ADAPTIVE APARTMENT SIMULATION

Adaptable space for the future high-density living

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Abstract. With China's rapid urbanization in the 21st century will bring many problems to the local architectural design industry. Specifically, the supply of land resources in developed cities such as Beijing and Shanghai is becoming more and more limited, and with it, the per capital living area of cities in the future will be further reduced. It can be foreseen that the high-density apartment in Chinese cities in the future will occupy the most crucial position. However, the high-density apartment living space also brings about the problem of building design efficiency and healthy living. Therefore, how to design these high-density urban apartments will become an essential issue for designers. In this context, the sensing and activation system provides a new approach to the high density and high utilization of limited space in the apartment. The research is to simulate use sensors and adaptable devices to create an adaptive apartment layout to improve the efficiency of the use of space in the apartment. Build a simulated adaptable living space with Rhino software and its plugins and Arduino sensor system. Construct a simulated adaptive living space through Rhino software and its plug-in and Arduino sensor system. By studying the simulation of high-density adaptive design, explore the advantages and potential of future adaptive design in high-density apartment design, and help the building Designers use adaptable solutions to face urban housing problems.

Keywords. High-density apartment; adaptable building; Rhino simulation; Arduino; sensing and activating system; Space

1. Introduction

In China, with high urbanization and rapid population growth, the contradiction between urban land and population is more and more prominent. Under such a realistic background, the demand for higher and higher building plot ratio makes the interior space design of modern high-density residence approach homogeneity. At the same time, driven by this highly simplified design, more design problems arise, such as the pursuit of high-density space layout and highly similar building facade design. From the perspective of design, this issue is not only a social issue but also a question about the future of architectural design -- that is, the future of urban collective housing, high-density apartments will appear in what way. This research mainly focuses on the use of adaptive architecture design to try to find a solution for the contradiction between private space and public space in the future high-density urban apartment, that is, to minimize the homogenization of the room layout of every internal space in the high-density apartment building. Most of the researches on adaptive architecture focus on how to reduce the impact of the building itself on the environment, rather than the function of redefining the function of the internal space caused by the change of the building structure on the internal space. Therefore, the primary purpose of my research is to coordinate the internal space of a building by changing the space of part of the apartment. This kind of research on the variable layout of architectural structure and spatial response is of particular significance for the future parametric design and even the research on the architectural structure or architectural space aesthetics.

2. Research Observations and Objectives

The purpose of this study was to use sensors and mechanisms to create adaptive apartment layouts to increase the efficiency of apartment space. The research is mainly carried out from two aspects: one is the simulation of the layout of high-density apartments, and the other is the collocation design of the apartment's adaptive system and Arduino induction. Through the simulation results, the space, area, and utilization ratio of the space of the traditional fixed space apartment and the adaptive apartment are compared. Through the final comparison data, it is proved that the space utilization ratio of the adaptive system in the apartment design is higher than that in the traditional fixed space design apartment. The connection between the sensor and the adaptive system in the simulation software proves that such an adaptable apartment is feasible in design.

3. Research Questions

There are several main problems in the simulation research of adaptive systems for high-density apartments. The first is how to use Rhino software to simulate traditional high-density apartments in fixed spaces. Using this simulated apartment becomes the framework for adaptive system simulation. The second is to build an adaptive system in this apartment simulated by Rhino, including how to move the adaptable system unit to match the functional space of the apartment and how to connect Arduino sensing equipment to the simulated environment. In this way, Arduino sensor-driven adaptive systems can be used to achieve, for example, how to move, expand or shrink spaces, and customize spaces. The third is to choose which Arduino sensor types are used as conditions to create an adaptive space that adapts to the occupant schedule. The last is how to evaluate the design efficiency and convenience of adaptive building apartments.

4. Methodology

The research background, relevance, and social value help clarify the scope and methodology of the research. Background research is particularly needed in the study of high-density adaptive apartments. This type of architectural design research is not evident in underpopulated urban areas. However, in the high-density cities of densely populated cities, the contradiction between population and land, and the contradiction between population and housing demand can reflect the value of research. Research on adaptive apartments can directly prove that adaptive apartments can become the mainstream of urban architecture in the future and also the development direction of the future construction industry. The purpose of this study is to investigate the space efficiency differences and the feasibility analysis of building structures between adaptive buildings, especially between high-density apartments and traditional apartments. Therefore, this research method requires software such as Rhino and Grasshopper to simulate an adaptive apartment to study the changes in the space of the adaptive apartment. At the same time, this software is also needed for comparative analysis of traditional apartments and adaptive apartments. The methodology of this research is based on the action research of "learning by doing"(O'Brien 1998). That is, iterating on the existing traditional high-density residential design to improve its defects, thereby solving the indoor space layout problem brought by high-density apartments.

