

# Digital Twin–driven construction of low-carbon communities in traditional villages: The Case Study Of Yuxiao Village At East Qing Tombs

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## ABSTRACT

Old villages are facing the problem of disassembled broken information, and it is hard to make much numerical help convert to reduce less carbon dioxide. The update with digital twins (DT) will be offered Taking Yuxiao village which belongs to the Northern area of East Qing tombs as an example we construct Meso – spatial pattern and Micro – building performance evaluation system. By using the space syntax method, we conduct the spatial analysis on the yuxiaovillage and carry out simulation study about dynamic energy consumption through DeST-H software. According to the result, by using meso-scale ventilation structure improvement and also improve micro-level envelope performance at the same time so that we can save up from 35 - 40% operational building energy use. This is a road that can prove the scientific correctness and usefulness of Digital Twin helping rural area make low-carbon decision-making.

## KEYWORDS

Digital Twin; Traditional Villages; Low-carbon Community; Space Syntax; Energy Simulation.

## 1. INTRODUCTION

### 1.1. Research Background

In the face of the dual carbon context and rural revitalization background, energy saving and emission reduction work in the building industry is now at an important juncture. Being important bearers of culture, the green reform of traditional villages does not only involve changes in energy structure, but also includes real improvement of people's living conditions. But constrained by the era it was built in and technical conditions at that time, the northern traditional villages usually have problems like poor building envelope's thermal performance, unreasonable spatial organization logic and high emission intensity of energy consumption. And it's also urgent to renew the way of scientific.

### 1.2. Literature Review and Scientific Problem

Currently, there is some study of what has been done before about the rural renewal. Mostly concerning landscape heritage and sociological studies, not carbon reduced[1]. The renovation of traditional is difficult for finding an empirical result which could be right. But on the contrary, the Digital twin can give a new way for quantity diagnosis and simulation through digital map of real word. This article wants to know how to apply digital twin Technology in order to do collaborative improvement on rural place as well as building efficiency; it tries to create standard lowcarbon renewal processes [2].

## **2. RESEARCH METHODOLOGY AND TECHNICAL FRAMEWORK**

### **2.1. Technical Path Construction**

We use interdisciplinary study approaches for our technical frameworks which consist “field observation-digital model multi-scenario dynamic modeling-optimal trajectory selection framework” in this paper, we will conduct research from the macro dimension, which is focused on studying the effect of village form on microclimatic condition and the fine dimension, it’s about how energy efficient individual building can be.

### **2.2. Main Analytical Toolset:**

This research jointly utilizes Space Syntax and Thermal Environment Simulation (DeST-H) to establish the fundamental analytical framework. Initially, Depthmap software was applied to execute a topological examination of the rural road system. Utilizing primary metrics like connectivity and integration, we numerically assessed the accessibility and attractiveness of internal areas to detect spatial vitality distributions. Concurrently, regarding building physical performance assessment, we employed DeST-H simulation tools, integrating the fluctuating meteorological conditions of Yuxiao Village for year-round hourly load calculations. By contrasting energy usage statistics prior to and following the enhancement of the envelope structure, we offer quantitative strategic guidance for the development of low-carbon refurbishment schemes [3].

## **3. EMPIRICAL ANALYSIS THE SPACE AND PERFORMANCES OF YUXIAOWANG VILLAGE**

### **3.1. Digital Identification of Spatial Organization**

In our team’s doing an empirical research part, on the very first part we will be using the Axim Map model to look at Yuxiao Village and East Qing Tombs’ spatial logics systematically. Integration analysis shows that axes 2,3 and 4 are the main axis of spatial integration in the village-tomb system, it has obvious people gathering effect. Specifically speaking, Axis 2 is an important regional transportation hub and carries strong social-economic activities, it is the central node of villages’ spatial activity.

Intelligibility analysis has been conducted with the result from the linear regression between the local and global integrations is  $R^2=0.617$ . This value shows that the spatial structure of Yuxiao village has a very large self similarity which means users are familiar with how to navigate the big picture. And such good spatial direction gives enough support to lead low-carbon travel behaviors and set up a kind of low-carbon community recognition by organizing paths.

