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Sustainable Cities: Reconsidering China's Urban Residential Policies*

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Abstract

Rapid urbanization, especially in developing countries, means that the worldwide tradition of low-rise housing is giving way to living in urban apartments. This implies huge environmental and sociocultural changes. For sustainability, dense and high-rise cities offer some advantages, but negative aspects too, especially for residential areas and low-income groups. A widespread residential model, in China and elsewhere, is high-rise urban "superblocks". However, equally high population densities can be achieved in several ways, including quite low-rise, with equal energy efficiency as well as other environmental and social qualities. Building on analyses of some urban blocks in Ningbo, China, we explore current trends and assess options for sustainable living in future urban residential areas. This paper delves into ten key points related to the overarching goals of sustainable and low carbon-cities. In particular, the arguments support low-dense urban design paradigms against high-rise urban superblocks. By exploring the case of Ningbo, China, we map some existing urban residential typologies and compounds. Through a comparative analysis, the study then focuses on key factors for reconsidering China's urban residential policies, and towards sustainable city paradigms.

Keywords

Sustainable Cities, Low Carbon Cities, Energy Efficiency, Urban Density, Sustainable Living, Urban Block, Low Dense

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1. Introduction

Whilst our focus in the context of this journal is primarily on energy/carbon, sustainable planning demands a holistic view, and we consider it essential to note briefly, broader economic and social considerations which necessarily enter into the complex task of urban planning and policy. In this paper, we refer principally to carbon; the energy implications are broadly similar as long as energy supplies are largely fossil fuel based.

City planning goals include all three areas of environmental, economic and social sustainability. Recognised "eco-city" objectives include improved urban microclimate, reduced heat island, low carbon footprint, mixed use, walkability, economic diversity and social cohesion. Resilience, the quality of adaptability and robustness over time, is a key goal that applies to all three areas. Choices as to *what kind of urban form* have large implications for energy and climate.

Cities have often evolved on the basis of economic factors linked to local resources, industry or favorable trade location. Rapid growth has often been at the expense of local environments and, ultimately, of living quality too: "*Hong Kong's first large-scale sustainability research initiative* (Barron & Steinbrecher, 1999) *has revealed the astonishing deterioration of the environment. The main environmental problems are associated with over-concentration due to high-rise and high-density development, and include poor air quality, water depletion, noise, and excessive waste production*" (Zhang, 1999). A central focus of our earlier research (ELITH Research Program, n.d.) is cities in hot climate developing countries. This is where most growth is occurring, where new urban millions are acquiring cars and energy amenities, and also where residential conditions for the poorest groups are worst. Rapid growth often implies hasty, poorly prepared or controlled urban development. The field of energy is one example; in countries like China and Thailand, which have good levels of skills and of governance, we hear that it is "too early" to pose strict requirements for energy efficient buildings. Many developing countries do not have the skills or governance needed to implement such measures at all. Hence, many cities are locking themselves into huge future energy use and climate emissions.

Principles for sustainable urban design are recognised and may not even cost more. Without substantial changes in how we plan and design cities, such principles are often neglected in the rush for development, coupled with a rather unquestioned belief in the high-rise model and the outdated zoning paradigm of the modernist era, as opposed to the mixed-use that is essential for eco-cities (Niemets et al., 2021). In addition, high priority is still given to private car transport which has great impacts on both the ecological and social characteristics of cities. Alongside the positive dynamic qualities of megacities, their scale and complexity imply very strenuous administration and governance, including for infrastructures, transport, energy and other services. Whilst the "compact city" offers potential advantages, it equally implies a "compact" concentration of negatives: high land prices, congestion, air pollution and noise. In some developing countries, these often result in poor sanitation, increasing urban poverty and low quality living environments. As a result, low-income residential areas may be especially disadvantaged in all the above.

What, then, are best options for future sustainable city living? The relatively new perspective of sustainability, both global and local, requires us to consider choices of urban form in integrated ways that address all three aspects of sustainability. Competing paradigms for cities include low-dense European typologies, "garden cities", modernist zoning and dense high-rise. Historically these have been evaluated largely on *economic* and *social* criteria, not *ecological*. Taking existing trends of residential housing in Ningbo, China as starting point, in this paper we discuss how today's essential focus on the third area ecology, including energy use, climate emissions and carbon footprint sheds new light on the suitability of options such as high-rise and low-dense.

Life cycle analysis is applied more often to individual buildings than to urban development as a whole. Given the goal of sustainable and low-carbon cities, some important "new" perspectives emerge which deserve attention when deciding which urban housing forms to choose. This paper highlights ten such points. They suggest that the low-dense paradigm merits revisiting, due to a range of advantages as regards sustainable design. embodied energy/carbon, recurrent costs, renewable energy, post-use and long term resilience, which have been little discussed in the research literature.

2. Urban Paradigms: Density

A widespread trend is that of high-rise urban living. Is this necessarily best, or most sustainable? One main argument is said to be the need to house many people in very compact cities. However, this is not strictly true; equally high population densities can be achieved in several ways, including quite low-rise (Salat & Mertorol, 2006; Cheshmehzangi & Butters, 2017). These have been shown to have equal potential for excellent energy efficiency, and reasonable cost, as well as possible qualitative advantages.

Densities are illustrated here with examples from studies in Ningbo, with comparisons to studies elsewhere. Previous studies of residential typologies in Ningbo (Cheshmehzangi & Butters, 2015) identify the trend of mid- to high-rise superblocks. Top-down, large scale master planning of residential blocks is the norm. The lack of climatic and energy design and lack of analysis of how residential blocks are shaping social qualities in the cities are main concerns of this study.

