AN INTEGRATED APPROACH TO SUSTAINABLE TRANSPORTATION, LAND USE AND BUILDING DESIGN

THE CASE OF THE LUOKOU DISTRICT, JINAN, CHINA

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ABSTRACT

Due the pace and the scale of urban development in China, the implementation of sustainable urban practices there is an essential step in addressing climate change. Chinese officials are becoming increasingly interested in sustainable practices including transit-oriented development (TOD) and green buildings. However, even though the concepts are supported, implementation sometimes falls short of desirable outcomes. In this paper, we present the preliminary results from a collaborative project carried out with planning officials from the city of Jinan (pop. 3.4 million), for a 3.1 km^2 (1.15 mi^2) district, expected to house 100-130,000 people by 2020.

The paper presents a proposed plan for the Luokou district. By integrating transportation, land use, urban design and sustainable building design early in the planning process, our approach identifies opportunities for improving energy efficiency that might have been overlooked by considering transportation, land use and buildings separately. The land use plan provides housing, office and retail employment schools and other public services. The urban design lays out these uses to create walkable neighborhoods and bike and transit access throughout the district. The current sparse, congested street network is replaced with a hierarchy of streets that accommodates all modes. Street widths and building densities are carefully adjusted to maximize the potential for passive solar heating and use of daylight in buildings. Green building designs meet or exceed Chinese energy performance standards (meeting EU standards). The environmental performance of the district is analyzed in both the local and the regional context using traffic micro simulation and building energy evaluation models. This design and analysis approach is intended to serve as a model for sustainable urban planning in other Chinese cities.

Keywords: transit oriented development, urban design, multimodal street design, China, developing countries

INTRODUCTION

Planning for transportation and urban development in Chinese cities

Working in city planning in China involves dealing with a context that has, at the same time, very promising features and very serious problems. On the positive side, most trips are still made by walking and biking and this is expected to continue for the foreseeable future. Transit ridership is high, and residential densities are high enough to support extensive transit use both in the center and in new suburban developments. City governments across the country are committed to continue investing in transit, and to providing ubiquitous facilities for bicycles and pedestrians.

At the same time, the increase in auto ownership in China in the past few years has overwhelmed the existing transportation infrastructure in many cities. Planning institutions have encouraged motorization as an industrial policy as well as a symbol of modernity and progress; while most cities have strived to build additional infrastructure to meet the growing demand for travel, they have not been able to keep up with the increase of auto use (*Liu et al. 2005*). An estimated 14 million new vehicles were added between 2000 and 2003 alone (*Cervero, 2008*), mostly in urban areas.

The resulting traffic congestion has had a negative impact on air quality, making Chinese cities among the most polluted in the world (*Appleyard et al. 2007*), and has contributed to making China the world's largest greenhouse gas emitter (*EIA, 2006*). Traffic congestion generated by cars has affected the mobility of other modes as well. Deteriorating conditions for non-motorized modes are discouraging people from walking and biking in a number of cities. These problems have been aggravated by an urban form incompatible with increased motorization, characterized by a sparse arterial network with highly complex and operationally challenging major intersections (*Gakenheimer 1999*).

Another point of concern is the gap between support for the concept of sustainable development and its implementation in China. Planning documents across China speak of "eco-cities" but for many new developments the land use plans have focused on laying out large blocks that reduce public space, making developers responsible for areas interior to the blocks. Likewise "green buildings" are widely discussed, but building design often emphasizes appealing architectural objects, with insufficient attention to context or climate considerations. Transportation plans propose increased transit use and speak favorably of transit oriented development (TOD), but many transport projects focus on accommodating cars, providing inadequate attention to the practical needs of walking and biking. Few plans present detailed urban design that integrates transportation and land use, or carry out a thorough analysis of existing conditions and prospective impacts of new developments. Ironically, though the stated objective is sustainable development, many new projects do not achieve a high level of energy efficiency, and the emphasis on accommodating the automobile is pushing out sustainable modes of travel such as biking and walking, or relegating them second-rate status.