5. Background Research

With the rapid growth of population, apartment design in future super cities will inevitably face a series of problems such as land supply and resource constraints. From the history of modern architecture, whether it is the eastern metabolism movement or the Archigram group of the new avant-garde, a large number of designers have made many ideas and attempts to solve the contradiction between urban expansion and land population. However, due to technical limitations, many designs can only become concepts on paper. With the development of science and technology, modern computer-aided architectural design technology and automation technology has greatly exceeded the last century(Beesley, Hirosue and Ruxton, 2004). This means that it is possible to design high-density urban apartments using computational design methods. Especially in the face of the rapid urbanization process of Asian super cities, such as Beijing, HongKong, Mumbai or the highly developed but densely populated Tokyo bay area and the high-density housing in the Seoul area housing supply problems are more prominent.

In the context of China, the rapid economic development of the past 20 years has brought two social problems: the increase the rural population that floods into the city also known as “floating population” and the shortage of supply caused by land expansion(Luo et al., 2018). Faced with the pressure of the inflated population, the government needs to provide a large number of public housing for low-income groups. Therefore, in future China, whether it is the government-supplied affordable housing or the commercial housing market, the urbanization problem has brought about the reality that high-density housing is the main direction of future residential construction. This development trend makes the design of these high-density low-cost apartments or public apartments an important carrier for adaptive high-density urban apartments.

The most significant problem in designing such adaptable and responsive apartments is how to use design software to complete the architectural layout of the building. For example, Rhino simulates adaptive architectural design to achieve efficient utilization of the interior space of the apartment. The Rhinoceros mimics how the flat plan of the apartment is adapted to structural changes, such as how it moves, expands or shrinks and How to arrange fixed space, such as pipe space, stairs and moving space, such as a kitchen, bedroom. For example, the kangaroo plug-in is used to simulate how the structure of the building moves to match the functional space of the apartment. Oungrinis and Liapi (Oungrinis and Liapi, 2014)documented a series of experimental architectural studies to explore the feasibility of adaptable buildings in the article "Spatial Elements Imbued with Cognition: A possible step toward the "Architecture Machine". In the article, the author conducted a mobile building structure experiment controlled by Arduino and a 3D simulation of the concept theatre on the Rhino software. This study provides an example of how to combine dynamic building structures, spatial functions, and existing software tools. For example, in the experiment of the concept theatre, the building changes its shape to meet the needs of the venue for different functions. Although the author's research is more focused on the adaptability of the building structure, and the object of the experiment is not the apartment.

In addition to directly changing the building structure to achieve the effect of a adaptive building. This effect can also be achieved with a reconfigured wall system. In the article "The Reconfigurable Wall System: Designing a Responsive Structure Reactive to Socio-Environmental Conditions"(Alani et al., 2018), Mostafa Alani and his team designed a wall that can interact with people, realizing the wall-to-wall between the walls themselves. Compared to the above-mentioned responsive building brought about by changing the building structure, Mostafa Alani's wall system is more feasible, and it is more operational and feasible in both Rhino software and solid model. For the research adaptive apartment, the significance of this design is to create a movable wall system to change the space directly, but just changing the shape of the space can not correspond to the effective space function can not improve the utilization of the apartment space. The Aurélie Mossé team believes that the use of new materials can also be used as a way to study how to adapt the interior space of an apartment. (Mossé, Kofod and Thomsen, 2011) Electric elastomers, as a material has the shape-changing properties of electricity, provides a new solution to the apartment's ability to change interior spaces. Unlike elastomers or steel, electric elastomers are flexible and electrically conductive, not only as a spacer for changing the spatial arrangement, but also as a response to more human activities in space. Of course, the downside is that new materials have high production costs and are not easy to use. Despite all the shortcomings, this new material provides a new direction for thinking about the interior layout of the apartment. How to apply Arduino and sensor technology to the space design of high-density apartment buildings to create a space suitable for the residents' time schedule?