Many studies such as LSE Cities/EIFER (2014) and (Jabareen, 2006) provide detailed insights into how various typologies perform, both in energy, economic and social terms. Comparisons from various sources (**Table 1**) show typical differences in average building heights, Floor Area Ratio (FAR) and Surface Coverage (SC) of various typologies. The superblocks are often gated communities and contain very little mixed use, normally limited to small retail and catering

Table 1. Urban density comparisons.

Urban Typology	SC	FAR	Average height
1) Ningbo low-dense traditional	0.50	1.4	2.4
2) Ningbo 6 storey block	0.23	1.2	5.0
3) Ningbo high-rise block	0.17	2.6	15.5
4) Jinan low-dense traditional	0.54	1.2	2.2
5) Jinan grid 1920s	0.31	1.7	5.8
6) Jinan enclave 1980s	0.34	1.8	5.3
7) Jinan superblock 1990s	0.22	2.0	10.1
8) Europe, detached housing	0.10 - 0.30	0.2 - 0.7	1.5 - 2.5
9) Europe, row/terrace housing	0.15 - 0.35	0.5 - 1.0	2.0 - 3.0
10) Europe compact city block	0.35 - 0.55	1.5 - 4.0	4.0 - 6.0
11) Europe slab housing	0.15 - 0.40	0.6 - 2.0	3.5 - 6.5
12) Europe modernist high-rise	0.10 - 0.25	1.0 - 2.5	8.0 - 14.0

Sources: for Ningbo (ELITH Research Program, n.d.) for Jinan (Jabareen, 2006), and for Europe (LSE Cities/EIFER).

outlets along the perimeter. The high-rise buildings have low surface coverage; but whilst the FAR and hence population density is up to twice that of older, traditional neighborhoods, it is not more than that of low-rise models such as typical city blocks in European and other countries.

The megacities of hot climate developing countries, where air conditioning is spreading rapidly, are experiencing increasing urban heat island effects. Crowded conditions and lack of energy amenities may, in a warming world, lead to very poor living conditions and increasing mortality. And whereas *high quality* high-rise may provide satisfactory living conditions, *low cost* high-rise may often lead to little better than "vertical slums".

In particular, for lower income groups, the 10 points below suggest that low-rise may offer advantages both in terms of ecology, costs and community. High-rise type housing developments also require correspondingly sophisticated infrastructures. In eco-technical terms, low-rise buildings allow for simpler materials and passive solutions which are a key to economical eco-design. They can be low cost. As evidenced both by traditional city neighborhoods and recent successful European eco-districts, they can offer variety, user satisfaction and social cohesion. Prioritizing relatively simple housing typologies may, in addition, avoid some of the technical, logistical and management challenges that developing country cities may have limited capacity to tackle.

3. Case Studies: Urban Blocks, Ningbo

In a typical urban area of Ningbo of around 1.5 km^2, comprising mainly residential blocks, one finds a variety of urban layouts (Figure 1 and Figure 2 and Table 2). All except block E are recent blocks. At present many have low occupancy due to rapid growth. Blocks E and H are two distinctive typologies of low-rise and high-rise respectively (Figure 3 and Figure 4), with similar surface coverage of 0.23 and 0.17 (Table 1). The six-storey block (E) has a fairly dense grid pattern with only a few internal green spaces. The newer high-rise block (H) has residential towers grouped around a large central green space. Both have some commercial units along the main street edges.

Figure 1. Study area of Yinzhou District, South Ningbo, China. Highlighted blocks indicate current occupancy below 70%, which also means there are large scale urban residential compounds with lower efficiency in occupancy and energy.

Figure 2. Section of the Yinzhou District highlighting the different urban masses of the two residential blocks studied, indicating the differences between two main variables of height and density between low-rise housing and high-rise urban apartment typologies. Block E is a typical example of low-rise typology, mostly common for construction before 2000. Block H, on the other hand, is a typical high-rise typology, generally common in recent two decades in most mid-sized and large-sized cities in China.

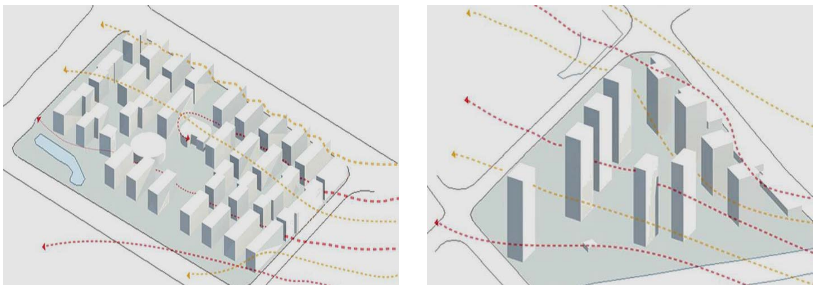

Figure 3. Blocks E (left) and H (right): heights, densities, and indicative summer wind flow. The analysis suggests ways of wind flow in between high-rise urban blocks vs. opportunities for cross ventilation in the low-rise typologies.

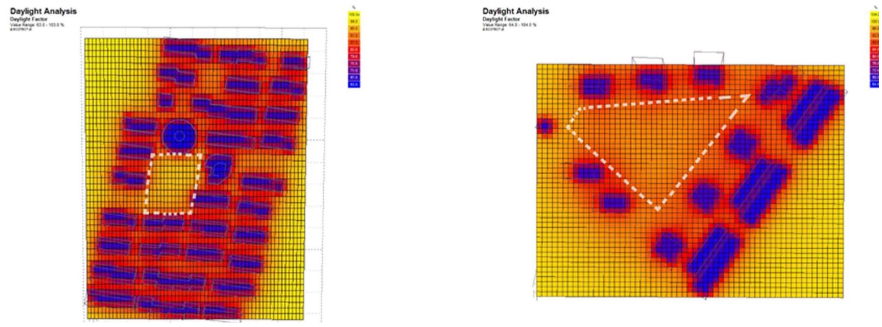

Figure 4. Blocks E (left) and H (right): comparative analysis of main open spaces and indicative summer insolation/daylight analysis. The analysis of Block E a denser urban layout and low-rise typology, with opportunity of having public places and shared spaces between the residential buildings. In block H, we see large open spaces, smaller building to plot ratio, and higher coverage ratio for green spaces, internal roads/paths, and parking spaces.

