts the residents with atlas distributed in a passive position of adaption.

Review of the evolution of management policies for rural dwellings in China revealed that the individual demands of residents should be taken into consideration to optimize universal design atlas put forward recently. Local architectural culture ought to be preserved as well, which requires the involvement of professionals. Diverse choices are expected to satisfy various living needs of the residents. In addition, deeper participation of residents in the construction process should be realized, equipped with systematic guidance from experts.

3. Research design and investigation process

3.1. Case study

In this project, Longchi area was chosen as a case study for rural dwellings planning and design. As indicated in Fig. 1,

the Longchi area is located in Luhe District, Nanjing City, Jiangsu Province, in the northernmost region of Nanjing, with Anhui Province to the northwest. The area contains 38 communities, some of which are ancient with historical conservation significance. Located along the gorgeous Chu River, the region has developed rural tourism industries such as hotels and restaurants.

Since Longchi is a low-gradient hilly location with a humid and rainy climate, there is a high density of buildings, thus patios and courtyards were frequently built in old buildings to form a temperature adjustment system alongside alleyways and back lanes. Located at the boundary of the north and south of China as well as the junction of two provinces, Longchi area has been divided into several administrative districts over the course of history, resulting in the establishment of an eclectic architectural culture in this area. The historical buildings are distinguished by the majestic style of Huizhou architecture and the beauty and delicacy of Jiangnan architecture. At the same time, it is also influenced by the canal culture and incorporates the beautiful and elegant qualities of northern architecture.

A field study conducted in Longchi area revealed that the existing rural dwellings were built in a variety of styles and at different times. According to the date of construction, the dwellings can be divided into three categories shown in Fig. 2. The first category was the houses built before the 1980s, which mostly consist of single-story buildings with brick walls that were decorated in the same way as the old buildings. However, these dwellings were rare and often abandoned, with the majority of them suffering from leaky roofs and cracked walls. The second group of dwellings, constructed at the end of the twentieth century, were primarily two-story structures, the majority of which were completed in cement mortar, with a few finished in gravel and shattered glass. Furthermore, the majority of them were ornamented with precast concrete patterned components. However, the façade of these buildings had deteriorated,

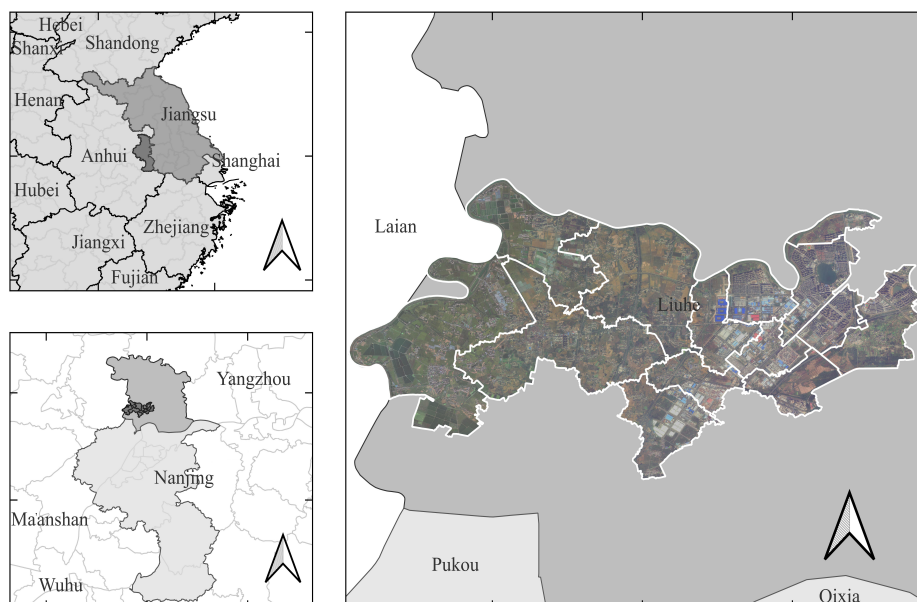


Fig. 1 Location of Longchi area.



Fig. 2 Three categories of the local dwellings.

and the interiors were inadequately furnished. The third category included dwellings that were freshly constructed or refurbished in the twenty-first century. However, the form and construction quality of them were inconsistent, and there was a general lack of regional cultural characteristics among these newly dwellings, appearing out of place in the setting of the old buildings.

In the course of the research, it was found that local residents have the will to build or renovate new homes, but self-built houses without professional design may have the problems such as significant waste of space, and appearance that varies greatly depending on the preferences of different residents. Therefore, an atlas of rural dwellings can provide local residents with guiding opinions based on their needs when building houses, and it can also aid in the overall planning of rural areas, promoting the modernization of rural areas and the development of new industries such as tourism and modern agriculture.

3.2. Method

When planning and designing the dwellings in rural areas, the local historical and cultural background should be investigated first, so that the final design can be fitted to the local architectural style. By analyzing the geographic information,

the basic parameters of the typical homesteads and residential buildings were obtained. The field research was conducted to figure out the living needs of local residents. Different functional rooms in the residence were separated into different modules, which were then integrated to create the basic residential form that met residential needs. Finally, the typical house types suitable for different families were obtained through the design, which can be adjusted according to the demands of the residents. The complete process of this method was illustrated in Fig. 3.

- Historical and cultural background research

Historical and cultural background studies and field research were conducted, with a focus on the unique traditional architectural traits, including the courtyard type, building structures, decorative symbols and other dimensions. Moreover, the impact of local climatic conditions on residential design was investigated.

- Geographic information analysis

The geographic information of the existing rural dwellings was collected and analyzed using satellite images and GIS platforms, providing a data foundation for the overall

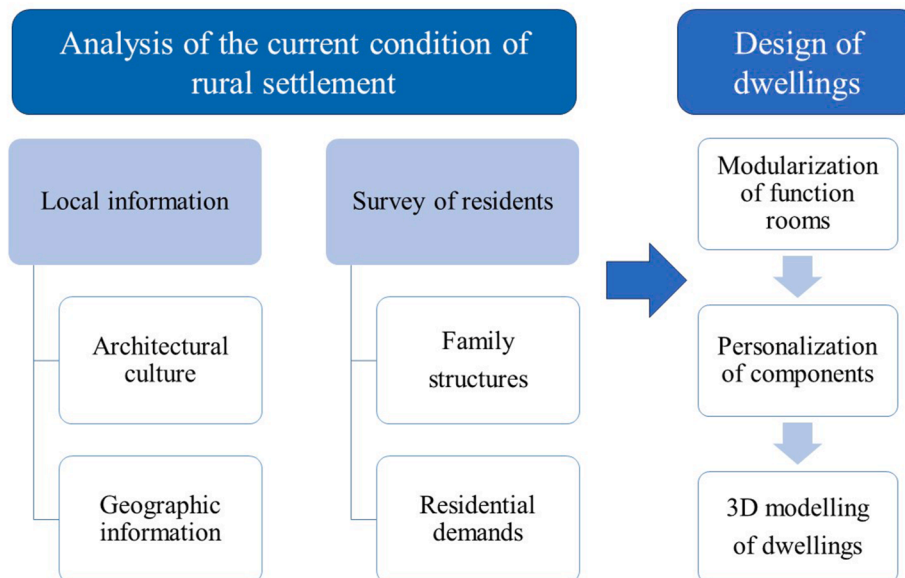


Fig. 3 Workflow of the proposal for planning and designing rural dwellings.

planning of the settlement and the design of typical rural dwellings. The primary rows of residences in the rural settlement, as well as their relative placements in relation to adjoining roadways, were determined from a regional planning perspective. In terms of dwelling designing, the geographic information such as shape and area of the homestead, the floor area, building density, plot ratio and other parameters was analyzed.