Transit oriented development as an approach to sustainable development

By transit-oriented development (TOD) here, we refer to development over the area within walking distance of a major transit station (up to one kilometer, equivalent of a 15 minute walk). Main features include a mix of residential, office and retail uses, as well as higher densities closer to the station, to increase transit ridership, and street designs throughout the area that improve conditions for walking and/or biking to the transit station.

Despite the difficulties with implementation, TOD continues to show promise for sustainable development, both in China and elsewhere. Previous studies have shown that TOD can reduce transport energy use and also create built forms that are energy efficient. (*Burchell et al. 1998*) Elements of TOD (among others) that lead to these results include density, diversity of uses, and pedestrian friendly urban design (*Cervero and Kockelman 1997*).

In particular, high density neighborhoods are correlated with fewer auto trips than their lower density counterparts (*Forkenbrock 2002*). High density is the norm in China; most new developments there consist of multilevel apartment buildings, with densities high enough to support high frequency transit operations as well as a wide variety of local services.

A bigger issue in Chinese cities is urban design, and in particular the relation between block size and the street network layout. The literature shows that, in the context of high auto ownership, neighborhoods with small blocks and gridded street patterns have higher rates of transit use, walking and biking than their counterparts with fewer street connections (*Cervero and Gorham 1995*). Chinese cities, however, have developed with very large blocks and a sparse network of major arterials. The blocks typically contain small internal streets for resident access, with a few gates leading to major arterials. Until recently, because auto ownership in China was very low and most people lived within an easy walk or bike ride to work, this superblock pattern of development apparently functioned acceptably. As commuting has grown and auto ownership increased, the superblock design has become less and less workable, either for autos or for pedestrians and cyclists. Efforts to accommodate growing auto use on the massive arterials have created increasingly difficult conditions for walking and biking. In some cases, bike lanes have been eliminated or narrowed to make room for cars. To cross the wide arterials, pedestrians sometimes have been relegated to overpasses or underpasses; in other cases they must travel long distances to reach an intersection where they can cross, yet the width of the street and the pressures of traffic create safety hazards even at these few intersections. Urban design thus has safety as well as accessibility consequences.

Given China's position as the world's largest contributor to greenhouse gas emissions, an additional and equally important reason for TOD is improving energy efficiency and reducing emissions. Studies have shown that by increasing transit ridership and, implicitly, the overall occupancy of vehicles, we can improve the environmental performance of vehicles, measured by passenger-kilometer-traveled (PKT) (*Chester and Horvath 2009*). Walking and biking are also important ways to reduce emissions and are facilitated in TOD design.

In terms of reducing energy use, however, working in the transportation sector alone will have only a limited effect in Chinese cities. Transportation only accounted for 11% of total energy use in China in 1998, and while the transport share of energy use is expected to grow, it will still be only 18% of the total by 2020. Furthermore, 60% of transport energy use comes from freight transport (*Dadi et al. 2003*). While TOD can help by improving the energy efficiency of passenger transport, more significant energy savings could be achieved by also addressing the environmental performance of the new buildings, as we propose in our plan. The building sector is projected to account for 26% of total Chinese energy consumption by 2020, and the margin for improvement is significant (*Dadi et al. 2003*). Moreover, as we will show in this paper, decisions made in the context of transportation projects can have significant effects on the energy efficiency of buildings, especially in a case such as Luokou, which involves building a new city district.

Many efforts at TOD have focused on single development projects. In our case, the TOD proposal concerns an entire subarea of a city. In fact, the Luokou district (130,000 inhabitants) is comparable, in terms of population, to a small city in Europe or the US. Moreover, while previous TOD proposals have focused on street design and land use density, our project goes a step further, by integrating building science considerations into the plan.