Table 2. Urban Block details and typologies (source: authors).

Block	Status	Occupancy now	Functional typology
A	Completed	Very low	Commercial + mixed use (no residential)
B	Under Construction	n/a	Commercial + mixed use (no residential)
C	Mostly completed	Occupied	Public Services
D	Under Construction	n/a	Proposed residential
E	Completed ca. 1990	Fully Occupied	Residential + commerce on street edge
F	Vacant	n/a	Awaiting development (residential?)
G	Under Completion	n/a	Public Services and Commercial
H	Completed ca. 2005	Most occupied	Residential + commercial on street edge
I	Completed	Occupied	Public Library
J	Completed in 2012	Low	Residential + commercial on street edge
K	Completed in 2012	Very Low	High-end residential

Whilst there were fewer cars in the 1990s, available surface areas in block E are now largely filled by cars. This alone has altered the spatial planning of residential developments, the number of parking spaces now being based on the number or size of residential units; e.g. one parking space per 100 m^2 of residential unit in the City of Ningbo. The newer block H has very extensive underground parking (Figure 3 and Figure 4). As we discuss below, both the cost and the carbon consequences of this are considerable.

Given the rapid pace of development, block E is almost certainly to be demolished and redeveloped into high-rise very soon, even though it is barely 20 years old. This typology is similar to social housing models in mid-20th century Europe, with the difference that in Europe, generally a maximum of four floors were permitted without a lift. In China such housing units are up to seven floors. Table 3 compares the layout, density and some performance features of these two blocks. In terms of energy and ventilation, several positive features of block E are evident.

4. Key Finding and Discussions

Powerful arguments can be found both for and against the "compact city" idea, which has been widespread in recent years. On the other hand, the social and community qualities of low-dense developments are well recognized. It is in particular with regard to energy efficiency and climate emissions that considerations of sustainability emerge. We now highlight 10 points where these may have important implications for urban planning choices. These are particularly, though not only, relevant to residential typologies.

4.1. Land Use and Population Density

Arguments for dense, high-rise residential development include shortage of land and the need to house many people in a compact way. This is not strictly true. An equally high overall density, measured in FAR or dwellings per hectare (dph) is achievable with quite low-rise. As shown in the very comprehensive LSE/Eifer study (2014), typical blocks in European cities like Paris, with six to eight floors, have a FAR of over 3.0 and even 4.0. This is not just equal to but considerably higher than the super blocks in Ningbo and similar cities.

Traditional housing in many cultures has been low-dense, from Mediterranean towns to North African *medinas* or Chinese *hutong*. These are often favourably situated and formed in ways that exploit local microclimate. Highly

Table 3. Comparison of blocks E and H.

Block	Spatial Layout	Density	Performance
E	One main communal space; minimal green areas; surface parking (very limited).	FAR 1.2; SC 0.23 Compact building layout of 10 m unit width and 17 m between units.	Cross-ventilation for all units; moderate energy consumption, 1 - 2 AC (air conditioning) units per apartment. Limited glazing. Solar access to all units. No units facing North, East or West
H	Large (gated) communal green spaces; surface and underground parking (for most not all units).	FAR 2.6; SC 0.17 High-rise clustered layout, 25 m deep blocks with 25 m or more between units.	Mostly one-sided units with no cross-ventilation, and poor daylighting; higher energy consumption, 2 - 4 AC units per apartment. Many units facing only North, East or West.

pressured megacities, on the other hand, often have to expand into climatically suboptimal areas such as flood plains or poorly ventilated valleys; or into ecologically valuable agricultural land and green areas. This may lead to residential development in unfavourable areas for both energy efficiency and living quality. Whilst high-rise may be necessary for some city centres, land use is not the real issue. From the perspective of population densities as well as from the *ecological* perspective of land use, dense and high-rise solutions offer no notable advantage, and significant downsides.

4.2. Urban Microclimate and Green Space

The megacities of the developing world are experiencing increasing urban heat island effects (UHIE), with associated discomfort and mortality. Green spaces have many important functions including microclimatic amelioration, urban ventilation, socialising and recreation (Yu & Nyuk Hien, 2006; Zhang et al., 2014; Cheshmehzangi et al., 2021a). The biodiversity hypothesis also posits that access to nature is a key to health and wellbeing (Hanski et al., 2012; Haahtela et al., 2013). Do high-rise residential typologies, in the typical large urban blocks, favour good living environments?

As regards ecological considerations such as urban microclimate with resultant energy needs for cooling, high-rise blocks do offer more ground level green space, plus that cleaner air and more air movement are available to high buildings. On the other hand, many countries show good microclimate solutions in low-rise traditional typologies, in both hot-and-dry and hot-humid climates. High-rise may cause unfavorable wind pressure zones and eddies. It may also be noted that with low-rise, as in the Ningbo six-storey block, very useful tree shading can extend up to three or four floors, but not higher. Vegetation design can thus provide shade and cooling as well as privacy in low-dense areas but far less so for high-rise apartment buildings.

It can also be noted that the interior landscaped areas in typical high-rise blocks are often little used and are designed primarily from an aesthetic standpoint only; whereas the green (and blue) infrastructures can and should be designed to enhance microclimate, water infiltration, low albedo effect and other specific ecological design objectives. Hence, high-rise is not necessarily "better"; and as illustrated in the block H example the green spaces are limited in size as well as functionality and biodiversity. Heat island effects may be better mitigated by larger (and truly public) urban parks at regular intervals. The potential cooling effect of around 2 - 3 degrees demonstrated in many studies, such as Chen and Wong (2006), offers a major reduction in space cooling needs.

