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How Tall is a sustainable building?

Paper based on a presentation at XXIII UIA World Congress of Architects, Torino, Italy 2008
Session HOPE, July 2, 1330, **Sustainability and Skyscrapers**

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Tall buildings sustainable?

In a world with ever greater population and consumption, loosing space per capita and resources depleting, and at the same time more and more urbanising, Tall Buildings are regarded as a possible solution for housing people and activities in a sustainable way.

The question is: what exactly is sustainable, and in how far can tall buildings provide this, or in other words, How Tall is still sustainable?

This is the central theme in this paper..

Introduction.

Architecture is famous for always causing emotion, and even more for tall buildings; it seems it increases exponentially with height. The tallest of them all, though still under construction, symbolises this in Optima Forma. From a well visited blog site [1] on Burj Dubai, we collected a few reactions in May 2008 randomly:

- We Need Two More Eyes And May God Give us 100 More Years to See and Experience the Beauties of DUBAI.

- this and all the buildings like are built from the slave labour of Asian migrants. they make up about 80% of the total population, are forced to live in walled-up slums, and have basically no rights.

- Wow!, I have to go there before I die!

- Dubai looks completely ridiculous and unsustainable, much like our extravagant desert cities, Las Vegas and Phoenix. This is a real monument to folly and the loss of foresight and reason. Its aall vanity. Enjoy it! It will look great when the city becomes a ghost town in 70 years.

- My dream came true today. I'm a proud owner of an apartment in this building today. Could not have asked more from Allah.

This is Dubai, a new city on the rise. But what about the "Old world's" tall buildings? Less Tall, but nevertheless, triggering Royalty: Prince Charles spoke out about London's ambitions in January:

"skyscrapers are disfiguring" London's skyline and "vandalising" the city's historic sites. He went on to talk about "damaging London's timeless character" and destroying views for future generations. Shuttleworth, architect of 'The Gherkin', replied: "He's wrong. London is not a museum. It has to be renewed for the next generation, especially as it attempts to become the world's leading city. We can't leave it as it is in medieval times." [2]

This discussion will continue, as many lobbyists groups are entering the scene. One of the London groups Development Securities PLC published a paper and lists arguments in phrases like: “Accommodate or die” : *To remain a major ‘world city’ London must accommodate significant growth within its existing boundaries.* [3]

The stage has been set, and continues in Torino, Italy: Torino is now facing he prospect of two Tall buildings, and has a similar continuing debate on the height of Piano’s design: it has been changed in height a few times, and is causing big debate and opposing campaigns on the web. In a recent presentation the comparison of the building with the city’s dome made it look less high than the dome, though nothing is decided yet.

It seems as if Piano has to do its utmost best to sell a tall building, making it look as small as possible.... [4,5,]

(So far, we are waiting for Berlusconi to speak out...)



Pro and contra

With these discussions it's no wonder that many have drawn lists of pro's and contra's for tall buildings. The more serious ones we find in several papers [6,7,8]

Among the pro's many are transport distance and fuel related, economies of scale in production, advantages of density and land use of course, as well as possibilities for mixed use and living working together, plus safety and more open spaces.

The con's cluster: increased materials and energy use for all building phases, over crowded areas, traffic jams, anti-social settings and shadowing for instance.

There exists a organisation called “council for Tall Buildings and Urban Habitat”, based in Chicago and funded by stakeholders in the building sector, On their recent conference they described Tall buildings this way:

The Tall building has a crucial role to play in this debate on the urban future. Itself the historical epitome of energy and consumption excess, the typology has the opportunity to re-invent itself as a model for denser, more sustainable cities; concentrated centers of work and life activity. Additionally, the financial and professional investment in each tall building project gives the typology an opportunity to push the agenda for sustainable design, experimental technologies and the real need for post-occupancy monitoring, for the benefit of the built realm as a whole.[9]

Of course the pro's are much better organised: Why would you organise against something, that might not happen, while the pro's have a interest in making this development happen? For this obvious reason, I probably could not find a council for “low buildings”. So we are depending on finding information from independent sources, that objectively analyse the pros and contras of tall buildings being sustainable or not.