- Survey of demand of the residents

Questionnaires were distributed to assess the household demographic structure of the residents and their preferences for the style of dwellings. Different populations result in various needs for functional rooms within the house, while even with the same population size, differences in membership can cause needs to fluctuate, which is a factor that must be taken into consideration when designing. The preferences of the residents for dwelling styles were studied and summarized.

- Modularization of functional rooms

Modularization designing was conducted on the rooms within the dwelling, which were categorized according to the function, with each type of room as a set of modules. For the same sort of functional room, multiple modules were designed according to sizes and living habits associated with the specific structure of the family. Different modules were selected and combined together to form a basic house type.

- Personalization options

Components used in dwellings can be selected by residents, such as doors, windows, walls, eaves, decorations and so on. A library of components designed following the specific style was prepared, in which various forms, colors, materials and techniques were present. And the menu-based customization approach was devised based on the particular needs.

- Design of typical house types

The design of rural dwellings was based on the style preferred by the residents. Once the functional modules were assembled, factors such as the shape and size of the homestead, the floor area, the way in which the building was combined with the courtyard, the way in which the dwelling was accessed from the road, the number of floors of the dwelling, and the purpose of use were also considered in the design. It is worth mentioning that the design of the house type also needs to reserve space for future renovation due to changes in family members or purpose of use.

4. Results

4.1. Characteristics of traditional rural dwellings

The overall style of Longchi area was grand and exquisite, with the distinctive shapes of each component depicted in Fig. 4. The plan division and façade decoration emphasize the symmetrical and clean layout. Colors used include white, dark yellow, and grey on the walls, maroon mixed paint on the wooden frames, and red and cyan on the brick walls.

The traditional dwellings typically had a two-sided sloping roof structure. Roofing materials included tiles made of various materials, mostly small green tiles, followed by flat tiles, as well as thatched and glazed roofs. The eaves of the homes were picked off, leaving space beneath them. And the gable was generally decorated with brickwork made of red and green bricks.

In local traditional dwellings, the wall higher above the roof was known as the mountain wall, served as both windproof and fireproof. The traditional eaves can be divided into three types: no-eave, stacked eaves, and multi-eave horse-head walls. While the multi-eave horse-head wall type has been widely used in the residential houses in Jiangnan area. With the outline stepped, the length of the eaves ridge varied with the depth of the house.

Doors can be categorized into courtyard doors and entry doors according to their position. Local courtyard doors

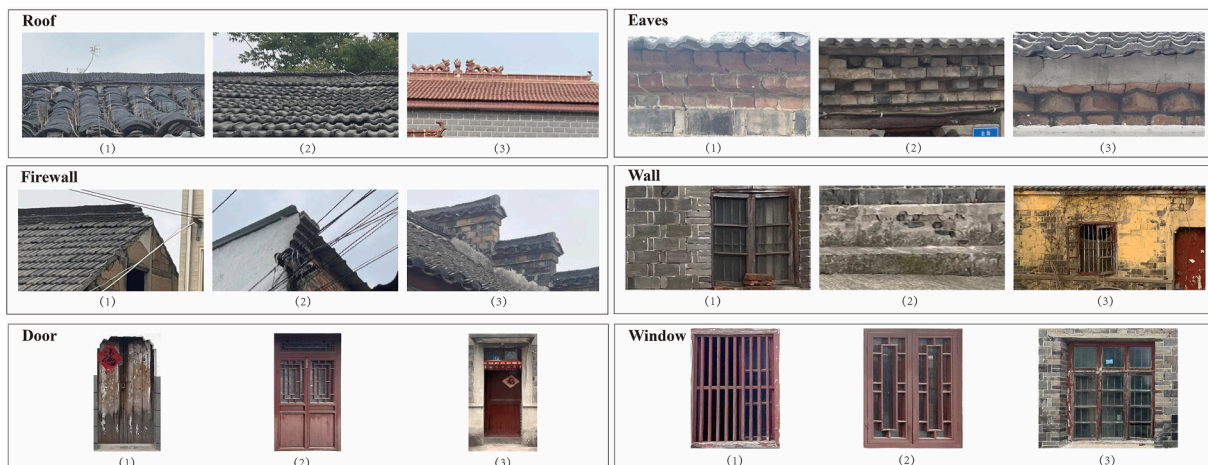


Fig. 4 Traditional forms of rural dwellings in Longchi area.

typically lacked door heads. Some of the entrance doors were decorated with openwork window panes and positioned on the floor, serving as both windows and doors, allowing for lighting and ventilation. While windows often featured some kind of pane pattern locally, they were ornamented with numerous straight lines and squares that formed a consistent geometric design.

4.2. Regulations of local government

The local government have issued clear plans and restrictions for rural residents to build houses. According to government documentation, villages could build residences with less than three stories, a story height of 2.8–3.6 m, and a floor-to-ceiling height of at least 2.5 m. In terms of size, since each homestead varied in shape and size, there was no consistent definition of homestead size. Generally, the homesteads were long north-south and narrow east-west. In terms of area, the original homestead, which was less than 135 m², was allowed to be expanded to 135 m² when a new house was built. While those in excess of 170 m² must be reduced to 170 m². A middle-of-the-road homestead required no alterations. Furthermore, the floor size was determined based on the number of family members in each household. A household of three or fewer people had a floor size of no more than 150 m², a four-person household no more than 200 m², and a five-person household no more than 250 m².

4.3. Geographic information analysis

The ArcGIS software was used to collect and analyze the geographic data of Longchi area. Satellite maps were used

to extract the homestead and building plots of all rural dwellings in Longchi area, and several sets of parameters, such as floor area ratio, floor area, building density, homestead area, and homestead shape factor of each household, were calculated and analyzed to summarize the typical characteristics of rural dwelling plots in the Longchi area. The results were shown in Fig. 5. Furthermore, the distribution among homesteads, as well as the distribution of homesteads and country roads, were evaluated to offer support for the design of the entry method and the connection between different rural dwellings, which were shown in Fig. 6.

4.3.1. Parameters of homesteads

It was revealed from the geographic data that the building density of rural dwellings in Longchi area was primarily between 30% and 70%, which was consistent with the local government’s restriction that building density should not exceed 70%. The most concentrated range was between 50% and 60%. In addition, there were also a lot of dwellings with a building density of 90%–100%, with a homestead area of less than 50 m² generally. As for the floor area, the rural dwellings in Longchi area were mainly distributed in the range of 120–320 m², with the majority of households having a floor area of 200–240 m², implying that the demand for floor areas of 200 m² and 250 m² will be greatest in the construction of new dwellings.