4.3. Building Services and Infrastructures

Building services, especially for ventilation, lifts and stairs, tend to take up large amounts of space in high-rise buildings. This has a significant impact on space usage and embodied carbon as well as on construction cost. In low-dense housing solutions, these requirements are significantly reduced, and they can be executed with simpler materials and technologies. This is doubly relevant for low-cost contexts.

Another common argument for large-scale, dense urban development is economies of scale. This is not always valid. There appear to be important cost considerations as regards low-dense compared to compact city infrastructures: "*The cost increase from the low to the medium-density scenario is nearly 100%, while the cost increase from the medium to the high-density scenario is just over 50%*" (Barter, 2000). These again pertain especially to low-income housing contexts: "*High demographic growth, low levels of economic development, high income inequalities, small urban budgets and shortages of environmental infrastructure, shelter and basic services have a critical effect on densification policies and the effectiveness of policy instruments. The merits of densification at a high level of development may disappear at a lower level and be counterproductive without significant improvements to this level*" (Burgess, 2000). Whilst the above sources focus on the economic aspect, the costs correlate broadly with higher energy use and emissions.

4.4. Renewable Energy Supply

Renewable energy supplies (RES) integrated into the roofs and facades of buildings in the form of photovoltaic panels (PVs) can cover the entire energy demand when it is as low as in *passivhaus* type buildings. There is, equally, over a decade of experience with buildings that produce more energy than they need (**Figure 5**). However, this is *only* possible in low-dense typologies. A PV roof on a skyscraper will provide only a small fraction of the required power. Similarly, passive solar heating cannot be maximised with high-rise buildings which shade each other from part of the solar radiation. It is also recognized that deep buildings have inherently higher energy demand (Steemers, 2003).

Figure 5. High-rise apartments, Ningbo block H: inappropriate climatic design with only a few of the apartments facing south and less opportunities for cross-ventilation, double-sided ventilation, and natural lighting (source: the authors).

Here again, advantages of low-dense solutions apply not only to housing. In dense cities there are naturally economies of scale and energy efficiency gains to be found in large systems, not least district heating and/or cooling. However, it is a broadly accepted goal that as much as possible should be covered by on-site renewable energy generation. If so, low-dense housing options offer a considerable advantage.

4.5. Design Factors

Dense city typologies narrow the choices for ecological design, eliminating quite many recognised solutions. In inner cities, one can seldom choose climatically favourable sites or building orientation. One cannot use courtyards and similar vernacular housing solutions to create an improved microclimate. Local materials will be less applicable; and lightweight materials, preferable in hot-humid climates, are less feasible in high-rise city buildings. Equally, in consideration of the low-income contexts, complex urban residential buildings render self-build or user-led management and maintenance impossible.

Several factors make it challenging, or expensive, to design low energy buildings of high-rise type. Solar protection, one of the absolute keys to low energy design in hot climates, is difficult in high-rise since more of the facades are exposed. Many units have unfavorable East or West orientation. Technologies to reduce solar gain are mostly expensive and seldom applied. Other units in the high-rises in a climate such as Ningbo's where some winter heating is also needed and sun is welcome, are North-facing only (and fetch correspondingly lower prices).

Further, tall urban buildings are for reasons of economy almost invariably quite deep, requiring large glazed areas, which lead to overheating (Niu, 2004). They tend towards apartments with one-sided ventilation (and poor daylighting), requiring air conditioning, hence increased energy use with mechanical rather than natural ventilation, plus increased energy for lighting. In addition, fire and façade maintenance requirements are far more onerous in high-rise.

The typology of the older low-dense block E, by contrast, permits architectural design using a higher degree of natural ventilation and where all units have sunlight. Low-dense typologies offer more opportunities for regionally adapted, low carbon housing, less dependent on added technology and based on economical, passive design solutions.

4.6. Operational Energy Efficiency

Buildings account for some 40% of global energy use and emissions. The largest energy requirement in buildings has normally been operational energy (OE), mainly for space heating or cooling in cold and hot climates respectively, plus for lighting, cooking, hot water and appliances. In hot climate cities, does a compact, high-rise typology offer advantages in this respect? This appears unlikely partly because the typology itself aggravates the heat island effect, thus increasing the need for cooling. Compact building form a good surface-volume ratio is favourable for operational energy efficiency, but as noted above, not in deep buildings where energy needs for lighting as well as for mechanical ventilation are increased. Detailed studies such as LSE Cities/EIFER (2014) and Jabareen (2006) demonstrate that the overall form of dense or high-rise building typologies is in terms of thermal energy performance, *no better* than low-dense. Between the obviously inefficient extremes of suburban sprawl and excessive high-rise, there is a large range of low to medium-rise solutions that can achieve optimal energy efficiency. Lifetime *operational energy* efficiency can thus be at least as good in low-dense housing, as in high-rise solutions.

4.7. Embodied Carbon

In today's low energy buildings, such as the *passivhaus* type, the operational energy needs are reduced to a fraction, often less than a quarter, of conventional buildings. This means that the energy/carbon required to produce the building itself, principally the production of the materials, becomes far more important. The embodied carbon (EC) is an increasing part of the overall life cycle picture; this trend is reviewed comprehensively in Ibn-Mohammed et al. (2013) and Sartori & Hesnes (2007). For example in a recent sustainable office building in Norway, the embodied carbon is very nearly equal to the operational carbon: 69 versus 75 tons CO_2/year respectively (Future Built Program, 2014). In discussions of "net zero" construction and regenerative design, it is also recognised that it is more difficult generally to reduce the embodied impacts than the operational ones (Cole, 2012).