Sustainability

A complex issue is of course the question about sustainability. What might be regarded as a 'sustainable' solution for a human being, or a city, might not be the same one as for a geo-biosphere balance. In the end however, a balanced global resource and climate situation is the most beneficial for mankind (and individuals) as well. The dilemma is that in general one could say that at this moment the living circumstances for our human race and city life are still improving: many countries are in the uplift becoming 'developed', the comfort in houses in developed countries is still rising, the health situation in general is improving, people are on average becoming older etc.

However on the side of resources and their impacts, the situation is obviously fast worsening: many resources face depletion, and the side effects of use and processing many resources, like climate change, is manifest and expected to grow if no drastic transitions are implemented.

This puts the general situation regarding resource consumption, and its impact like climate change upfront in future strategy, to maintain a reasonable level of sustained wellbeing and comfort for individuals and city life.

A third aspect, generally regarded as part of sustainability, is economics and cost. Of course, on a micro scale, this is of significant importance: Investing is always aimed at profit, otherwise its senseless. However on macro scale, if profitable local investments leads to dramatic consequences related to climate change, or to running out of resources to invest in, the importance becomes relative. This is a second dilemma we face.

In this context we will have to explore in how far Tall buildings can contribute to win-win situations in both dilemmas, or not. Or where the optimum will be.

Do they provide improved socio cultural accepted and healthy shelter for people and activities, while at the same time provide shelter with the least impacts and burden on resources compared to other solutions, and relative to the cost of the total development?

In search for answers we have to analyse the several aspects, and look into already established research, and see in how far answers with a broad and holistic outlook can be formulated

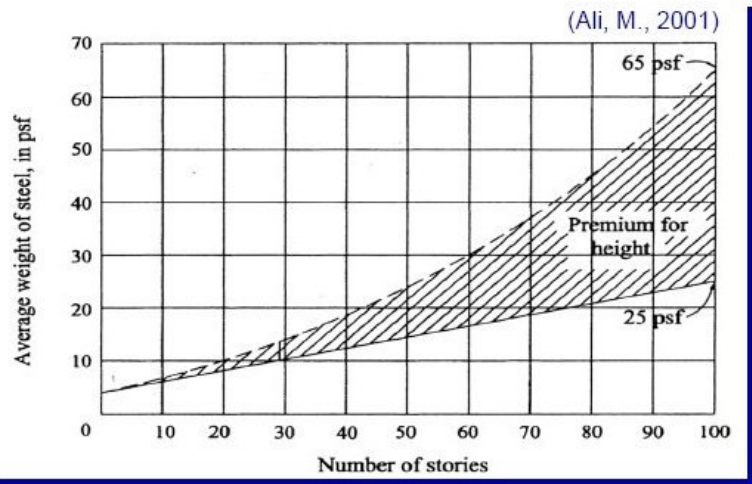
Research

The overview starts with a look at the basic resources used related to the buildings itself, continues with the building in its surroundings, and followed by a look at the social and cultural consequences of living and working a tall building urbanity, claimed as one of the advantages.

height and weight

A first important relation exist between the amount of resources needed to construct buildings in relation to height. From own research the weight per m² of a few buildings was estimated. On average a 4 to 5 floor apartment building in The Netherlands comes close to 1 ton per m² living area. The archetype of all skyscrapers, The Empire state building is around 1,7 tonnes, The tallest at the moment, Taipei 101, consumes 1.8 tonnes. These figures are significant higher as for the 5 level low rise benchmark, none of them however optimised for "sustainable materials". The difference could possibly be even more since the low rise could be constructed from renewable materials: Wood for instance, as is the trend in Swedish multilevel housing nowadays (upto 8 levels).

But also in Sweden we find the 50 level iconic *Turning Torso*, the apartment building by Calatrava in Malmö . And the architectural drive to image Calatrava's body looking backwards in the mirror, adds up to 3.4 tonnes per m2.... The price for "Architecture". Though few structural analyses for the relation height and weight are available, these confirm the



trend: in 1991 Coell et al published a relation of steel frame construction with height, showing a hyperbolic increase with height.[10] And Buyukozturk et al, tabulated from Ali, in the CIB world congress 2004 showed the relation of steel construction with lateral loads (wind). turning points seems to be 150 meters for steel, and 250 meters for concrete, where weights start rising strongly non linear. [11,12] For the total building a factor 2 at least in weight seems to occur above 150 meters. What happens above 500 meter is unknown yet . The nearly completed Burj Dubai will give indications, if figures will be published.