How to use Arduino to develop apartment interior space management, such as the arrangement of apartment interior space and functions at different times. How to flexibly change the interior of an apartment using sensor technology, such as human infrared sensors, pressure sensors, or light sensors. For example, a temperature sensor and a clock unit can be utilized to form a real-time change in space system based on temperature changes

(Goud et al., 2017). For the same reason, the temperature sensor can be changed to Bluetooth or infrared, and space is changed by different factors. It is even possible to automatically generate a variable space by a random computer program under the feedback of the sensor, so as to achieve the responsiveness and adaptability of the high-density apartment. (Christensen, 2014)

A final consideration is the is use simulation software to evaluate the efficiency and convenience of responsive architectural and traditional apartment design. The animation is used to calculate whether the parameters can be adapted to respond to the higher spatial efficiency of the apartment compared with the traditional small apartment. In fact, the efficiency of space utilization is difficult to evaluate, but the comparison of other parameters can be used to achieve comparison of space use efficiency. For example, comparing the circulation of the interior space of a building to get a visual result. (Suter, 2015).

6. Case Study

6.1 Simulation of fixed space apartment room layout

According to the statistical yearbooks of Beijing and Shanghai, the per capital living area of the two cities in 2017 were 32.56 (Beijing Municipal Statistics Bureau, 2018) square meters and 30.01 square meters (Shanghai Municipal Statistics Bureau, 2018), respectively. This means that most of the high-density apartment areas in the city are in this size, that is, a residential house that can accommodate two adults is approximately more than 60 square meters. Therefore, the design of high-density apartment model with fixed space as the reference is shown in Fig. 2. This apartment model has the most basic apartment elements such as bedroom, living room, kitchen, and toilet. The entire area is about 64 square meters, and the practical area is about 60 square meters.

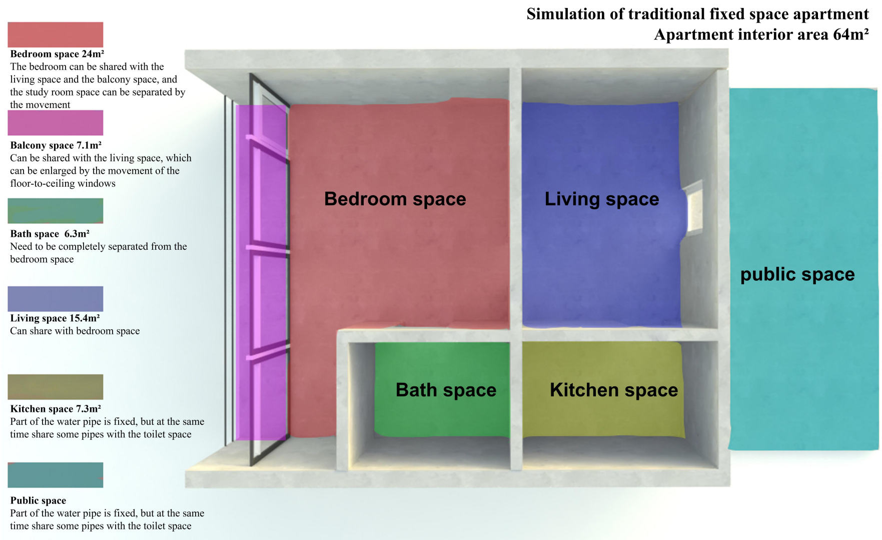

Figure.1 fixed space apartment room layout

6.2 Adjustable space management and selection

Based on the above simulation model of a fixed-space apartment, the design of the adaptive apartment can make adjustments to certain spaces to maximize the use of a single functional space in the apartment. For example, corridor space, in a fixed space apartment, corridor space is a passage connecting different spaces in each apartment connected by a door. This space can be considered as a public space divided by circulation in the fixed space apartment, and the corridor space is connected to the wall. If in an adaptive apartment, this space that can be moved but cannot be modified can be regarded as a semi-changeable space. Another example is bedroom space. The size and function of a fixed space apartment are fixed and cannot be changed. But in an adaptable apartment, the bedroom space can be re-sized and adjusted for different uses, and such a space can be considered an alterable space.