Studies show that the largest carbon items in a building life cycle analysis (LCA) are often cement products and steel. In a Swedish study of an office building, concrete comprised 69.6% and steel 11.4% of the EC (Wallhagen et al., 2011). In an Italian apartment building these two comprised 76% of the EC (Blenghini, 2009). Cement products (reinforced concrete, mortar and blocks) and steel comprise over 70% of the EC in a Chinese high-rise building case study (Zhang & Wang, 2015). In low-rise, simpler materials can be used. These cannot easily be substituted in high-rise buildings. It should be noted, further, that the *embodied* fraction will increase as operational energy decreases drastically in future low energy buildings.

We need to consider not only the buildings themselves but also the site works associated with different types of housing development. In dense urban projects such as the high-rise Ningbo block, the large green areas between the apartment blocks consist only of a thin green layer on top of extensive engineering works such as underground parking, culverts and other infrastructural services. Embodied carbon will almost inevitably be higher in high-rise structures, as well as their site works, due to the need for carbon-intensive materials such as reinforced concrete (RC) and steel. LCA studies have addressed buildings and seldom the associated site works and infrastructures. The carbon footprint of this kind of inner city infrastructures, including underground parking, may be very large; up to one-third of the total carbon footprint, as a study of the Ningbo block H suggests. This fraction too will increase as buildings themselves become less carbon-intensive.

Two other components of the embodied impacts of buildings are the energy required for transport of materials to site, and on-site energy use. These are fairly minor of the order of a few per cent each: "*Embodied energy is dominated by building material manufacturing, representing 90%, and the share of transportation and construction is 4% and 6% respectively…This proportion is very close to the average value of 18 case studies in Sweden and Denmark examined by Nässén et al: 91% for material manufacturing, 3% for transportation and 6% for construction*" (Chang et al., 2012). These fractions, whilst minor, are also likely to be higher in the case of large urban buildings, where local materials will seldom be appropriate, and where cranes and other energy-intensive site equipment are needed. Here again it can be noted that they will also become more significant as operational carbon decreases in future.

4.8. Recurrent Embodied Carbon

The preceding point pertains to the *initial* embodied carbon in construction materials, or a cradle-to-gate LCA perspective. However, the recurrent embodied energy/carbon inputs over a building's lifetime may for some building components be as much as the initial embodied fraction (Mequignon et al., 2013). Buildings, as well as urban infrastructures, have large requirements for ongoing maintenance, repair and replacement of parts. Complex inner city structures will normally require more onerous recurrent inputs than low-rise areas. Simpler low-rise solutions are less likely to need specialists and are thus more amenable to low-cost housing contexts. Cleaning and repairs may be far more onerous; a particularly demanding example is maintenance of high-rise facades.

4.9. The Post-Use Phase

The post-use environmental impacts of dismantling and disposing of or recycling buildings have been less studied, although it is often considered to be minor. This phase requires more attention. Recycling aluminum for example saves roughly 85% of the energy that would be needed for virgin aluminum; and recycling steel saves over 50%. But recycling concrete requires 5% *more* energy than new concrete, "*owing to increased energy required to break up the old concrete*"; and "*recycling plasterboard is 48% more energy intensive than using virgin material*" (Gao et al., 2001).

Current LCA methodologies do not account satisfactorily for this phase, where a cradle-to-cradle (C2C) perspective is, at least to some extent, necessary. The post-use phase of urban structures may be far in the future, but here too our choice of urban form will have its consequences. The post-use impacts are almost inevitably higher with dense urban and high-rise housing, compared to low-dense, due to complicated demolition and recycling or disposal of more complex and polluting construction materials and technical components.

4.10. Resilience

Resilience, a keyword in sustainability discussions, has economic and social dimensions but equally technical and environmental ones. This again demands a long term and holistic view of environmental impacts and emissions. Complex, high-rise buildings offer less *flexibility or* "*generality*", hence less resilience to future modification and adaptation, both as regards functional change and technical innovation.

Amongst leading examples of low-dense urban housing in Europe is the Vauban district in Freiburg, Germany (Cheshmehzangi & Butters, 2017; Butters, 2021) (see **Figure 6**). This urban transformation shows ecological, economic and social resilience. It provides a good example of resilient urban building types. Transformed in the 1990s from a former military area, all the buildings were converted to new uses, both residential and commercial. New low-energy "infill" housing has been added. The buildings, largely housing, are typical of many low-dense European city districts that have shown to be easily transformed to low, even zero energy housing. Many of these typically older buildings are being successfully "greened" whereas more recent, large-scale urban ones are being demolished after less than 50 years. These examples, despite being fairly low-cost (and involving the users), demonstrate types of buildings that due to their low-dense and construction characteristics can be refurbished to very advanced energy efficiency standards, reducing the operational energy not by 20% or 30% but to near zero.

Further, as regards the embodied impacts, both the Vauban and the Swiss examples underline the important point that embodied carbon is in very many cases best addressed by refurbishing existing buildings rather than demolishing them and producing new ones, given the embodied carbon required for new materials. This is confirmed in LCA studies comparing scenarios of refurbishment versus replacement, such as (Gurigard, 2011).

Figure 6. Vauban low-dense eco-housing district, Freiburg, Germany (Source: the authors).

To some extent, the above supports a broad argument in favor of technical *simplicity* in building solutions. This again applies particularly to housing. Some researchers consider that the trend of extremely energy-efficient *passivhaus* type housing is too complicated and even risky in relation to everyday operation and occupant behavior (Harrysson, 2015); which is even more likely to be problematic in low-income contexts. Hence here again low-dense typologies offer, certainly not the only but certainly favorable options.