The case of Jinan: planning problem and study approach

Jinan, a city of 3.4 million approximately halfway between Beijing and Shanghai, recently designated its Luokou district as a redevelopment site. Situated along the Yellow River at the northern city edge, the 3 square kilometer (1.15 square mile) district is a low-lying area, protected by a levee. The district has been partially cleared; the remaining uses include older single story housing, mixed industrial uses, and a few relatively new apartment buildings. To the current population of around 30,000 inhabitants, the city plans to add another 100,000 by 2020 to help accommodate the city's expected population increase to 4.5 million.

The district is located along Jiluo Avenue, the main north-south corridor of the city, connecting Luokou to the Central Business District and the tourist area some 8 kilometers (5 miles) to the south. The district's location fairly close to downtown, along a major connector route, can be an asset, as proximity to job centers may make the district more attractive to developers and residents, but it also can also be a problem if Luokou is developed simply as a bedroom community, because the street capacity is extremely constrained. There is only one other major arterial connecting the district to points south. Indeed, Jinan features a particularly sparse street network. Block faces of over 600 meters (2,000 feet, or over five times the length of a football field) are not uncommon. This block design results in large amounts of traffic being concentrated on very few streets and intersections, which in turn leads to high levels of congestion.

In 2007, the Energy Foundation asked researchers from the UC Berkeley Center for Global Metropolitan Studies to work alongside the Planning Department and the Planning Bureau in Jinan, to propose a plan and develop guidelines for sustainable urban development in the Luokou district. We viewed this as an opportunity not only to address the future development of that particular district, but also to develop an approach that would be robust and applicable to similar projects in the future, integrating transportation, land use, and building design.

An earlier proposal for the district laid out the district in large blocks of about 400 x 300 meters (1300 x 1000 feet). These blocks contained internal streets, but few were shown as open for the use of the general public or connected to internal streets on other blocks. In the earlier proposal, the district was served by a limited network of five east-west arterials and eight north-south arterials internal to the site and the two existing arterials connecting south to the rest of the city. Only one arterial – the ring road along the river – was shown as providing east-west regional connections. These arterials were very wide, 80 to 120 meters (260 to 400 feet), but nevertheless provided only three to four lanes per direction, and included signalized intersections. While no district level employment forecasts or traffic analyses accompanied the proposal, any downtown traffic would have to use the two through-arterials or make a circuitous trip on the east-west road to other, more distant routes to downtown. .

We began by looking at district itself and the existing streets and development. However, because only the major arterials and a few developments are slated to be preserved, we focused primarily on new development concepts.

Here, our objective was to develop alternatives that would simultaneously accommodate many work, shopping and school trips on site, mostly by walking and biking, and facilitate transit use to connect to other parts of the city, reducing peak period auto traffic. In accordance with the city's criteria, we developed a land use plan that accommodated between 100-130,000 people, and provided local jobs in retail, service, and office establishments for a nominal jobs-housing balance. We concentrated higher densities and employment along the main arterials and BRT routes, and placed all residential areas within walking distance of transit and retail. In recognition of the district's location behind a levee and its high water table, we also included a central canal in a linear park through the site, which could serve as drainage in case of flooding.

Our street designs reflected the anticipated transport mode share for the city as a whole, which officials projected as about 25% cars, 25% transit and 50% walk and bike. The street plan is based on a dense street network with blocks of no more than 120 x 120 meters (400 x 400 feet) to facilitate pedestrian and bike movement. We also designed a hierarchy of streets, whose size and function is matched to the adjacent and nearby land uses and levels of anticipated activity. The streets and intersections are designed to accommodate all transport modes, which required new design solutions for handling turning movements for bicycles and high volumes of pedestrian crossings, as well as cars and both local buses and bus rapid transit (BRT). We used modeling software to ensure that our block layout and land use requirements were compatible with sustainable building design with regard to access to daylight, passive solar heating and natural ventilation. We also used traffic analysis and simulation software to determine how well the street designs would function, under different assumptions about the percentage of trips that would remain on site versus travel to downtown and other major destinations.