Correspondingly, the distribution of homestead area was concentrated in 150–400 m², with 250–360 m² being the majority, significantly exceeding the government restrictions for newly distributed homesteads, which must not exceed 135 m² per household standard. And the number of homesteads with the area less than 150 m² was 1779,

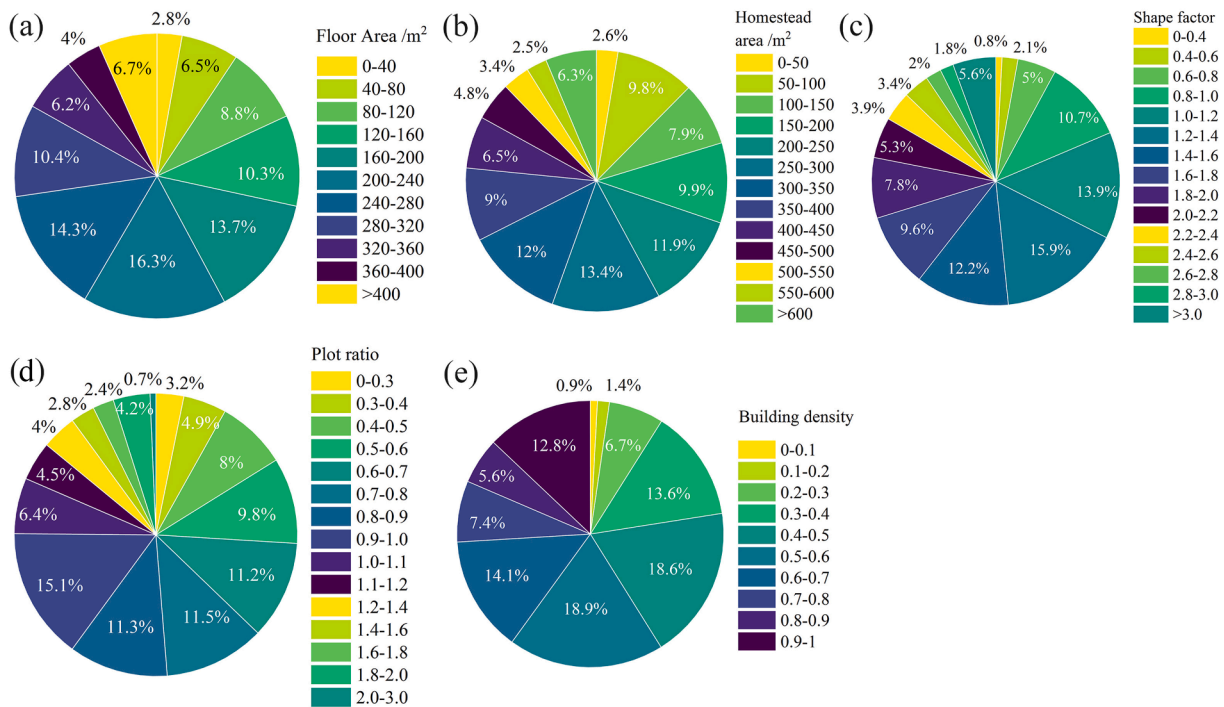


Fig. 5 Geographic information: (a) floor area, (b) homestead area, (c) shape factor of homestead, (d) plot ratio, (e) building density.

Forms of homesteads



Fig. 6 Typical forms of distribution of dwellings.

accounting for only a small portion of the Longchi area, indicating that the majority of homesteads will be reduced when new dwellings are constructed, which was because the fact that the tightness of the rural land resources, making more efficient land use methods proposed. Moreover, the relationship between the shape and orientation of the homestead was determined by evaluating the shape of each homestead and calculating the ratio of the north-south to east-west distances. Homesteads with a shape factor of less than 1 have a wider east-west width, those with a ratio of more than 1 have a longer north-south depth, and those with a ratio of approximately 1 have a square plot. According to the data, the shape of the rural dwellings in the Longchi area was dominated by a long north-south and a short east-west orientation, which contributed to natural light in the buildings.

4.3.2. Distribution of rural dwellings

The existing dwellings in the Longchi area can be divided into two categories based on how the buildings were arranged: townhouses along the road and detached houses in the fields. In turn, the distribution of dwellings and roads can be classified based on the various orientations. The main guideline of facing north to south was followed when building residences in the countryside, but the difference in the orientation of the nearby roads resulted in the emergence of diverse ways of approaching the building.

Using satellite maps, various important types of homesteads and buildings distribution in the Longchi area were summarized. The first were isolated buildings in the fields that were not surrounded by other dwellings, so they were usually close to square and had a bigger floor area. These residences were entered from the south yard, and in certain cases, if the homestead was far from the main rural roads, the pathway in front of the compound was paved to lead to it. In turn, townhouses can be further categorized based on changes in surrounding roadway alignments. For residences near east-west roads, the south yard entry was usual; nevertheless, some homesteads with roads in front and behind may choose a dual north-south approach. For

dwellings near north-south roadways, the gate was typically situated on the side.

4.4. Information on the residents

A questionnaire was distributed both online and offline to residents of eight settlements in the Longchi area, which covered the family structures, the living habits, and the demands of the residents in terms of the functionality and style of their dwellings. A total of 269 valid samples were received and the results were displayed in Fig. 7.

According to the survey, the majority of households in the Longchi area had a resident population of three, accounting for 34.8% of the total number of households. Since the floor area of a dwelling was associated with the number of persons in a household in the regulations issued by the local government, the household structure of the residents of the Longchi area can be classified into three types based on the floor area of the rural dwellings. That is, families of three persons or less with a floor area of 150 m² or less, households of four persons with an area of 200 m², and households of five persons or more with an area of 250 m². However, even in families with the same number of people,

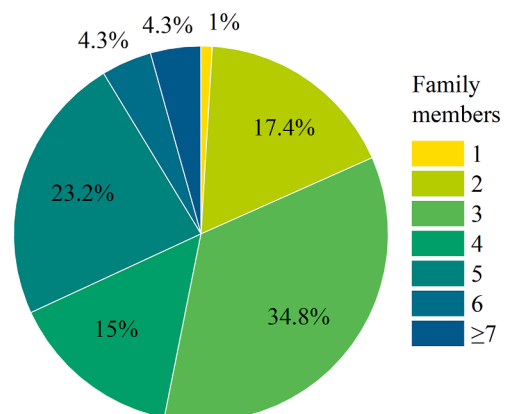


Fig. 7 Analysis of local family members.

the ages of the members can have a significant impact on the need for functional rooms. Taking a three-person family as an example, a family with a couple and one child would require only two bedrooms, whereas a family with three generations of young and old would require three. Families with elderly members also need to give special consideration to age-friendly design.

The functional rooms in current dwellings were investigated and the basic functional rooms needed for a particular structure of home were summarized. The difference in the number of functional rooms corresponding to different structures was most noticeable in the bedrooms, followed by the baths, but the number of living rooms and kitchens was often stable. The number of bathrooms necessary for different families varied mostly based on the number of members, with only one bathroom required for households of three or fewer, two for households of four, and three for larger, more complex structures of five or more, as indicated in Eq. (2). While the number of bedrooms varied significantly. A simple equation relating family structure to the number of bedrooms was summarized in Eq. (1). And x is the number of elderly members in the family, y is the number of middle-aged members, and z is the number of young members, including children. A rural family normally includes no more than two elderly people, so the maximum number of bedrooms required is one, or none if there are no elderly members. The number of bedrooms estimated by this relation may not be an integer, hence the ultimate number of bedrooms is determined by the largest integer that does not exceed the result, as shown in Eq. (1). The total number of functional rooms that can satisfy the basic living needs of the family is the sum of the number of bedrooms and bathrooms plus four, which equals the number of the kitchen, dining room, living room, and the central room. Using this method, the basic functional rooms required for various family structures can be easily obtained, providing guidance for the design of dwellings appropriate for diverse families.

$$n_{bed} = \begin{cases} \left\lfloor \frac{y+1}{2} + z \right\rfloor, & x=0 \\ \left\lfloor 1 + \frac{y+1}{2} + z \right\rfloor, & x \neq 0 \end{cases}; \quad (1)$$

$$n_{bath} = \begin{cases} 1, & x+y+z \leq 3 \\ 2, & x+y+z=4; \\ 3, & x+y+z \geq 5 \end{cases} \quad (2)$$

$$n = n_{bed} + n_{bath} + n_{cen} + n_{liv} + n_{kit} + n_{din}. \quad (3)$$

The summary of the specific family structures and the functional rooms required correspondingly were listed in Fig. 8.