Relation height and weight, Ali,M 2001, as tabulated by Buyukozturk et al, 2008. [11,12]

height and energy

The next issue is the relation of energy and climate with height. Again, only few researches are available with a sound comparison of similar buildings performance with height as a changing parameter. Guthrie from Arup composed a graph from Lam et al, showing a interesting relation for Hong Kong buildings electricity use related to height: there seems to be some critical increases at above 7-10 floors , and again around 25 floors. [13,14]

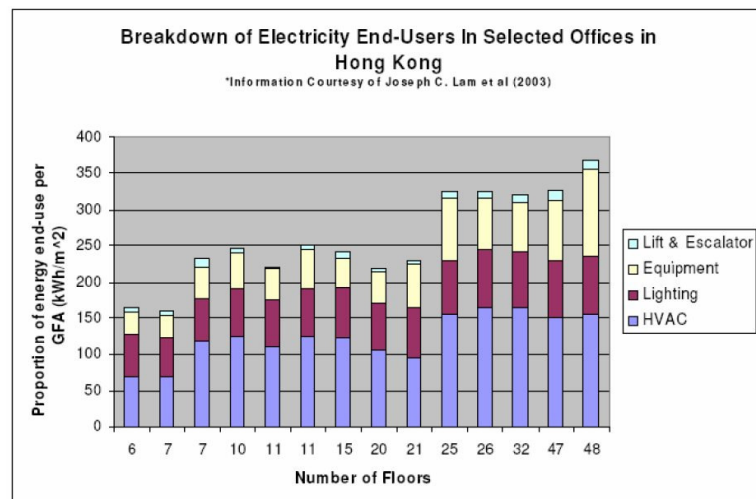


Figure 5. Breakdown of Electricity End-Users In Selected Offices in Hong Kong: Joseph, C. Lam, Ricky, Y.C Chan, C.L Tsang, Danny H. W. Li, Energy Conservation and Management, 45 (2004) 829-844.

A indicative study by van Den Dobbelen et al, researching both energy and materials performance of 6 typical arrangements of space, shows a basic relation between horizontal, compact and vertical organisation of space. The two extremes, the tower and caterpillar variants, having a 90 respectively 80 % efficiency performance for energy and weight compared to the most compact variant.

A follow up study involving real buildings, studied among others the Commerzbank in Frankfurt, the highest office in

	Cube	fence	warehouse	slab	caterpillar	tower
energy	1,0	1,02	0,93	1,02	0,92	0,92
materials	1,0	0,92	0,93	0,91	0,82	0,80

Europe at that time. The study revealed a dramatic drop of efficiency in materials and weight, compared to a reference building, and using the Dutch LCA based GreenCalc tool. For energy the improvement factor was 0,63 (times the reference) and for materials 0.27. It is concluded, but more broad studies are needed, that energy and weight increase with height, per m2, but at 36 levels the loads for both energy and materials start increasing exponentially .[15]

Renewable energy

With more and more 0-energy buildings entering the built environment, and even energy plus houses being commercially available, the question is raised if Tall buildings can compensate their increased energy consumption by generating their own demand. A “0-energy skyscraper”?

A first serious attempt is made by the Bahrain World Trade centre: a two tower building with in between 3 wind turbines, each 29 meter in diameter. The test runs this spring (2008) went well, and the building is supposed to come in operation this fall. The Website reports a possible 11 % of the buildings electricity demand can come from the wind turbines . [16]



However Guthrie, [13] stated at the latest CBTUH conference that wind in general can provide no more than 5 % of the electrical needs.

When it comes to Photovoltaic integrated in facades, he estimates a 10-15 % of the needs as a possible maximum. The shape, orientation and the overshadowing will greatly influence this figure. “The greater the concentration of high rise buildings the less the opportunity.”

He suggests that in the “hot sunny areas of the world power generation from tall solar chimneys or solar arrays as part of a community strategy should be developed.”