In the remainder of the paper, we discuss the elements of the plan that are particularly critical to its overall performance: the district street network, the major arterial connecting to downtown, intersections and their performance, and sustainable building design.

THE PLAN FOR THE LUOKOU DISTRICT

Designing the district's street network

The problem of the existing network is not only the small number of streets, but also lack of connectivity. A significant percentage of the street network is made up of very narrow alleys that do not always provide direct connections across city blocks. The result is that through traffic is concentrated only on the main arterials. Currently, around 18% of the total land area in Luokou is used by streets, with block sizes of over 600 meters (2000 feet). The earlier plan for the district proposed a similarly small number of streets.

Chinese planners are sometimes reluctant to increase street space because it will increase the public costs of road maintenance. However, our calculations show that the number of blocks can be increased from 45 in the initial proposal to 129, with block faces reduced to a more walkable 120 meters (400 feet,) by increasing the land devoted to streets by a modest amount, to about 23%. With 23% road space, Luokou would still have a significantly lower street percentage of its land devoted to streets than downtown San Francisco, or Manhattan, for example, which both stand at over 30%, according to our calculations. With the increased number of streets, the resulting block sizes would be more conducive to non-motorized modes, as the finer grain network would allow more paths that are direct across the district and would provide more street crossings. The key is to also restructure the network to provide more connectivity and more direct paths through the district.

The current street network is composed of only two types of streets, major arterials and small alleys for local traffic (figure 1a). Our plan introduces a hierarchy of streets, ranging from the existing major arterials, to narrow neighborhood streets (figure 1b). The major arterials would continue to carry every type of traffic but would have more intersections than under current design and would require sophisticated traffic signal timing. An additional street type we introduce is the minor arterial, which would carry feeder bus lines to the BRT stations on the major avenues, and would feature wide bike lanes. We also introduce traffic-calmed streets with one narrow lane in each direction, where street design features would allow motor vehicle use but only at low speeds. The traffic calmed streets would include both bike lanes and sidewalks and would handle some through traffic, but would not accommodate bus routes. They would connect in some cases to the major arterials but cross traffic might not be permitted. Finally, neighborhood streets would be provided for local access only.

Figure 1 – Luokou street network

1a (top) – existing street network; 1b (below) – our proposal for restructuring the network

Connecting to downtown: Jiluo Avenue and the importance of a multimodal approach

Jiluo, the main road linking the district to the city center, extends far beyond the project site and the project's planning control. Even if the mixed use development and denser street network we propose would relieve some of the pressure on Jiluo, problems seem unavoidable if this one arterial must handle most of the traffic heading downtown. While a second arterial does connect through to other districts from the western edge of Luokou, it is neither as large nor as direct as Jiluo and is not likely to carry even half of the inter-district traffic. Other routes exiting the site are circuitous (e.g., using the ring road to reach other major arterials) or continue only a short distance before requiring traffic to return to Jiluo.

If Luokou land uses were able to capture a high percentage of the trips its residents make and as a result, few trips were generated to or from the district, our preliminary analyses indicate that the district street network could handle the traffic. However, if Luokou develops primarily as a residential district, so that large numbers of work trips are outbound towards downtown, Jiluo would almost certainly become heavily congested. In order to gain a better understanding of this situation, we simulated traffic conditions for the AM peak hour on Jiluo.

Lack of access to robust data was a major constraint in performing this traffic analysis. Without the necessary information to accurately model travel demand in the new development, we had to rely on a series of assumptions. In the absence of local trip generation rates we used rates from US sources (*SANDAG 2003*) and assumed that trip origins would be proportional to the sum of parcel-level trip generation estimates (based on land use and sq. meters of development) along each street. We adjusted these trip numbers to reflect the anticipated mode shares in Jinan, where long distance trips are split between not only between cars and transit, but also include trips by bikes and electric bikes. We knew the current mode split in Jinan, and assumed it would be the same for Luokou.