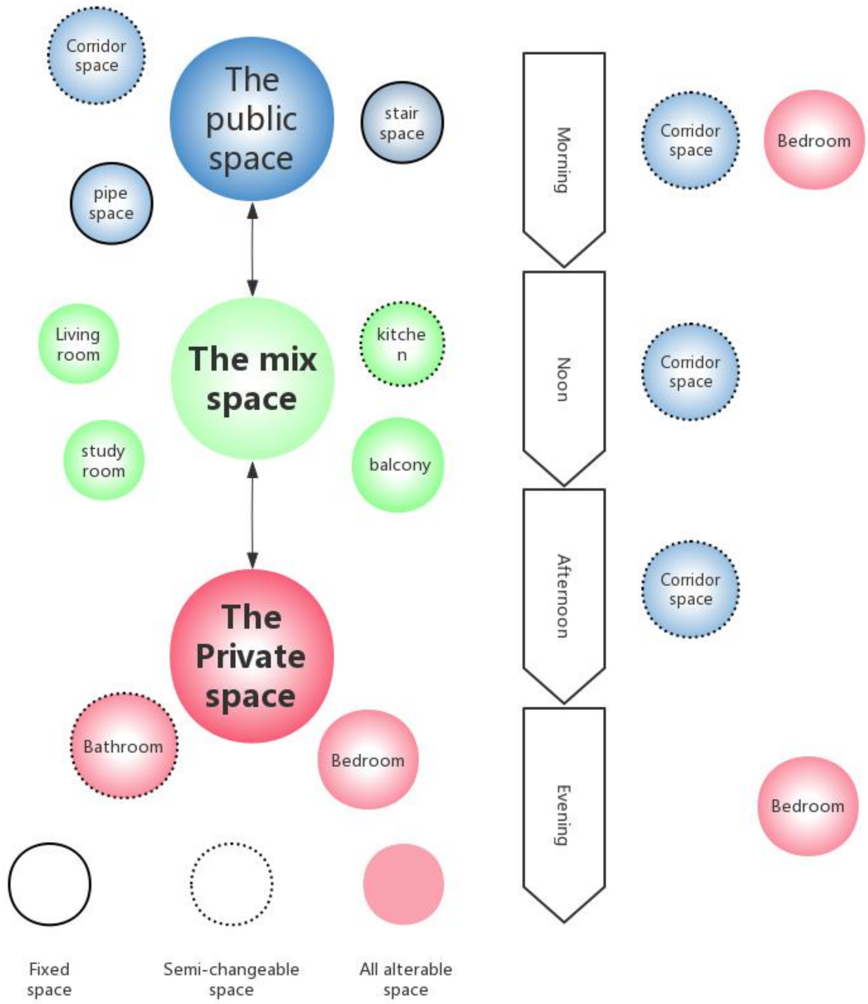

Figure.2 Classification of different spaces in an apartment

According to the use time, use function, privacy, and variability of the apartment space, the adaptable system needs to refer to these factors when rearranging the interior space of the apartment. For example, the adaptable system must ensure that the private space and the public space are completely isolated. For example, toilet, bedroom. Or change the size of the space to a limited extent, such as the kitchen.

6.3 Composition of adaptable component system

Due to the limitations of the area of high-density traditional apartments, this has led to the need to make most of the adjustable modules relatively small in order to use the adaptability system flexibly. When it is necessary to adjust the size of the space, a large partition is formed by these small modules to achieve the function of dividing the interior space of the apartment and re-arranging the space. Therefore, the fixed walls and doors and windows in the previously simulated apartment will be replaced by a system with adaptability

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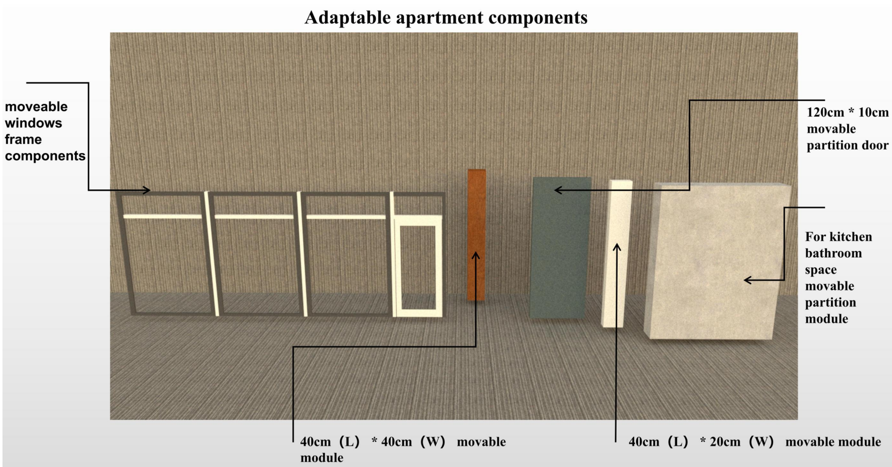