4.11. A Brief Summary

Given that some of the above points may not be relevant in all cases, and that some are of fairly minor import, their cumulative significance nevertheless appears considerable. The 10 points do not pretend to be exhaustive but suggest that low-rise options can offer advantages in terms of environment, energy efficiency and climate emissions.

To summarise briefly, the above 10 points argue in favour of low-rise typologies, highlighting critical attributes to low carbon strategies, better energy efficiency, and more opportunities for sustainable urban design. Moreover, key aspects like urban energy management and low carbon transitions could be benefited significantly if such residential policies could be reconsidered for the ongoing and future urban development projects. To start with, we argue in favour of smaller urban residential blocks, low-rise typologies, and the development of compact urban environments that are integrated with other critical factors of urban mobility, land-use, morphology, spatial planning, public place design, etc. We urge designers and planners not to limit their approaches to these 10 highlighted points. Instead, their role is to advocate potential sustainable paradigms against the current unsustainable trends of urban development, which are often high-rise, large scale, and not energy efficient. The following section provides examples related to housing and energy, urban mobility, and low carbon strategies to discuss other sustainability factors further. More importantly, our findings highlight the scope for reconsidering residential policies to ensure future development approaches align with key directions of carbon neutrality, sustainable cities and communities, and sustainable development agenda or the sustainable development goals (SDGs). China is a suitable example as urban residential typologies have changed drastically before and after the millennium. These changes have not only changed the Chinese cities' characteristics but also urban morphology/form, spatial layouts, car ownership levels, accessibility, energy efficiency, and other design factors that require much careful attention for future housing reforms and urban design control measures.

5. Other Sustainability Considerations

5.1. Qualitative Aspects of Housing and Energy

In order to maintain a holistic view, a few of the interrelated broader issues are now noted very briefly. Whilst we highlight energy and carbon issues, there are well-known economic and social arguments for low-dense housing environments, including qualities relating to identity, safety and conviviality (Butters et al., 2020). High-rise housing blocks with low surface coverage offer large open spaces but these are often inaccessible to the public, under-used and largely aesthetic only. High-rise environments are also recognized as being problematic for children and security. Many of these well-known factors have particular relevance for low-income housing contexts.

There are in addition, newer "sustainability" discussions relating to qualities of transparency, governance, and participation. Agenda 21 formulated at the 1992 Rio conference states that a prerequisite for sustainable development is user understanding, support and participation. The interrelationship of socio-economic and eco-technical factors must be underlined; the community-enhancing qualities of small-scale, low-dense living are important not only for qualitative reasons but indeed for energy use and climate emissions too. A study of poor communities in Peru found that "*social fragmentation, material poverty and marginalization were working against people's wellbeing and making in difficult for them to live sustainably. The latter was exemplified by increased waste, extensive use of chemical fertilizers and growing deforestation*" (Guillen-Royo, 2011). Similarly, a large post-occupancy study on low-energy housing in Europe shows, as do others, that energy efficiency gains are far below what has been expected due largely to cultural and behavioral factors (Sunikka-Blank & Galvin, 2012).

There is a growing awareness that quantitative objectives such as reduced energy use and climate emissions are heavily dependent on non-technical factors. Whilst seeking advances in technical solutions, this interrelationship of technology and sociology should not be forgotten. It appears particularly critical in the field of housing. Low-dense may offer some advantages in this sense too, with positive consequences for water and energy use, wastes and climate emissions.

5.2. Housing and Urban Mobility

A note must be added on the issue of urban mobility, although transport energy lies outside the scope of this paper. In developing countries, acquisition of private cars is a seemingly unstoppable ambition or is considered as a matter of status. In hot climates, they add to the heat island effect. Transport is recognized as perhaps the toughest challenge for sustainable cities (Wang & Yuan, 2013). In life cycle analyses (LCA) of buildings, if transport to and from the buildings is included, as in some Norwegian LCA systems, it can be seen to form *the major part* of the total energy and climate impacts associated with buildings (and principally, their location) (Future Built Program, 2014). This again highlights new perspectives that the sustainability agenda brings to urban planning.

Whatever the urban density, transport is a key to urban energy and GHG reductions. Whilst the "compact city" optimizes *the potential for* transport hubs and public transit, it often overlooks a key eco-design goal: walkable cities. Where cars are given priority, vast areas of city land are occupied by roads and parking; and congestion (inefficient mobility, the opposite of the goal) is inevitable. In walkable developments, such as the Vauban eco-district, inhabitants possess cars but the key difference do not need to use them much (Nielsen, 2007). The traffic consumes far less energy, occupies much less land, and causes less pollution, noise, and danger. Hence, a walkable city *cannot be* a car city.

In other words, very high urban density *only* makes sense if there is low car use. Very low density on the other hand, the "suburban sprawl" paradigm is obviously at the other extreme, necessitating high transport emissions. As noted above, in between the extremes there lie a range of low- to medium-rise options that may represent a good balance and offer excellent energy and carbon performance.

5.3. Looking Back, or Looking Forward?

Finally a brief return to the six-storey 1990s housing block E in Ningbo. Discussing advantages of low-dense does not imply nostalgia, nor uncritical approval of such examples of housing. The layout of block E is monotonous and the quality of construction is poor. The area is in disrepair. Car parking and green spaces are not well organized. On the other hand, the green spaces are small but intimate and well used; the one larger communal open space in particular. In addition, there is a pleasant public park nearby which is in constant bustle and activity. The typology is simple, as are the materials, the building envelope is compact and this housing type is easy to construct to a very high level of energy efficiency. The unit cost is low. Given a more imaginative layout and design and up-to-date construction this model could provide many qualities as well as a very low carbon footprint (**Figure 7**). In consideration of all of the 10 points discussed above, low-dense housing has many advantages and deserves revisiting in updated, sustainable forms.