Since Luokou is connected to the rest of the city by only two roads, Jiluo Avenue and a second, less direct route, all traffic bound for downtown would have to use one of these two routes, and our assumptions involved only the proportion of traffic carried by each street. We then tested different scenarios, considering both work and non-work trips in the am peak.

In the first scenario, we allocated half the peak period traffic to the peak hour, consistent with current travel patterns in the city. We estimated that some 4,000 cars, 5,500 bikes (regular and electric) and 31 articulated buses (150 passengers/bus) would travel southbound during the AM peak hour. With three car lanes in each direction, even with almost 70% green time for through traffic on Jiluo, it was clear that the street could not handle this traffic level; the queues spilled back to block the downstream intersections. We did not consider adding car lanes as a solution, since the focus of our work was to give priority to transit, walking and biking and the street is already very wide. Adding car lanes would have worsened conditions for the other modes, and this was not justified from a sustainable development perspective.

In a second scenario, we assumed that, due to congestion on Jiluo, 40% of the peak hour traffic would divert to the other, narrower arterial. This reduced southbound traffic on Jiluo to 2,400 cars, 3,000 bikes and 18 articulated buses. In this case, the queues along Jiluo stopped short of downstream intersections, and the road network could handle the traffic flow exiting the district, though operating close to maximum capacity. However, further south of the site, other development is already using a significant share of Jiluo's capacity; Luokou cannot claim it all. The diversion to other paths thus simply moves the bottlenecks to other locations.

The traffic analysis highlights the importance of strategies for jobs-housing balance, to reduce the number of commuters to downtown by providing sufficient jobs in Luokou and making sure that the type of housing and public amenities provided match the type of jobs present on site. In addition, our analysis suggests that greater attention should be given to efforts to increase people throughput on Jiluo and other major streets through effective transit planning.

Encouraging other modes

Observations elsewhere in the city have found that motor vehicle lanes are frequently carrying under 500 veh/lane/hr, mostly because of congestion and conflicts at intersections. In comparison, transit lanes, bike lanes and sidewalks all have the capacity to carry larger numbers of people.

Our proposal for Luokou includes provisions for encouraging the use of transport modes that are less space intensive. For short distance travel, we gave walking and biking the highest priority. All our street designs incorporate bike lanes and bike parking facilities. We set a minimum sidewalk width of 3 meters (10 feet), but often used sidewalks up to 8 meters (25 feet) wide on major streets, with continuous tree canopy to create a comfortable environment in the summer, and landscaped medians or parking lanes between sidewalks and car lanes, for added safety. For longer trips, we gave priority to BRT, bikes, and e-bikes. On large arterials, such as Jiluo, we provide separate lanes for regular and e-bikes, so that they may travel at different speeds.

The BRT system in Jinan has been developed as a separate project that began well before our involvement with Luokou. By the time we began working on a plan for the district, the decision to locate a BRT line on Jiluo Avenue had already been made. We estimated the likely ridership on this BRT route as part our analysis of the Luokou district. This estimate should be taken with precaution, since the data available to us was rather poor. Based on the expected mode split in Luokou, the BRT should account for 25% of all trips. Based on the projected population, as well as the land use plan, we estimated the amount of outbound bus trips that would be generated during the AM peak hour to be approximately 4,000. Accommodating this many riders would mean running a fully loaded articulated bus every two minutes (150 passengers / bus). It is technically possible for a BRT system to carry more passengers than that, by running buses in convoys, or using longer stations that allow buses to overtake. The problem in Jinan, however, is the congestion at major intersections, which is causing the BRTs to experience significant delays. The actual capacity of the BRT corridor will therefore be significantly lower than what would be theoretically possible.

Managing multimodal intersections

In the current street configurations, safety is a major concern for non-motorized transport modes. Every year, about 25,000 pedestrians are killed in traffic accidents in China, over twice as many as in the United States and the European Union combined (*Yang and Otte 1999*). An estimated 60% of traffic fatalities in China involve pedestrians and bike riders (*Weinert et al. 2006*). Our own observations suggest that this is due to both driver behavior and poor street design.