The questionnaire results shown in Fig. 9 revealed that in rural locations, the living room was the most important space within the residence, followed by the courtyard, where most daily activities such as meeting guests, resting, and conducting farm work took place. And expectations for a given functional room varied among the residents. For the living room, which is the most essential room in the house, 76% of residents wanted it to be large enough to host large gatherings, as well as sufficient lighting and south-facing

windows and doors. In terms of bedrooms, 72% of residents desired the master bedroom to be equipped with a toilet, whereas master bedrooms with a cloakroom, adequate lighting, and privacy were also emphasized. While sufficient ventilation was the primary demand for both kitchens and toilets.

Due to the rural location, agricultural demands must also be considered when designing dwellings. 66% of residents suggested the requirement for outside space for drying crops, which is often done in the yard. In addition, over half of the residents required a separate room to store food or farm equipment. Furthermore, the growing tourism business in the Longchi area has led inhabitants to desire the commercial component of their dwellings. Nearly 55% of them expected business space, with 37% wishing to transform the houses into B&Bs with eating, entertainment, and residential services; grocery stores and restaurants along the street were also popular possibilities. Several residents also wanted to run a private nursing home within the dwellings.

In terms of architectural style, 82% of inhabitants favored a simple modern design, with a minority percentage choosing a Western or opulent dwelling. It is worth mentioning that the dwellings to feature traditional components and regional characteristics were expected by some residents.

4.5. Modularization of functional rooms

The rooms in the dwellings were organized into seven categories based on the needs of residents and their long-term living habits, with each category consisting of a set of modules. Central rooms, living rooms, bedrooms, kitchens, studies (for certain families, the study module might serve as a storeroom for storing food or agricultural equipment), bathrooms, and stairwells were the seven functional module categories. Each group of modules had components with various sizes and arrange forms from which residents can select. Constrained by length, the central room, bedroom, and kitchen modules, which were the most typical function rooms in rural dwellings, were chosen as examples for the specific description of functional rooms modularization in this paper, as shown in Fig. 10.

The central room, which is a unique functional space in rural dwellings, is located on the first floor of the house in the best direction. It is the core of the whole house, which not only has the functions of daily life and leisure and reception of guests that the common living room has, but also has the comprehensive place for ancestor worship and enshrinement of gods that is unique to rural areas. In some rural dwellings, the central room also doubles as a dining room. With the function of integrating the internal and external activities of the family, the central room is the most important functional and spiritual space for the residents. Unlike the efficient use of space in the living room, the center rooms were more formally arranged during the modularization process. The main door was usually set in the south direction, and facing the door was the table for ceremonial rituals, plus tables and chairs for gatherings or meals only in the center, with no other displays usually present. Therefore, unlike the living room, which had a large difference in width between the two sides, the center room was closer to square.

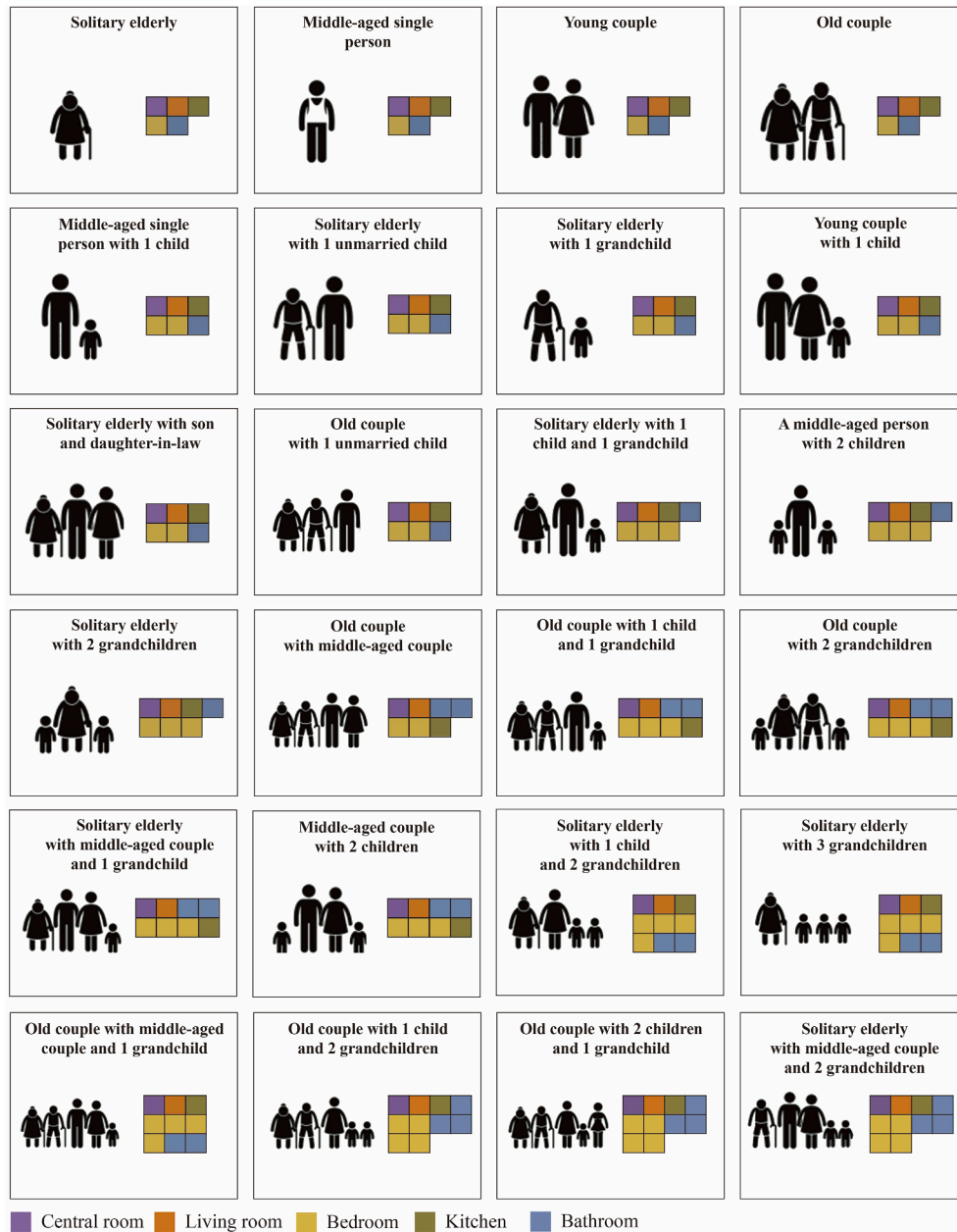


Fig. 8 Different family structures and the function rooms needed in correspond.