It must be mentioned here that there are a few designs announced, that should come close to providing all energy by the building itself. However, these are for the moment just drawings and claims. (see some of the buildings in the weblinks)

Recently some new insights in energy optimisation has come to be studied. Its in the concept of exergy-based building design, that builds on the simple fact that different energy end-uses require different levels of energy quality (more precisely different levels of ability of energy flows to perform mechanical work) in order to provide for their functional performance. Energy end-uses directly associated with mechanical work require a higher quality of energy, whereas the conditioning of occupied spaces in principle requires very low quality energy carriers. Exergy-based design principles aim at matching the quality of supplied energy to the thermodynamic requirements of its use.[17]

This could help reduce the load, however in a same way for low rise.

So far unexplored by my knowledge but very interesting when tall buildings become real tall, up to 1 kilometre, and interesting from an exergy perspective, is the differences in climatic conditions over the height of the building. It was analysed in a paper by Kueng et al, [18] They describe the changes of wind velocities, humidity, temperature, and air density with height: For instance higher wind speeds will increase the convection and there for heat transfer of a building, up to 8 %, and increase heat gain in summer by 1 % at mid level. But also this could result in 6-15 % energy savings by fan operation. The decreasing air density over height, results in lower energy demand for ventilation of 10 %. For hot and humid climates the reduction of moisture with altitude can result in a 4 % reduced cooling load in summer at mid level. Their conclusions state that architecture could reflect these differences. Also spatial organisation is affected: Cooling dominated spaces at the top, and heating dominated at ground level. And assessments should be carried out with different climate zones over the height...

Density versus height

The increase in energy and materials consumption of tall buildings could be acceptable, if the increased 'footprint' is compensated with reduced footprint due to freed land by high densities, related to more open spaces, reduced road needs and such . Not only to compensate but with a net positive result. As Guthrie formulated: The negative issues of increased energy use and more material can be offset by improving efficiency and considering the benefits that location and concentration might have for the community.

Trends

To explore the relation between density, land use and tall buildings, a first impression can come from data gathered in a database on skyscrapers [19], which ranks cities according skylines. It's a limited but indicative approach , by which skylines are ranked as the total points by buildings an their height (starting from a certain level) . Its not a real surprise we find Hong Kong first and New York second . Seoul has been rising coming third now. A few others are Tokyo, at 8, Dubai at 13, Istanbul (as the 1st European "city at 28 (!), with London at 34 and Paris at 44. In general over the past few years we could see Chinese cities rising, with now 5 in the top 20, and more moving upwards.

Now this is just a total count of high-rises scores. If we relate this to the cities population density, the list gets quite different.: Now the top 3 is Cairo, Macao and Paris, with New York moved to 15 and HK to 25. In Cairo its not about high rise buildings, but related to an overcrowded city. However especially Macao and Paris become interesting, since they have nearly the same density, but Macao with an average of 28 high-rise buildings per km². And Paris with only 4 (Paris city, in between peripherique) . Its shows its possible to reach the same density with different geometric approaches.(and therefore potentially lower energy and materials consumption). New York has 7 buildings per km², with half the population density, and Hong Kong 7 buildings, with only 30 pct density of Paris downtown.

If we look only at buildings per km² , Macao becomes 1st, but surprisingly Benidorm in Spain moves third place) with 60000 inhabitants (in winter...). And in the top 100 we see many Spanish speaking cities moving up compared to the general index. Apparently the Spanish culture is capable of adopting more high-rise buildings per km².

Interesting is a comparison between Tokyo and Seoul. Both share the same area in km². the same amount of high-rise buildings, with Tokyo a little bit less dense: 13000 to 16000 per km². Buildings per km² are the same, but skyline ranking puts Seoul on 3 and Tokyo on 8 . this implies that the Seoul buildings on average are higher. Now this might have consequences for transport, but amazingly the amount of cars in Tokyo is 164/1000 and in Seoul 230/1000!

And Osaka, a little less dense, but same amount of high-rise buildings as the other two, has only 68 cars/1000.