Figure.3 Adaptable apartment component

This system will include five components: the first is a movable floor-to-ceiling window frame, which is located between the balcony and the bedroom, and is mainly used to adjust the size of the balcony. The second part is a movable module with a height of 40 cm and a height of 40 cm. It is mainly used as a movable partition and storage space. This module will be located between the bedroom and the living room to adjust the bedroom. Role of space and living room space. The third component is a 120 cm long and 10 cm thick movable door, which is mainly used as an expandable door for the bathroom. The fourth part is a removable module that is 40 cm long and 20 cm thick. It is also between the bedroom and the living room as the second component, but because this component is thinner, its function is similar to that of the second component. In addition to being a partition of the interior space of the apartment, it also needs to have the function of a door, which can ensure that the dwelling can walk smoothly in each space according to the instructions of the sensor. The last component is a thick partition located between the kitchen and the bathroom. It is 236 cm long and 40 cm thick. Its main function is to adjust the size of the kitchen and bathroom. In addition, the space contains most of the water pipes and household appliances, so this part is a fixed-line movable and semi-storable module.

6.4 Composition of Arduino sensor system

According to the previous simulation analysis of the fixed apartment space, the Arduino sensor driving methods can be divided into three types. The first type is the sensor that senses the movement characteristics of the human body. The purpose of this type of sensor is to adjust the adaptable components in real-time. A module functions as a door in the entire system. The second is to adjust the position of the adaptable system according to time, because people have a certain time regularity, so adjust the size of the space according to time, for example, the living room and kitchen space will be larger during the day. In the nighttime, the bedroom space will be even larger. The last one is to control the movement of the module manually. First of all, there is a need for security. In addition, this also leaves the occupants the freedom to arrange their own space.

Figure..4 Human body infrared sensor

Use the human infrared probe to connect the Arduino development board, and then simulate the movement of the modular unit that acts as a channel in the adaptable apartment in Rhino through Firefly and Grasshopper. In the simulation, the sensor drives the module when the sensor senses that the human body is moving in the direction of the channel. The left side of Figure 7 below represents the traditional apartment layout simulated by the adaptable system, and the right side represents the components after the movement.

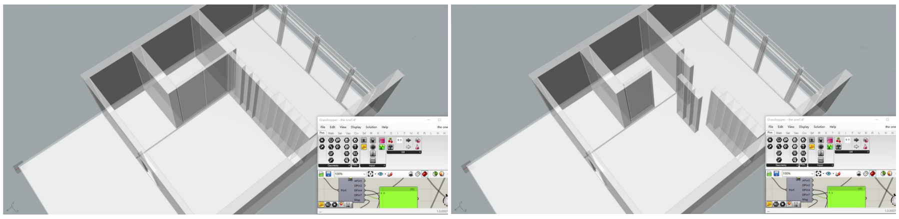

Figure.5 Adaptive module driven by real-time sensors

Time-driven ways of adapting to apartments are slightly different, such as the arrangement of bedrooms and living rooms. So arrange a point in time as a condition for adaptive system changes. This driving method is shown in FIG. 8. The bedroom remained in the entire apartment until seven o'clock in the morning. However, after seven o'clock, the wall separating the bedroom and the living room moved, and the entire bedroom and living room reorganized into a large public space.

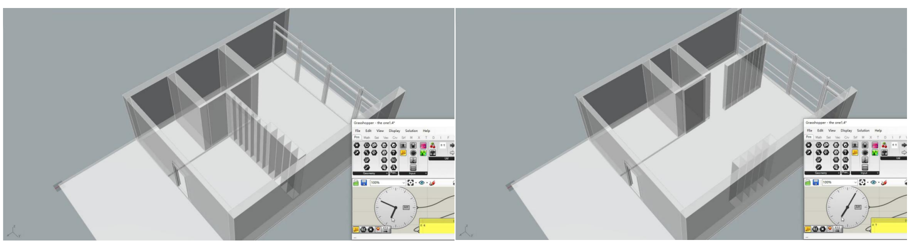

Figure.6 Time-driven adaptable modules

Manual control gives the occupants a greater ability to arrange space freely. In the simulation, a balcony is used as an example. If the residents of the apartment can meet the large demand for the balcony, the bedroom space can be divided into the balcony. The same residents can customize each partition as shown in Figure 9.