The large block sizes in Jinan and other Chinese cities mean that distances between signalized pedestrian crossings can exceed 600 meters (2,000 feet). Thus a short journey from a residence situated in mid-block to a store just across the street, for example, can become over 1.2 kilometers (4,000 feet) long. Pedestrians frequently choose to simply cross mid-block, in unsafe conditions, rather than walk the extra distance to the signalized crossing. Our proposed street network, with smaller block sizes, provides a street crossing every 120 meters (400 feet), or approximately five times as many crossings as the current configuration. We assume each would be signalized.

For bicycles, however, even signalized intersections can be unsafe if bikes are not given their own signal phases. This is particularly true for bikes trying to make left turns at major intersections. Since, in current street configurations, bike lanes are placed between car lanes and sidewalks, a left turn for a bike involves crossing all lanes of traffic, usually without a protected left turn signal.

According to the projected mode split for the Luokou district, regular and electric bicycles together will capture an estimated 67,000 daily trips in 2020, 30% of total travel. Pedestrians will account for an additional 20% of the trips. It therefore is crucial that street designs, and especially intersection configurations, carefully consider bike and pedestrian movements.

We developed guidelines for how the intersections between each type of street should be configured, focusing on pedestrian crossings and bike turning movements. The very wide existing streets, which will be retained in future plans, posed major design problems. A pedestrian moving at a speed of 1 meter (3.3 feet) per second (*Knoblauch et al. 1996*) would need 80 seconds to cross the 80 meter wide Jiluo Avenue. A bicycle moving at an average speed of 6 meters (20 feet) per second (*Khan et al. 2001*) would cross Jiluo in about 14 seconds. In reality, since bicycles and pedestrians stop at a red light and queue, this time would be even longer for the entire queue to clear.

Given the large volumes of traffic expected on Jiluo, it seems unrealistic that cross streets could have over 80 seconds green signal time. The solution used in many Chinese cities, underpasses or overpasses, can work, though these options are costly to build, maintain, and provide security. They are not entirely effective, however, as pedestrians may continue to cross on the street level against the light or midblock even when there is an overpass or underpass. Another solution would be to acknowledge that pedestrians would not be able to cross major arterials in one phase, and to provide pedestrian refuges midway across major arterials. Still another approach would be to limit most street widths to four lanes or less, in order to allow safe and convenient crossings for slower, non-motorized modes. However, as the next section discusses, wider streets may have advantages from a building energy perspective that also should be considered.

Integrating building design: street width and building energy use

As noted earlier, decisions made in the context of transportation and land use projects, such as street widths and building densities, can have significant impacts on building energy use.

In order to gain a better understanding of the situation, we used building energy modeling software, Energy Plus, to simulate the performance of a typical building in Luokou. We defined our typical building as an eleven-floor apartment building, with all units facing south. The building was placed on the north side of an east-west street, which was lined up with buildings of similar height. We determined that an average height of eleven floors was appropriate for the levels of density required for this district.

We ran a series of simulations of building energy use in the climate of Jinan, based on weather data from the US Department of Energy, comparing the energy used for space heating, depending on street dimensions. We found that when increasing the street size from 15 meters (45 feet) to 25 meters (90 feet), ceteris paribus, building annual energy use for heating went down by 11%. The explanation was that, on a wider street, the building on the northern side had more access to direct sunlight, which they could use for passive solar heating. When increasing street width from 15 meters (45 feet) to the size of a major arterial, 100 meters (300 feet) heating energy use went down by 20%.