Figure 7. The six-storey Ningbo block E. (source: the authors).

6. Conclusion

Low-dense housing has been a popular model in recent decades, not least in the Nordic countries, primarily due to the social qualities it offers; energy and carbon concerns now offer new reasons. High-rise may for several reasons be less favourable not least in energy/climate terms. There are clear arguments on both sides, of which some, such as in regard to thermal efficiency, embodied carbon or land use are objective, others more subjective. The task is to achieve a good balance of these, given inevitable trade-offs, with the ultimate sustainable development goal of a *high standard in all three areas* of ecology, economy and society. Solutions involve both quantities and qualities and these are interrelated. For this task, we require holistic tools, such as the Sustainability Value Map (Butters, 2012). The sustainable city paradigms (Cheshmehzangi et al., 2019; Cheshmehzangi et al., 2021b), explored in this study, help achieve better urban energy management systems and transitions towards low carbon cities (Cheshmehzangi, 2020) and low carbon transitions.

Finally, the science of life cycle studies gives us new ways of seeing things. New considerations relating not least to energy efficiency and climate emissions invite us to reconsider policies and models for urban housing. This paper does not pretend to offer answers so much as questions; however, many of the above points are relatively "new" considerations that argue for renewed interest in low-dense type housing solutions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Barron, W., & Steinbrecher, N. (1999). *Towards Sustainability*? Centre of Urban Planning and Environmental Management, University of Hong Kong, Hong Kong.

Barter, P. A. (2000). Transport Dilemmas in Dense Urban Areas: Examples from Eastern Asia. In M. Jenks, & R. Burgess (Eds.), *Compact Cities, Sustainable Urban Form for Developing Countries* (pp. 283-296). Spon Press.

Blenghini, G. (2009). Life Cycle of Buildings, Demolition and Recycling Potential: A Case Study in Turin, Italy. *Building and Environment, 44,* 319-330. https://doi.org/10.1016/j.buildenv.2008.03.007

Burgess, R. (2000). The Compact City Debate: A Global Perspective. In: M. Jenks, & R. Burgess (Eds.), *Compact Cities, Sustainable Urban Form for Developing Countries* (pp. 21-36). Spon Press.

Butters, C. (2012). A Holistic Method of Evaluating Sustainability. In T. Haas (Ed.), *Sustainable Urbanism & Beyond* (pp. 38-43). Rizzoli.

Butters, C. (2021). Myths and Issues about Sustainable Living. *Sustainability, 13,* 7521. https://doi.org/10.3390/su13147521

Butters, C., Cheshmehzangi, A., & Sassi, P. (2020). Cities, Energy and Climate: Seven Reasons to Question the Dense High-Rise City. *Journal of Green Building, 15,* 197-214. https://doi.org/10.3992/jgb.15.3.197

Chang, Y., Ries, R. J., & Lei, S. (2012). The Embodied Energy and Emissions of a High-Rise Education Building: A Quantification Using Process-Based Hybrid Life Cycle Inventory Model. *Energy and Buildings, 55,* 790-798. https://doi.org/10.1016/j.enbuild.2012.10.019

Cheshmehzangi, A., & Butters, C. (2015). Refining the Complex Urban: The Study of Urban Residential Typologies for Reduced Future Energy and Climate Impacts. In *Proceedings of 8th Conference of the International Forum on Urbanism* (pp. 1-17).

Cheshmehzangi, A., & Butters, C. (2017). Cities, Climate and Cooling. In A. Cheshmehzangi, & C. Butters (Eds.), *Designing Cooler Cities: Energy, Cooling and Urban Form: The Asian Perspective* (pp. 5-19). Palgrave Macmillan. https://doi.org/10.1007/978-981-10-6638-2

Cheshmehzangi, A. (2020). Towards Urban Energy Management: A Brief Review of China's Recent Transition in Urban Energy Demand. *Low Carbon Economy, 11,* 1-24. https://doi.org/10.4236/lce.2020.111001

Cheshmehzangi, A., Butters, C., Dawodu, A., & Xie, L. (2021a) Green Infrastructures for Urban Sustainability: Issues, Implications, and Solutions for Underdeveloped Areas. *Urban Forestry & Urban Greening, 59,* Article ID: 127028. https://doi.org/10.1016/j.ufug.2021.127028

Cheshmehzangi, A., Dawodu, A., & Butters, C. (2019). Greening Urban Housing: The Impact of Green Infrastructure on Household Energy-Use Reductions for Cooling. In P. Hefele, M. Palocz-Andersen, M. Rech, & J.-H. Kohler (Eds.), *Climate and Energy Protection in the EU and China* (pp. 95-101). Springer. https://doi.org/10.1007/978-3-319-99837-4_7

Cheshmehzangi, A., Dawodu, A., & Sharifi, A. (2021b). *Sustainable Urbanism in China*. Routledge. https://doi.org/10.4324/9781003027126

Cole, R. J. (2012). Regenerative Design and Development: Current Theory and Practice. *Building Research & Information, 40,* 1-6. https://doi.org/10.1080/09613218.2012.617516

ELITH Research Program (n.d.). *Lead Partner Warwick University, See Acknowledgement*. https://warwick.ac.uk/fac/sci/eng/elith

Future Built Program (2014). *Ostensjoveien 27, Hovedresultater og Sammenligning av Alternativer*. Report, in Norwegian, Analyses of a New Low Impact Office Block. https://www.futurebuilt.no/content/download/5266/file/__stensj__veien_27_klimagassberegnin-ger___Hovedresultater_og_sammenligning_av_alternativer_NCC_TR_og_KS_ved_Civitas_v29_01_2014.pdf

Gao, W., Ariyama, T., Ojima, T., & Meier, A. (2001). Energy Impacts of Recycling Disassembly Material in Residential Buildings. *Energy and Buildings, 33,* 553-562. https://doi.org/10.1016/S0378-7788(00)00096-7

Guillen-Royo, M. (2011). Reference Group Consumption and the Subjective Wellbeing of the Poor in Peru. *Journal of Economic Psychology, 32,* 259-272. https://doi.org/10.1016/j.joep.2009.12.001

Gurigard, K. (2011). *Klimagassregnskap for vernede boligbygg*. Civitas, Oslo. Report, in Norwegian, Emissions Analysis Old Housing Compared to Replacement with a New Building.