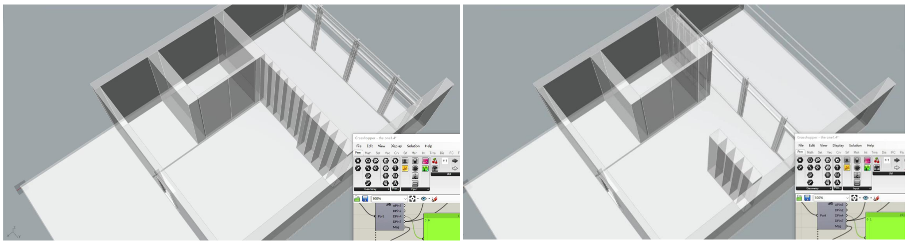

Figure.7 Adaptive module in manual control mode allows free adjustment

6.5 Firefly plug-in and sensor judgment data into simulation data

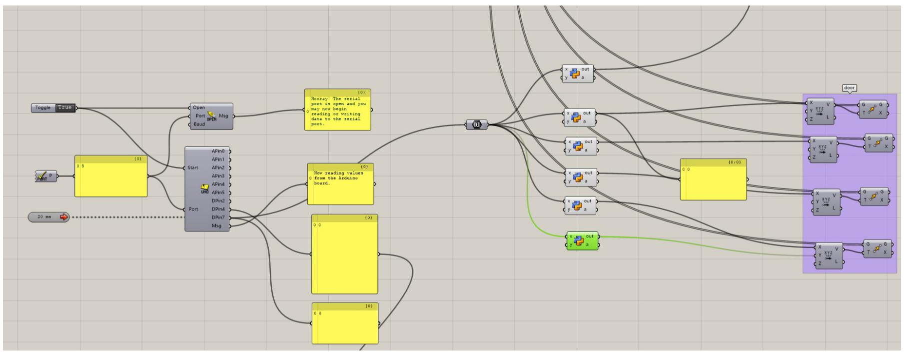

Figure.8 Firefly plug-in, Python program, and battery diagram of some simulation modules

The Arduino development board and the sensor system are connected through the Firefly plug-in to form a whole analogue chain of sensor-development board-grasshopper-analogue adaptive modular unit. As shown in Figure 10, each battery diagram simulates an independent adaptable module. The Firefly plug-in imports the data received by the sensor, and then uses the signals determined by Python to drive the adaptability module to move Finally, this data is output into a specific distance to be simulated by Grasshopper. The logic flow is shown in Figure 10 below.

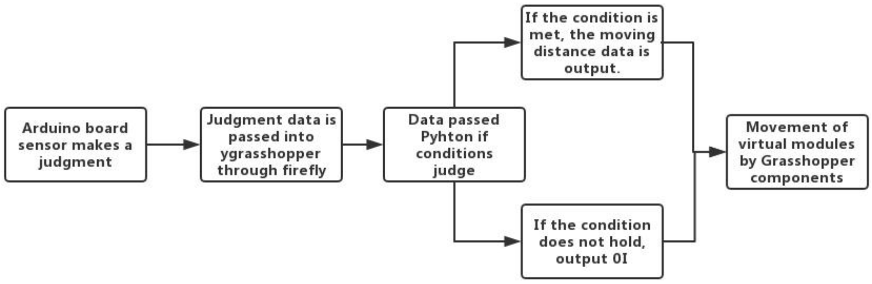

Figure.9 Logical flowchart of the entire simulation judgment process

Figure 12 shows an example of the simplest Python judgment program. The sensor data generally uses 1 and 0 to indicate whether the signal was received. Therefore, if the data imported by Firefly in the Python judgment program is 1, it means that Python needs to output A distance data is given to the Grasshopper component to complete the simulation of the adaptive system. Conversely, if the output data is not 1, Python does not need to move the data to the Grasshopper component, or outputs data to the Grasshopper component to make the simulation adaptable system module return to the original position.

```
__author__ = "CXATWC"
__version__ = "2019.10.30"

import rhinoscriptsyntax as rs
import time

if x == 1:            # Determine the value of x
    print '600'

else:
    print '0'
```