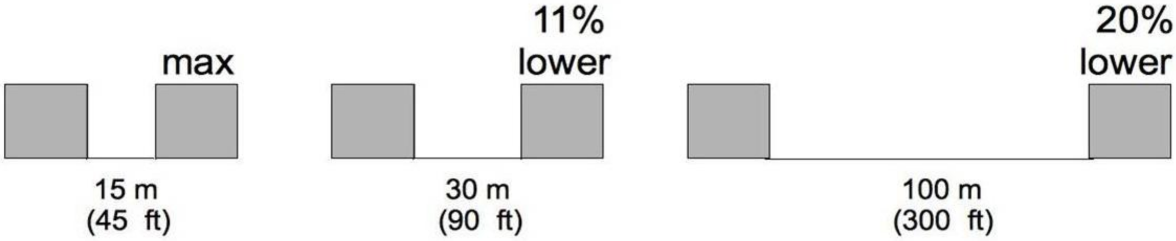

Figure 2 – Relationship between street width and building energy use (space heating)

The 20% reduction in space heating loads should be regarded as a conservative estimate. According to our calculations, it is possible, through very aggressive design techniques (very high thermal insulation, extremely high performance windows) to lower heating loads by as much as 50%. Space heating is the most important component of building energy use in China, accounting for over 54% of the total (*Dadi et al. 2003*).

Since this represents annual energy use, there was a corresponding increase in energy use for cooling, due to the unwanted solar heating in the summer. However, this problem can be remedied by adding appropriate window shading, which protects indoor spaces from overheating during the summer, while taking full advantage of solar heating in the winter. Due to the nature of the local climate in Jinan, with a longer heating season, buildings situated along wider streets will generally have a better environmental performance than those along narrower streets.

Street width also influences the amount of useful daylight that penetrates into a space. This is particularly important for commercial and office buildings, where lighting is a significant energy load. Using the same three street widths from the previous example, we ran a different simulation, analyzing the amount of daylight in a typical office space, and how it changed with street width.

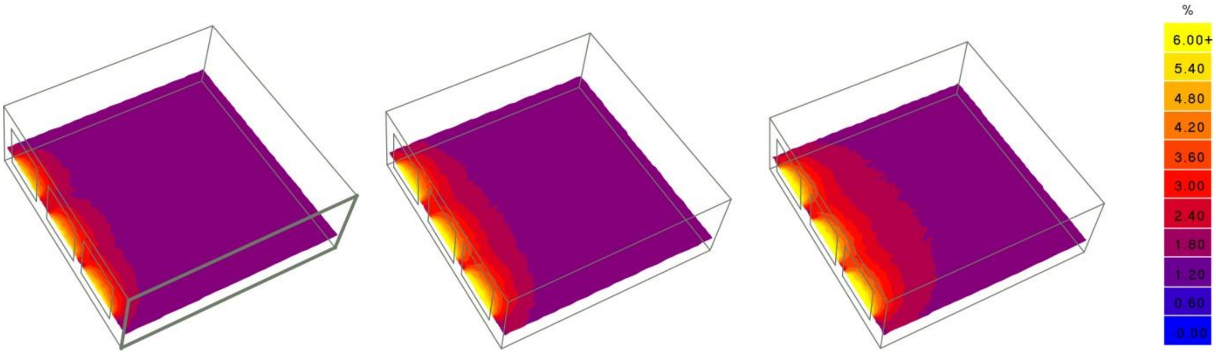

Figure 3 – Daylight factor in an office space on a 15m, 30m and 100m wide street

The building on a wider street will always have more daylight available than one on a narrower street, offering the possibility to use fewer lighting fixtures during daylight hours and thus save energy. As opposed to the heating and cooling loads, this relationship does not depend on the local climate, and is universally valid.

Based on our building energy analysis, we estimate that, by carefully considering building energy requirements in the early phases of planning a neighborhood, it is possible to reduce overall building energy consumption by over 25%. In the case of Jinan, this involves using generally wider streets.

Having previously noted the accessibility problems posed by wider streets to non-motorized modes, we sought a compromise between considerations for transportation sustainability and improved building performance, illustrated in our street design concepts (figure 4).