Place by points	City	Population	Area km ²	Buildings ²	Points ²	density p/km ²	rank by density	build/km ²	rank by buildings	cars/1000
71.	Cairo	6789479	215	167	1213	31579	1	0,8		96,8
19.	Macao	453733	21	596	4300	21606	2	28,4	1	
44.	Paris	2144700	105	443	2146	20426	3	4,2	16	
31.	Mumbai	11914398	621	877	3453	19186	4	1,4		
38.	Makati	484176	27	145	2566	17932	5	5,4	8	
77.	Bogotá	6776009	384	310	1008	17646	6	0,8		
3.	Seoul	10331244	616	2872	16559	16772	7	4,7	12	229,3
97.	Pasig	471075	31	50	763	15196	8	1,6		
22.	Buenos Aires	2965403	200	1582	4056	14827	9	7,9	4	90,9
21.	Jakarta	9341400	661	351	4261	14132	10	0,5		120
8.	Tokyo	8130408	621	2770	11986	13092	11	4,5	14	164,2
24.	Osaka	2598589	220	1085	3943	11812	12	4,9	11	68,6
74.	Kaohsiung	1720400	154	43	1097	11171	13	0,3		
2.	New York City	8274527	800	5636	36899	10343	14	7,0	6	109,2
61.	Taipei	2719293	272	169	1452	9997	15	0,6		

www.emporis.com, Tabulated by author

These trends provide some practical insight, which suggest that there is not a significant advantage in land use by tall buildings . But again very few studies could be found that tackle this relation structurally and undisputable. It is also, I must say , a difficult research with many parameters involved.

China for instance has the name to construct many tall buildings in order to house efficiently the increasing urban population, However, so far this has been accompanied with a net loss of arable land{20}! One of the reasons seems that only individuals of rural families have moved, and no land has become available in change of more land use by urban growth. A second reason is that due to increased wealth the size of housing is growing, increasing the needed for the same amount of people . A rebound effect, that was already known, among others in Kibbert's work [21].

So if there would be a net profit from high density construction, that exists in an ideal situation. The practice is always different , never ideal, and involves also lots of rebound effects.

The China study reveals also that the relation between density and environmental performance is low, which is confirmed by another study looking at electricity consumption of cities.[22] This however may well be depending on cultural differences. A quick comparison between skyline ranked cities in Europe and electricity consumption , as far as comparable figures were available, suggest that electricity consumption is linear rising with higher skylines. Again, this is only indicative information, a solid study lacks.[23]

A conclusion is also that as far as claims on advantages and disadvantages are made , they lack a solid research base. Which then creates unfunded statements like: *Accommodating the same number of people in a tall building of 50 storeys as in a large building of 5 storeys requires roughly one tenth of the land* : [24] Pank et all in a London study. This is a very suggestive way of assuming advantages. And only related to the buildings ground projection.

It's seen more often, like in the previously mentioned lobby report: It states, in answering the self-posed question "Where should we put them?": that: "Well-designed tall buildings should be located in strategic clusters and well served by public transport in London.". In other words it says: "we (the developer) build, and shift the transport problem to the community, regardless the cost and environmental implications".

It also underlines that except for a few that can land with a helicopter on the roof, the tall building is in fact like a dead end street: there is only one way in or out, with all the pro's and contra's with it.

It's a continuous debate about the ins and outs of the Compact city, as is analysed by Sung Woo Shin, looking at vertical cities [25]. The real performance is yet to be measured.

However that mainly applies for new buildings. Existing built environments, in which a low rise building is replaced by a high rise building, always increase the stress on the urban fabric, leaving the local authorities with the problems to solve.

However not relevant for the environmental burden of tall buildings, the question could be raised is it safe to live anyhow in tall buildings, and do people in fact want to live in tall buildings? To summarize as "life in Tall buildings" what are the merits and socio cultural advantages and disadvantages ?

safety

It starts of course with the question is it safe and secure to live and work in a Tall buildings? This is intensively discussed after the collapse of the world trade centre, leading to discussion about adding more escape routes via stairs and escalators for instance. But escalators are the limiting factor for the height of buildings, since they take up major part of floor space. A new development is that high-rises should be connected at different levels, to provide escape routes horizontally. What you are in fact doing then is not designing tall building, but stacking low rises, to copy the advantages. And in an earthquake area high-rises close to each other increase the danger of domino effects. [26]

Socio cultural perception

When all is set, the question is how people perceive living and working in a tall building environment. Stephen Lau, at Hong Kong university, has intensively researched this [27]. The "compact urban form implies intensification, high density, mixed land uses, efficient public transport and dimensions that encourage walking and it is argued to have both negative and positive implications on urban living space and thereby quality of life and sustainability." Continuous research on the social cultural aspects of high density living in the Asian compact cities indicate that preference for high-rise and high-density living given a choice is determined by individual preference on lifestyle. On the whole, the most preferable indicator that affects the physical location of an apartment is View, Air and Usable space for the sub-tropical city dwellers. For Hong Kong the outcome of the research was that a majority likes to live in high rises.