The bedroom module comes next, which was also designed in the south part within the dwellings with windows on the south wall to ensure natural light. Due to the aging of the rural areas, age-friendly design needs to be given special attention when designing rural dwellings. In the modularization, a separate module was designed for the elderly bedroom. Compared to a normal bedroom, the elderly bedrooms were equipped with a separate bathroom or at least a toilet for easier access. The layout was also more spacious, especially at the entrance of the room and on both sides of the bed, to ensure that there was enough width to allow the passage of wheelchairs. Moreover, the elderly bedroom should be placed at the first floor in general.

The most prevalent shape of kitchen in rural settlements was the north-south wide east-west short, which was solely

used for cooking. To better adapt to the usage pattern of standing and wandering in front of the cooktop, the north-south side of this module was significantly longer than the east-west side, resembling the scale of a hallway. A separate space was designed in a kitchen module, served as the storage room to stack firewood, crops or agricultural implements, and in some families, it may be used as a dining room.

It is worth mentioning that the modularization of functional rooms offers greater flexibility in the case of irregular homesteads than the ordinary design method. Since the spatial distribution within the residence was not a fixed whole but independent and assembled modules, the modular design can dynamically adjust the spatial form and connection when facing complex plot types. For example,

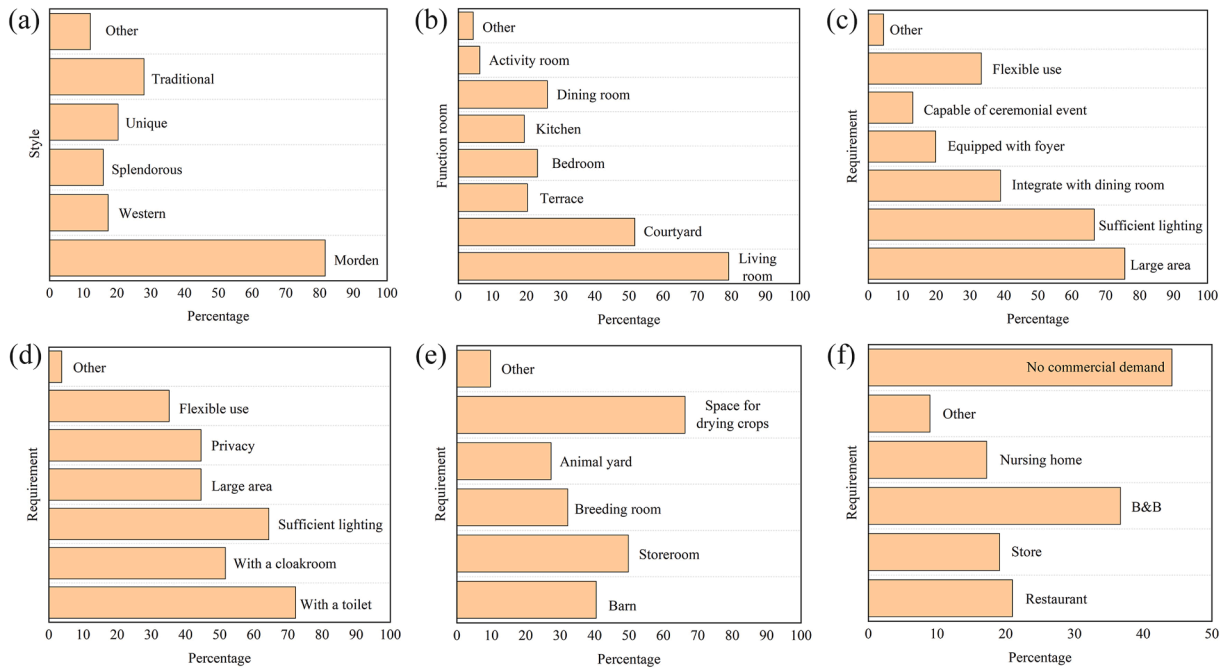


Fig. 9 Results of the questionnaire: (a) preference style of dwellings, (b) most important space in house, (c) requirements for living rooms, (d) requirements for bedrooms, (e) requirements for outdoor space, (f) requirements for commerce.

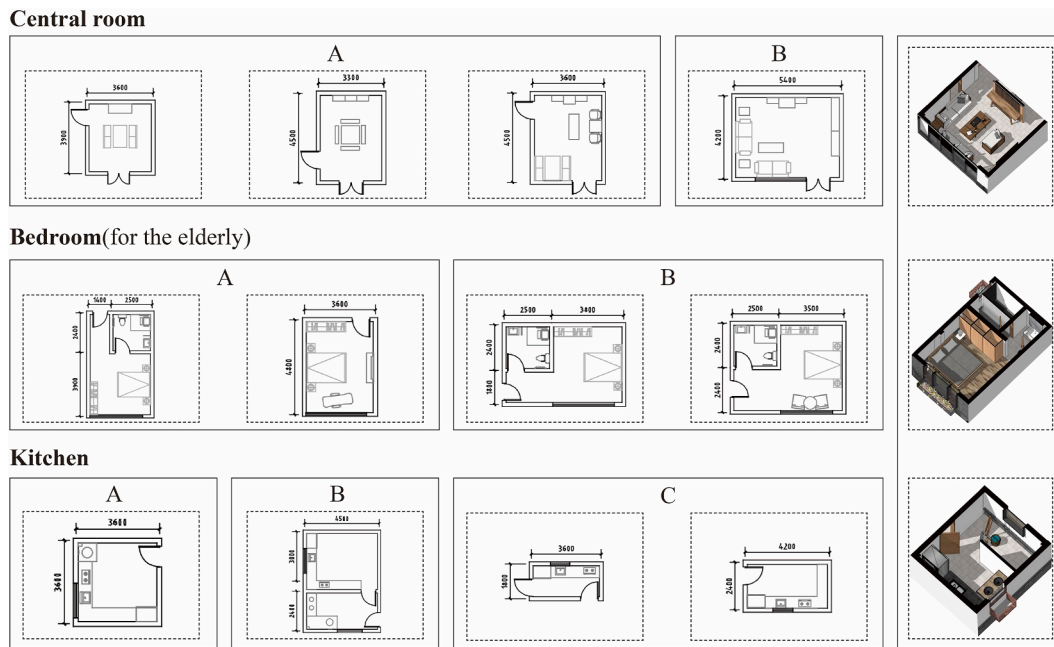


Fig. 10 Modules of the function rooms.

for non-rectangular plots, the modularization of functional rooms facilitates the splitting of plots, which enables the design method similar to that of regular ones. Modularization can effectively solve the problem of spatial fragmentation brought about by the irregular plot, and for ordinary homesteads, it also improved the flexibility of spatial use and the freedom of residents in spatial planning.

4.6. Customization of structure components

All the components used in the typical house types can be replaced according to the preferences and needs of the residents, increasing the adaptability of the atlas. A library of components in dwellings was generated, and a menu-based customization approach for the components was

devised based on various needs. The personalized components included doors, windows, walls, railings, patterns, and so on, a total of eight types of components, the styles, materials, techniques and other information of which were listed in advance, and the residents could choose the construction plan of different components by themselves after receiving the component menu. Typical characteristics of traditional houses summarized during the research were employed in the design of the components, as displayed in Fig. 11, to give them both modern craftsmanship and appearances which were more in line with the local culture.