Figure.10 An example of a Python judgment program

6.6 Final simulation results and space utilization efficiency analysis

Figure.11 Adaptive apartment room layout during the day and night

The simulated apartment layout during the day and night is used to analyze the advantages of adaptive apartments over traditional apartments. As shown in the daytime apartment layout shown on the left in Figure 13, the adaptable apartment can set up a living room, living room and kitchen during the day. This can greatly increase the indoor activity area during the day and can also use adaptability Modules create an independent learning space. The layout of the apartment at night is shown on the right side of Figure 13. The partition formed by the adaptable module re-separates the public and private spaces, and the area of the bathroom is enlarged at night to make the residents have more bathing space.

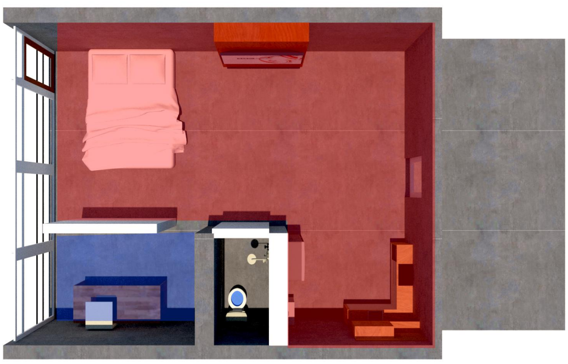

Figure.12 Adaptive apartments in public spaces during the day (red) and additional learning spaces (blue)

Specifically, compared to traditional fixed-space apartments, the use of indoor apartments during the day brings a huge improvement in the use of indoor areas. Comparing the public living spaces in Figure 15 and Figure 2, we can find that when using the traditional solution, the high-density The public space of the apartment is limited to a small area, which is about 15 square meters in the simulated apartment shown in Figure 2, which is about 25% of the total net indoor area. However, in the simulated adaptive apartment, the The public space can reach 50 square meters. Under the same area, this public living space can reach 80%. But at night, adaptive apartments are not much different from fixed-space apartments in improving private space.

7. Significance of Research

The purpose of my research thesis is to verify the advantages of adaptable apartments to high-density apartment designs in a simulated environment. Through the drive of sensors and a simple Arduino development board, the system can be used more effectively and reasonably in the same frame as traditional apartments, such as integrating space and rebuilding space. Its importance lies in providing feasible cutting-edge trial solutions for the future construction industry, engineer industry, and structure industry when building high-density urban residential environments. At the same time it provides for computational designer an important reference, that is, when the city of the future to continue to develop human settlements become more prominent, if more computational designers need to focus on building links between adaptable architecture and computational design.

Finally, returning to the topic of adaptable apartments, it is true that adaptable apartments will not increase the actual apartment area. At present, there are still problems that are difficult to construct and maintain at the physical level. But with the maturity of materials AI technology, this research provides a new solution for the future design of high-density apartments.

8. Conclusion

The adaptive apartment made of Arduino system simulated by Rhinoceros and Grasshopper shows higher space utilization rate and more flexible room layout ability than traditional fixed space. This kind of adaptable apartment can solve the livability problem caused by the smallness of the apartment area in the high-density urban residence. In this research, a variety of adaptive modules and Arduino induction control system for adaptive apartments are simulated in the same traditional apartment space with different use conditions. For example, living room space expansion in the daytime, bedroom space expansion in the nighttime, balcony area expansion, and indoor circulation simulation. By comparing the area of the single functional plane and the size of space in two different types of apartments, this paper analyzes the advantages of adaptable apartments. For example, under the use simulation with time as the condition, the adaptable residence can significantly expand the used space of the occupant and improve the space use efficiency, or users of the room can have more space layout ability under the condition of simulating the occupant's demand. The simulation means that compared with the traditional fixed apartment interior layout, adaptive apartments give apartment residents more free space arrangement and provide a more comfortable space environment in the limited space of high-density apartments. Through these studies, it can prove that it can adapt to the apartment system and solve the small and rigid space layout of high-density urban apartment buildings in the future. In the future, due to the miniaturization of the control system, the popularization of new materials and the maturity of artificial intelligence system, this modular adaptive apartment program can be developed into a more comprehensive and integrated urban system.

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