In general the response towards such questions and implications are based on human perceptions, preferences, adaptability and tolerance which differ across each cultural and urban context.

Farming

A side topic, gaining attention these days, is the increased vulnerability of cities, in times of stressful situation with regard to daily resource provisioning. Agricultural communities have by definition a self surviving potential, but in cities there is hardly any escape or backup if energy supply stops or world food distribution hampers. This is recognised nowadays and urban farming is fast becoming a hot issue. And with heights increasing, vertical farming is studied by many. In the Netherlands the Pig skyscraper was studied: stacking 40 pig farms on top of each other, with two ground floors as slaughter house, and top floors for manure collection and energy generation. Even the pigs situation improved, with balconies for an outside walk.

Taiwan is studying vertical food crop growing on facades, and other proposals include farming areas in different levels of the building.

A paper at the recent CTBUH congress calculated that: "a single vertical farm with an architectural footprint of one square New York City block and rising just 30 stories (approximately 3 million square feet) could provide enough calories (2,000 cal/day/person) to comfortably accommodate the needs of 50,000 people, and mainly by employing technologies currently available." [28,29]

Conclusions

In general there is hardly structural and fundamental research available that covers an overall analysis, from a resource point of view, including energy, materials, land use and infrastructure. Besides, many topics have not been touched upon in this essay, like for instance the heat island effect, much discussed and a growing concern.

It seems however fair to conclude that from a resource (energy and materials) point of view tall buildings are not very efficient, and the outlook for 0-energy tall buildings is far from optimistic.

Tall buildings performance as part of compact city development and efficient land use, which can also be advantageous to have space available for harvesting renewable energy and materials, seems to provide no direct advantages. For sure not in existing areas, where low rises are replaced by high rises, freeing no land and increasing pressure on transport and infrastructure, at the cost of community.

In new developments, so far no examples with calculated advantages have been found, and if available, rebound effects may counterbalance these. Due to lack of structural research for the new developments land use advantages or disadvantages, this could get the benefit of the doubt.

Whether people like to live in Tall buildings, and if it's safe for instance, technically or socially, are considerations of the second order, and has no relation to a global balanced use of resources.

Based on the above findings, there is only negative impacts found, and so far no clear obvious reason for tall buildings. Phrased as in policies, you could say:

No Tall Buildings, "unless". (unless proven to be resource profitable)

The question how Tall is sustainable, can not be answered in this paper, in terms of meters. It will be most probably an average of the Paris downtown area heights, which in the 19th century, before the industrial revolution, provided not only, as we can see now, a very efficient way of land use, but also a highly socially integrated way of living, with elder people

on the first level, the middleclass family on the second, the young couple on the third floor and up to the students and maiden in the highest two levels. It was the period before elevators.

The assumption that the height of a building can be determined by a optimisation process for all factors involved seems for the moment wishful thinking, solid tools and models lack. . A last question keeping my mind busy, is, that if resources do not provide decisive parameters, then how does an investor and project developer decide for the height, from an economical point of view?

This is answered by a story from the architect of the highest under construction, Adrian Smith:

“(it)...was the desire from some members of the development team(EMAAR,rr) to keep the height of the tower down to something in the 550 meter range. This height, they felt would still achieve the desired goal of the worlds tallest building when completed ...I couldn't get the tower to look or feel like the competition scheme and the massing schemes that we developed were also not satisfying to Mohammad Alabbar. ...”

“...Each meeting during this phase with the client we would produce another massing model. Each time we would inch it higher and there would be pressure to reduce it. Finally, after the developer of the palms in Dubai surfaced a concept by I.M. Pei that was significantly taller than the 550 meters limit we were up against, EMAAR allowed us to pursue taller schemes. ...” [30]

Its ego after all.

Looking to the future, its obvious that energy and materials efficiency related arguments, will increase in weight, and become more decisive for the kind of buildings we will be able or want to construct. If electricity supply fails, it's a long way up and down a tall building, and it seems that the vulnerability of a built environment increases with height, which might be the motor behind the vertical city trend, including food crops growing inside. But if that's sustainable in the long run.....

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