The link between the new building components and the traditional components lied in the formal, material and symbolic transposition of regional architectural features. Formally, the new components abstractly reinterpret the main features of the local traditional buildings. The wall system inherited the structural logic of the hollow brick cavity wall through interlocking perforated masonry, retaining the double hollow structure while translating the traditional openwork decorative geometric patterns into a modern minimalist interface. The door assemblies, including solid wood gates and partition doors, retained the grand style of traditional courtyard entrances as well as the translucency provided by traditional lattice screens by simplifying the decorative carvings and adjusting the proportions. The window elements visually imitated the maroon wood grain of historic windows and doors. In terms of the materials, a mix of blue brick, red brick and cement mortar preserved the blue-grey, russet and beige tones, and modern hollow block components and frame construction have improved the thermal performance and structural stability. As for the decorative details, cultural continuity was achieved through symbols. Simplified geometric carvings on the plinth resembled the tiered gables of traditional eaves, and the diamond pattern used in traditional architecture was applied to the precast bricks, which together embed symbols typical of the local traditional architecture into the modern dwellings.

Rather than replicating ancient forms, these components evoked the historical memory through tactile materials, light and shadow interactions, and proportionality. Driven by technological evolution and aesthetic change, these new architectural components form an expression that links historical culture with contemporary residential style.

4.7. Design of typical house types

According to the needs of the residents, the modules of the various types of functional rooms were combined, and the customary habits were followed in the process of combination. The living room module was located in the center of each floor, with the other functional modules surrounded. The bedrooms were placed on the south side to ensure natural light, and the stairwells were positioned toward the middle for convenient access. Therefore, the combination of modules was the initial form of the residential building, which was then combined with courtyards and terraces to develop a specific type of rural dwellings fitting the homestead shapes.

Thirteen types of rural dwellings were designed for the Longchi area, with homesteads area of 135 m² and 170 m². Because the members in the family varied, the real floor area can be adjusted by altering the number of floors and yard area for the same homestead area. Each of these house types had unique characteristics, and the applicable scenarios varied depending on the style and size of homestead of each household as well as the demands of residents. The upper portion of Fig. 12 depicted the appearance and basic information such as the floor area, homestead area, and the suitable family structures, with the function modules and components used listed below. All of the house types were flexible and can be modified. In other words, the kind and amount of function modules can be altered, which was conducive to the application and promotion of the atlas. Following the design method, more

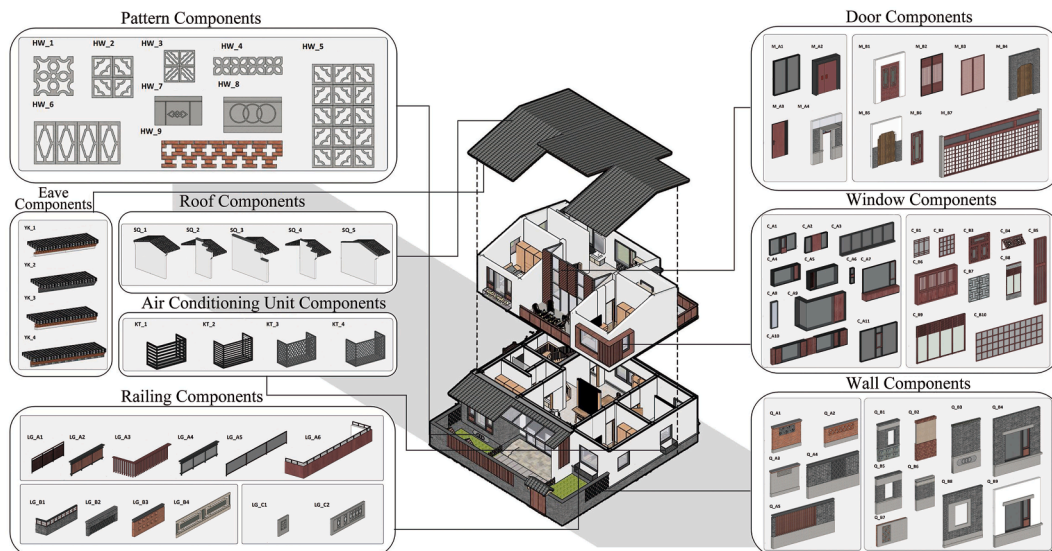


Fig. 11 Alternative components used in typical house types.



Fig. 12 Typical house types designed in the atlas.

house types can be developed efficiently than just those presented below.

4.7.1. Characteristics of the house types

First, there were three types of dwellings with a homestead area of 135 m² and a floor area of 95 m², designed for families of three members or less. With only one floor thus being easy to carry out various activities, Type 1 was suitable for families with two elderly people. Both Type 2 and Type 3 had two floors with the floor area of 150 m². The terraces were built on the second story in each, reserving space for future renovations. Type 2 was more adaptable in terms of usage, with more functional modules that inhabitants could modify from the original dwelling, while Type 3 had greater space for activities within rooms.

Types 4 to 10 were dwellings designed for three to four-person families. With two floors, Types 4, 5, and 9 have 135 m² of homestead area and about 200 m² of floor area. Type 4 was a detached house located in a field with a good view and a courtyard on the side, which was convenient for

planting or setting up farm equipment. Due to the constraints of the adjacent dwellings, the storage role fulfilled by the side courtyard in Type 4 was transferred to a separate storage room in Type 5. Type 9 featured a smaller footprint and large courtyards on both the east and west sides of the building since it was designed for homesteads that are wide from east to west but shallow from north to south. Being adjacent to a north-south roadway, the south side of the building was usually shaded by the nearby buildings, and more outdoor space would contribute to increased light for the building.

With three floors but the same floor area of 200 m², Type 7 and 8 had a larger outdoor space for diverse activities than the previous types. The courtyard of Type 7 was located in the center of the homestead, separating the front and back buildings, which were linked by a corridor. The one-story structure in front can be utilized for business purposes, whereas the three-story building behind was designed for residential usage. Type 8 included spacious terraces on each floor for outdoor activities and to preserve space for future

renovations. Moreover, the first floor features a large living room for gatherings. These qualities also made Type 8 suitable for renovation as a B&B. With the same characteristics as Type 8, Type 6 had only two floors, indicating that it required for a larger homestead area. Large terraces were designed on both the north and south sides to be used as sunrooms.

Finally, there were Types 11, 12 and 13, designed for families of five or more persons and were three-story dwellings with 170 m² of homestead area and 250 m² of floor area. Types 11 and 12 were narrow from east to west and long from north to south, while Type 13 was almost square and suitable for locations with low building density. The functional modules of Type 11 were designed to be more in line with the living habits of rural residents, with a large courtyard on the south side for agricultural activities such as planting and drying, as well as for parking. Type 12, on the other hand, was specifically intended for people who desire to operate a B&B. The stairwells were positioned in the middle of each floor, usually where the living rooms were located. The remaining room modules on either side of the stairs remained only served only basic functions, such as bedrooms, bathrooms, kitchens and dining rooms. The wider southern side enabled Type 13 to receive more light, and a large terrace with a nice view was designed on the third floor to take full advantage of it.

4.7.2. Energy consumption indicators

Analysis was conducted of the thirteen typical house types in terms of energy consumption. The shape coefficient of building and the area ratio of window to wall for each orientation were chosen as indicators for performance evaluation.