ASSESSMENT

Looking at Luokou and its larger urban context from the different perspectives of transportation, land use, and building energy performance, we have identified a number of simple solutions to existing problems.

Increasing the connectivity of the network by using a grid pattern can significantly lower block sizes, with only a limited increase in total street area. This is important in order to distribute traffic over a larger number of routes, and provide more crossings for pedestrians. It does, however, require many more traffic signals and more sophisticated signal timing plans.

Simple design solutions, such as a continuous tree canopy over sidewalks and bike lanes, continuous street frontage with ground floor retail, adequate street crossings, and careful intersection design can significantly improve conditions for non-motorized modes, and promote their use. This applies to both medium and long distance bike trips, and to biking and walking to nearby amenities. By encouraging the use of transport modes that are more energy efficient and less space intensive than the private car, we can reduce greenhouse gas emissions per kilometer traveled, and increase passenger throughput on major arterials.

Another important lesson learned was that looking at sustainable development only from a transportation or building performance perspective, without considering how urban systems interact, can result in important issues being missed. If, for example, we were concerned only with transportation sustainability, we would want to maximize building density in the vicinity of transit stops, in order to increase transit ridership. However, our building energy simulations have shown that, beyond a certain point, increasing building density lowers the potential for effective environmental design. Previous studies have also highlighted the problem of reduced potential for environmental design in high-density urban environments, mainly due to overshadowing (*Chrisomallidou 2001*). On the other hand, focusing exclusively on building performance can lead to recommendations such as increased setbacks, or a very low building density, which in return can adversely affect the pedestrian environment, or even lower transit ridership.

By studying the different systems together, and considering their interactions, we were able to provide a set of recommendations for Luokou that consider the implications on a broad range of urban systems, from transportation, to land use, building design, and open space. We placed the highest buildings along the widest streets, and along major arterials, so that they have the best access to sunlight. Since major arterials are also BRT corridors, this made sense from a TOD perspective, by increasing density in the proximity of transit stations. Whenever we wanted a narrower street, we also used a lower building height along the street, to enhance the building's energy performance. In cases where buildings had to be higher and we did not want to add more car lanes to a street, we kept the same street size, measured curb to curb, and chose to widen sidewalks and bike lanes instead (figure 4).

Figure 4 – Example of street and building design

We recommended a range of residential densities throughout the district, between 54 and 109 units per acre, depending on the land uses present on the block, as well as a range for floor area ratios (FAR) between 2.6 and 2.9. These densities are high enough to promote extensive transit use, walking and biking. In addition, our building energy simulations indicate that by limiting FAR and residential densities to these values, we ensure optimal solar and daylight access for buildings, which is a key feature of sustainable building design.

These density specifications are combined with urban design guidelines that control the quality of the pedestrian environment. We provided detailed recommendations on street design types, intersections, street sizes, and on associated building elements such as heights, window to wall ratios, façade thermal performance criteria, and specifications for window shading devices.

These guidelines do not simply seek to optimize the performance or the sustainability of a building, block, or street. Instead, they represent the best level of performance of one system, without having an adverse effect on other urban systems. They are a series of compromises between transportation, land use, and building design, in order to promote truly sustainable urban development.

FURTHER RESEARCH

While this project dealt with a specific site, the Luokou district, our findings have implications other areas in Jinan, and other Chinese cities as well. Issues such as long block faces, low capacity street networks and the resulting congestion are present in many other Chinese cities. Like Jinan, most of these cities have residential and employment densities that are high enough to support high quality transit service, yet street and intersection designs often prioritize car traffic and discourage other modes. Given that most urban street networks in China have relatively lower capacities compared to those in the US or Europe, they experience higher congestion at much lower auto ownership levels. In this context, the most successful transportation policies are those that promote less space intensive transport modes. For this reason, TODs as well as pedestrian and bike oriented street designs show promise for promoting sustainable urban development in Chinese cities.

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