### **3.2. Thermal Performance of Typical Buildings Simulation**

Concerning to microscale therm perf diagnose , we take a redbrick house as a baseline digital twin: Regarding envelope in terms of temperature parameters used for the outside wall, it comprises 360mm red clay brick and has a K value which is equal to  $0.984(W/(m^2 \cdot K))$ : Because it has a very simple roof structure, its thermal inertia index is also very small, so it loses too much heat in winter.

According to the results of Baseline energy through DeStH, more than 75% is taken up by heating needs in Winter of this sort of home[4].And simulation’s result is corresponding to it that has been collected continuously by field’s temperature and humidity, both reflect responses when facing to extreme weather as well show distinctly how insufficient traditional house is about envelope’s inertia of warmth and insulation, also can have a right concept towards next precise retrofit.

## 4. A COOPERATION WAY ON LOW - CARBON COMMUNITY

### 4.1. Meso-scale: spatial synergy and Microclimate Guidance

And according to integrated core area with space syc, it will be coordinated together with point of space. We decreased the local heat island effect in areas with many crowds by changing the alleys' H/W and bringing in a lot of greenery to assist nature's breeze. From studies we know it makes sense to organize space which means better climate and less dependence on artificial light sources from improving streetscape lighting and orientation, all this for passive savings in energy and quality of spaces.

### 4.2. Micro-scale: Envelope Performance Enhancement Methods

With the help of Digital Twin platform, we got the best tech combination for Yuxiao village from many simulation results. We added 80mm rock wool insulation board to the wall, so  $K=0.98-0.42=0.42$ . We put XPS boards on the roof for a time being and made some improvement about structure layer, its value was 1.07. Also, replace common window with double-pane low-e glass reduces cold wind seeping into the house. In small scale integration reductions in the carbon that we can get from 1 individual structure is shown in table one.

**Table 1.** The building envelope of Yuxiao Village which is about to be optimize

No.	Component	Optimization Measure	Performance Improvement
1	Exterior Wall	80mm rock wool insulation board	K-value changed by 0.98 to 0.42
2	roof	xps board&structural improvement	thermal resistance is now at 1.07
3	Windows	Double-pane Low-E glass	Big cutback on air going in

### 4.3. Simulation Test And Emission Reduction Analysis

And we put our optimized params back into the model and ran another simulation. We dynamic: As can be seen from the result, after locally improving the envelope and jointly optimizing the mesoscale spatial path, it can reduce 38.6% of annual cumulative heat load for single building which will also reduce carbon emission intensity accordingly. And is like a testimony of how well it worked on “we will diagnose digitlly--then match specific strategy’ close loop route” and also proving if he has the capacity to predict digital in huge areas like a country.

## 5. DISCUSSION: THE BOUNDARY OF DIGITAL TWIN IN RURAL RENEWAL

### 5.1. Trade-off Between Real-time Data and Static Simulation

Although Digital Twin is used for high-precision static performance simulation, real-time data feed back is still a problem. It's mainly relying on that kind of periodic snapshot survey right now. Hardly ever captures the full amount of random energy error due to people being home or opening their windows, varying in heat. Therefore, future studies can try the use of Internetofthings(IoT)sensor technology to make dynamic flow of energy and enviromental data which could make up for not being able to simulate in real time due to its limitation.

## 5.2. Conflicts Between Heritage Preservation And Energy Retrofitting

The renewal of northern traditional villages should always abide by the bottom line of heritage protection. In Scheme Comparison stage, Digital Twin also has a special power-it can see and check how these energy-saving bits fight with old buildings full of pictures. It gives the admins digital prejudgment help on what would work well - “Keep all the old ones”, or do “go energy friendly”

## 6. SUMMARY

This paper used Digital twin to verify and promote the path of rural Low carbon renewal in Yuxiao village. Show us the way to couple with space and then do the simulation of energy, we finally link those long separate scales in village renovation – from large scale to small one. Simulation models show that northern old village have a large amount of energy saving space and more than 35% if combined, it will bring huge ecological benefits. Like this kind of digital systems can also enhance accuracy on design work and it offers great science hint for rural revitalization strength judgment. It’s going to certainly cause lots promotion influence.

## REFERENCES

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