The shape coefficient of building, defined as the ratio of the exterior area of a building in direct contact with the outside air to the volume it encloses, is an important factor that influences the energy consumption of a building. As the shape coefficient of building decreases, the exterior area per unit of building volume decreases, and the resulting heat loss from the envelope decreases. The area ratio of window to wall is the ratio of the total area of exterior windows in one orientation to the total area of exterior walls in the same orientation. Generally speaking, a larger area ratio of window to wall means more building energy consumption. The indicators were calculated for each house type and the results were presented in Table 1.

The majority of the house types had a shape coefficient of less than 0.5, which was reasonable given the climate of hot summer and cold winter in Longchi area. Among them, type 10 has the smallest shape coefficient due to the nearly square plot. Similarly, among Types 11, 12, and 13, which all had a homestead area of 170 m² and three stories, Type 13, with a square building layout, had the lowest shape coefficient of building. Type 7, on the other hand, had a significantly higher one than the other house types, owing to its design objective of having a store at the front and a residential at the back, which resulted in a considerable increase in the total surface area of the two buildings connected by a corridor. And Type 11 also had a particularly high coefficient due to its complicated shape.

Observing the area ratio of window to wall of the various orientations of each house type, it is clear that the design concept of making full use of south-facing light increased

Table 1 Indicators of each house type.

Type	Shape coefficient of building	Area ratio of window to wall			
		South	North	East	West
1	0.388	0.306	0.186	0.022	0.032
2	0.421	0.398	0.266	0.086	0.133
3	0.394	0.418	0.391	0.122	/
4	0.453	0.426	0.102	0.257	0.158
5	0.413	0.424	0.082	0.070	0.060
6	0.420	0.308	0.380	0.111	0.045
7	0.541	0.313	0.213	0.070	0.085
8	0.440	0.440	0.297	0.165	0.131
9	0.430	0.298	0.083	0.130	0.244
10	0.369	0.387	0.171	0.075	0.136
11	0.519	0.397	0.222	0.111	/
12	0.476	0.448	0.141	0.105	0.073
13	0.427	0.372	0.327	0.126	0.037

the ratios of south-facing facades over those of other orientations. This was especially noticeable in the house types with huge south-facing floor-to-ceiling windows, such as Types 8 and 12. All house types satisfy the window-to-wall area ratio for residential buildings in hot summer and cold winter climate zones. The area ratios do not exceed 0.45 for the south orientation, 0.4 for the north orientation, and 0.35 for the east and the west orientation. It is worth mentioning Type 9 had a much higher area ratio in the west direction than the other types. Because it was designed for a homestead adjacent to a north-south road, meaning that the gate of the dwelling was situated to the west, resulting in a bigger window area.

4.7.3. Flexible space

It was demonstrated by the field research that the needs of rural residents for functional rooms may fluctuate over time. Changes in family lifestyles and populations might impact the kind and number of functional rooms in a house. Therefore, the designed dwellings were not completely constant, while the functional modules could be modified according to the residents. Using the mathematical models obtained in the previous section, the basic functional modules of the thirteen house types were counted. Since the family structures suitable for a particular house type were diverse, and thus the basic modules required were different, the least required modules were identified. With the basic functional modules determined, what remained was a space that could be flexibly utilized. In addition, a portion of terrace space has been reserved in some house types for future renovation. Furthermore, the courtyards of each house type also served as multiple roles that can be renovated by residents, considered to be the flexible space as well. By reserving the flexible space, the efficiency of space utilization was enhanced.

The total flexible space of each house type was counted and the results were shown in Table 2. Most of the house types had more than 30% of the floor area of the flexible modules, and with the space reserved for renovation, the total area of the flexible space was close to 50% of the floor area, which can fully meet the actual living needs of the residents. In general, each house type had an abundance of

Table 2 Flexible space of each house type.

Type	Floor area/m ²	Flexible modules			Space reserved for renovation		Yard with multiple use Area/m ²
		Number	Area/m ²	Proportion	Area/m ²	Proportion	
1	95.00	1	8.64	0.091	8.64	0.091	40.00
2	150.00	4	55.08	0.367	23.52	0.157	40.50
3	150.00	3	41.13	0.274	22.68	0.151	40.50
4	190.00	3	37.80	0.199	/		40.00
5	200.00	6	67.02	0.335	/		40.50
6	190.00	5	66.78	0.351	17.10	0.090	70.00
7	198.50	4	62.88	0.317	/		91.80
8	200.00	5	67.80	0.339	12.15	0.061	40.50
9	180.00	3	33.21	0.185	14.10	0.0783	45.00
10	190.00	5	83.40	0.439	/		52.50
11	250.00	7	69.72	0.279	23.40	0.094	68
12	253.00	6	51.40	0.203	12.35	0.049	74
13	254.00	8	120.96	0.476	/		65.6

bedrooms and storage space, which might be used as guest rooms, agricultural tool storage rooms, or study rooms. Among them, Type 13 had the largest area of flexible space, and a large number of bedrooms within it can be used for commercial purposes, such as running a B&B.

5. Discussion

In the design approach proposed in this paper, participation of residents during the dwelling design and construction process was emphasized. Firstly, information about the homestead, including size, shape and distribution, and family structure was provided by the residents, and the living needs were recognized so that the basic functional modules can be decided. Suitable room types for each module were selected by the residents, and the room layout plan was generated by the designer. After the components of each section being selected by the residents from the menu according to their preferences, the final 3D model of the dwelling was developed.

In the case study at Longchi area, thirteen typical house types were developed to form a guiding atlas, which can be further developed into more house types through modularization and customization, as presented in the previous section. In order to understand the application potential of the atlas, another field research was conducted at the end of the project. Residents' perceptions and evaluations of the ensemble were obtained through the questionnaires, with the results shown in Figs. 13–16.

A total of 103 valid samples were recovered, consisting of 20 young residents under the age of 30, 76 middle-aged residents who were between the ages of 30 and 60, and 7 older residents over the age of 60. The demand for dwellings renewal had similar distributional characteristics among the different age groups. Overall, about 65% of the residents had the desire to update their houses, of which 40% would like to take some renovation measures to improve the living comfort, while 25% prefer to construct new dwellings. Prior to this study, the average value of the awareness of atlas among residents was only 2.71 on a five-point scale, which means

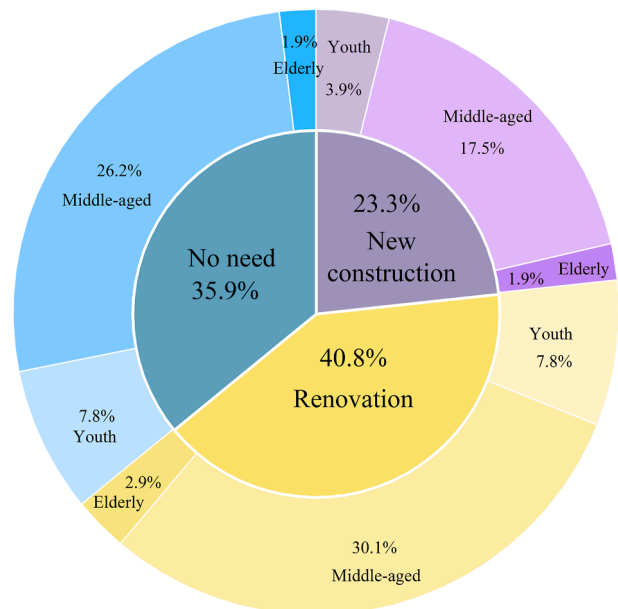


Fig. 13 Demand for dwellings renewal.