Haahtela, T., Holgate, S., Pawankar, R., Akdis, C. A., Benjaponpitak, S., Caraballo, L., Demain, J., Portnoy, J., von Hertzen, L., & WAO Special Committee on Climate Change and Biodiversity (2013). The Biodiversity Hypothesis and Allergic Disease: WAO Position Statement. *World Allergy Organisation Journal, 6,* 3. https://doi.org/10.1186/1939-4551-6-3

Hanski, I., von Hertzen, L., Fyhrquist, N., Koskinen, K., Torppa, K., Laatikainen, T., Karisola, P., Auvinen, P., Paulin, L., Mäkelä, M. J., Vartiainen, E., Kosunen, T. U., Alenius, H., & Haahtela, T. (2012). Environmental Biodiversity, Human Microbiota, and Allergy Are Interrelated. *Proceedings of the National Academy of Sciences of the United States of America, 109,* 8334-8339. https://pubmed.ncbi.nlm.nih.gov/22566627 https://doi.org/10.1073/pnas.1205624109

Harrysson, C. (2015). Energy Use and Indoor Environment in Detached Housing from 2000 and Earlier. *Bygg & Teknik, 5,* 20-31. (In Swedish)

Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., & Acquaye A. (2013). Operational vs. Embodied Emissions in Buildings—A Review of Current Trends. *Energy and Buildings, 66,* 232-245. https://doi.org/10.1016/j.enbuild.2013.07.026

Jabareen, Y. R. (2006). Sustainable Urban Forms, Their Typologies, Models, and Concepts. *Journal of Planning Education and Research, 26,* 38-52. https://doi.org/10.1177/0739456X05285119

LSE Cities/EIFER (2014). *Cities and Energy: Urban Morphology and Heat Energy Demand*. Final Report.

Mequignon, M., Adolphe, L., Thellier, F., & Haddou, H. A. (2013). Impact of the Lifespan of Building External Walls on Greenhouse Gas Index. *Building and Environment, 59,* 654-661. https://doi.org/10.1016/j.buildenv.2012.09.020

Nielsen, G. (2007). *Miljobyen Freiburg*. Transportokonomisk Institut. https://www.frias.uni-freiburg.de/en

Niemets, K., Kravcheko, K., Kandyba, Y., Kobylin, P., & Morar, C. (2021). World Cities in Terms of the Sustainable Development Concept. *Geography and Sustainability, 2,* 304-311. https://doi.org/10.1016/j.geosus.2021.12.003

Niu, J. (2004). Some Significant Environmental Issues in High-Rise Residential Building Design in Urban Areas. *Energy and Buildings, 36,* 1259-1263. https://doi.org/10.1016/j.enbuild.2003.07.005

Salat, S., & Mertorol, A. (2006). *Factor 20: A Multiplying Method for Dividing by 20 the Carbon Energy Footprint of Cities: The Urban Morphology Factor*. Urban Morphologies Laboratory, CSTB and ENSMP.

Sartori, I., & Hestnes, A.-G. (2007). Energy Use in the Life Cycle of Conventional and Low Energy Buildings: A Review Article. *Energy and Buildings, 39,* 249-257. https://doi.org/10.1016/j.enbuild.2006.07.001

Steemers, K. (2003). Energy and the City: Density, Buildings and Transport. *Energy and Buildings, 35,* 3-14. https://doi.org/10.1016/S0378-7788(02)00075-0

Sunikka-Blank, M., & Galvin, R. (2012). Introducing the Prebound Effect: The Gap between Performance and Actual Energy Consumption. *Building Research & Information, 40,* 260-273. https://doi.org/10.1080/09613218.2012.690952

Wallhagen, W., Glaumann, M., & Malmqvist, T. (2011). Basic Building Life Cycle Calculations to Decrease Contribution to Climate Change—Case Study on an Office Building in Sweden. *Building and Environment, 46,* 1863-1871. https://doi.org/10.1016/j.buildenv.2011.02.003

Wang, R., & Yuan, Q. (2013). Parking Practices and Policies under Rapid Motorization: The Case of China. *Transport Policy, 30,* 109-116. https://doi.org/10.1016/j.tranpol.2013.08.006

Yu, C., & Nyuk Hien, W. (2006). Thermal Benefits of City Parks. *Energy and Buildings, 38,* 105-120. https://doi.org/10.1016/j.enbuild.2005.04.003

Zhang, B., Xie, G., Gao, J., & Yang, Y. (2014). The Cooling Effect of Urban Green Spaces as a Contribution to Energy-Saving and Emission-Reduction: A Case Study in Beijing, China. *Building and Environment, 76,* 37-43. https://doi.org/10.1016/j.buildenv.2014.03.003

Zhang, X. Q. (1999). *High-Rise and High-Density Compact Urban Form: The Development of Hong Kong*. Centre of Urban Planning and Environmental Management, University of Hong Kong.

Zhang, X., & Wang, F. (2015). Life-Cycle Assessment and Control Measures for Carbon Emissions of Typical Buildings in China. *Building and Environment, 86,* 89-97. https://doi.org/10.1016/j.buildenv.2015.01.003