that the majority of residents still know very little about house type atlas before, and that the promotion of atlas requires more effort. Then the residents were asked about the expected access to information, which was a multiple-choice question with overlapping between different options. The results revealed that 85 residents showed their willingness to learn about the atlas through the Village Hall Committee (VHC), reflecting the vital role of the VHC in publicizing and promoting the new policies. And 54 residents also expected the government to issue relevant announcements to explain the contents of the atlas, which implies that the official information channel is recognized. There were also 55 of residents who want to diversify their understanding of the atlas through online media and other sources. There were 32 residents indicated that introductions from friends and relatives would also increase their interest in the atlas,

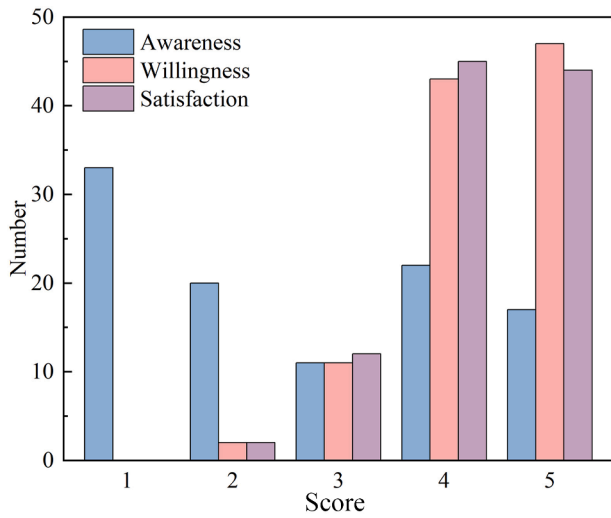


Fig. 14 Opinions on the atlas.

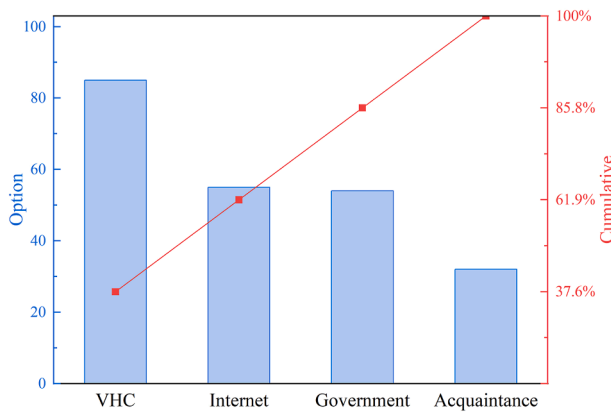


Fig. 15 Expected access to information about the atlas.

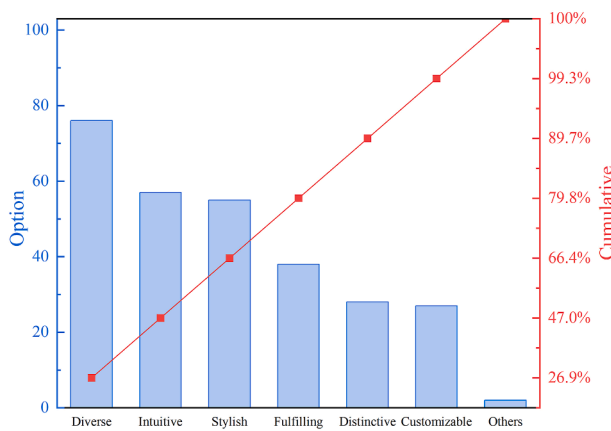


Fig. 16 Advantages of the atlas.

which demonstrated that for rural residents, the endorsement of acquaintances was also a guarantee of the credibility of the information.

After informed in detail of the atlas developed for the Longchi area during this field study, all residents gave it

a moderate score or higher. The average score of willingness to use the atlas to provide guidance on dwellings construction was 4.31 on a five-point scale, and the satisfaction with the atlas was 4.27 on average. It was mentioned by 73.8% residents that the atlas provided diverse options for dwellings, catering to the needs of different residents. More than half of the residents were also satisfied with the aesthetics of the dwellings and the intuitive presentation of the atlas. In the questionnaire, residents were asked to rate the homes in the atlas from three aspects, including whether they met their living needs, whether they were aesthetically pleasing in design, and whether they were adapted to the local culture and environment. All aspects received ratings higher than four on a five-point scale, and in particular, the aesthetics of the design received an average score of 4.36. The fulfillment of residential needs and the consistent with local culture were also recognized by residents, receiving average scores of 4.20 and 4.23, respectively.

In addition, various suggestions have been proposed that can help further refine the design method and enhance the feasibility of atlas application. Publicity of atlas was emphasized, to help residents more aware of the new tools. The cost effectiveness of using atlas for residential construction and the convenience of subsequent maintenance were also issues of great concern to residents. It was mentioned that the promotion of atlas would be greatly enhanced if the government could launch corresponding subsidy policies.

The results of the questionnaire showed that both the method of providing the atlas and the house types presented were highly appreciated by the residents, implying that this method was well worth applying and promoting. More importantly, resident participation was emphasized in the overall design method, both in terms of preliminary research on living needs, self-selection of functional modules and components, and increased flexibility in the space utilization. Recognition of the design method proposed in this project also implies the necessity of increasing the degree of resident participation in policy development.

6. Conclusions

In this paper, an information-adapted systematic method for planning and designing rural dwellings was presented. With which the comfort of living was enhanced while the continuity of architectural culture was preserved, and local policies were effectively integrated with the demands of the residents. Furthermore, rural residents were provided with professional guidance when constructing their homes. The method was initially applied in the Longchi area of Nanjing, China.

Through the fieldwork, the components of the dwellings with regional characteristics were summarized, and their styles were applied to parts of the components of the new dwellings. After researching the preferences of the residents, the overall style of the new dwellings was also balanced between contemporary architecture and local traditional dwellings.

Local geographic information was analyzed to determine the typical shape and size of homesteads, as well as the distribution of homesteads and dwellings. Furthermore, the

types of homesteads used to design new dwellings were selected in combination with local policies for rural dwellings.

Through the field research, the structure of the family and the type and number of functional rooms needed were presented as a set of relational equations, according to which the functional rooms fulfilling the basic needs of the family can be identified. Furthermore, all but the most basic functional modules can be replaced in the designed house type, improving the flexibility of space utilization.

By calculating the shape factor and window-to-wall ratio of each house type, it was suggested that the final design resulted in the house types with good thermal performance, improving the thermal comfort of the residents while reducing the energy consumption of the buildings.

After all the design processes were completed, another field survey was carried out to find out residents' perception of the atlas and, furthermore, of the method for planning and designing rural dwellings. The results showed a high level of acceptance of both the atlas developed and the overall method, suggesting that this design method deserves to be promoted.

By exploring the traditional architectural culture and characteristics of the certain region, adapting the specific homestead forms and local policies, and using the modularization and customization approach, this design method can be applied to rural settlements in different regions with diverse culture backgrounds in the future. The special architectural forms adapted to the local climate in different regions, which have developed over a long period, can also be preserved and continued in this way. Moreover, it is worth mentioning that when planning large-scale settlements, additional techniques such as parametric design and assembly technologies can be incorporated, making the methodology more advanced from design to construction.

Ethics statement

The authors declare that their Institutional Ethics Committee confirmed that no ethical review was required for this study. Written informed consent for participation was not required because all participants' data was anonymized before the statistical analyses were done.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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