What is Sustainable Urbanism?

An Introduction to Concepts, Metrics and Strategies

How to Use This Module

This is the third e-learning module for a series of courses in urbanism, architecture and building crafts known as the "European School of Urbanism and Architecture." The programme was designed for new students to the study of urbanism and building, and for professionals and practitioners who wish to increase their level of understanding of important new topics in best practice. More information in this programme is available at www.esua.org.

If this is your first time learning about this subject, and you find this module interesting, you will have the option to take more modules on line in the future. But this on-line element is really only a part of the full course of study. This module is designed to be integrated with a hands-on learning programme that will allow you to learn in the most effective way known: "learning by doing." You will have the opportunity to participate in field studies of actual projects, working alongside leading practitioners, and using the latest tools and techniques.

This module is specifically designed as an introductory course for those coming to study building crafts in the programme, but may be taken by others as well.
The full project-based curriculum is now in the pilot phase, and is planned to be launched as a full-time programme after several years of development. You can learn more at www.esua.org.

Each e-learning module begins with a short reading, and then gives you links to additional reading. The final examination includes a short multiple-choice section, and a written essay portion that you can enter through a form, or email to the course instructor as a text document.

Introduction

Today the word "sustainability" is very much in the news, and in professional thinking and discussion. Its prominence reflects real scientific concern that our current practices are not sustainable, and if we do not reform them, we will face severe shortages of critical resources, and other severe social, ecological and economic consequences in the years and decades ahead. Among them, the phenomenon of climate change looms as particularly serious.

But what is sustainability, to be precise? How can we know when we have achieved it, and when we are perhaps just fooling ourselves – doing small things to make ourselves feel better, when bigger problems go unsolved and even unaddressed? And if we do know what it is that we really need to achieve, how can we do so effectively?

This introductory course will look at these topics, with a particular focus on the urban built environment. It will also point you in the direction of further independent study.

The built environment plays a dominant role in the question of sustainability, and for good reason. A major portion – perhaps half or more -- of the energy and resources we consume today are consumed as a result of the characteristics of the built environment, and the ways we interact with it. The buildings, their heating and cooling, their furnishings, their appliances, all are major users of resources, generators of wastes and toxins, and emitters of carbon and other greenhouse gases that contribute to climate change.

Moreover, this is only the start of the story. Buildings do not exist in isolation from one another. If they are widely separated or poorly distributed, we may use much more energy in moving between them, and in distributing energy and resources to them. If they are not grouped so as to take advantage of shelter, sun, shade, they may use significantly more energy. If they do not take advantage of natural efficiencies such as waste energy recovery and district energy systems, they are likely to use more resources.

Finally, if the buildings, and the urban pattern that surrounds them, is built to support and to accommodate a high-consumption, high-throwaway lifestyle, then the evidence suggests that their inhabitants are much more likely to use more energy and resources. The built environment will not force them to do so, but it will shape their options, and make it more difficult to do otherwise.

Conversely, if buildings, and the urban systems that surround them, are built to support and to accommodate a high-efficiency, low-energy, low-resource-waste lifestyle, then the evidence shows that their inhabitants are far more likely to live in that lifestyle. If the inhabitants can easily walk or take transit; if they need not travel as far for their daily needs, which are well-distributed; if they have inviting outdoor space nearby, where they can spend time with others, without using large amounts of energy and resources; and if more people can share efficient facilities like power generation and infrastructure; then the evidence shows that even those with relatively high household income, can have a relatively resource-efficient, energy-efficient lifestyle.

Therefore, what we are learning from the research is that the urban form is a critical aspect of the challenge of sustainability. This means that when designing for sustainability, we must move beyond the scale of the building, and design for sustainable urbanism.

What is sustainability?

First, let us be clear on our definitions of the problem. Perhaps the best-known definition of sustainability, and therefore the one we will use here, is the one given by the Brundtland Commission (formally known as the World Commission on Environment and Development), a panel convened by the United Nations in 1983. The commission was created to address growing concern "about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development."

Among other things this meant that sustainability is not just an environmental problem, but a social and an economic one too.

The Commission established a definition for sustainable development that is still widely used today.

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:
- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs"

On the one hand, human beings have essential needs (food, clothing, shelter, culture) which must be met through activities in the environment – such as agriculture, fishing, construction, mining and logging. On the other hand, these resources have limits, and if they are depleted, or if the activities cause intolerable damage to the environment (such as excessive pollution), then the ability of future human beings to meet their needs will be compromised – perhaps severely.

So the challenge is to balance the needs of all human beings, and assure their access to resources – not only those in the future, but those today who live in poverty.

And not only are we concerned with those who will live in the relatively near-term future – the next century, say – but we must also think about the needs of our descendants in ten centuries, or a hundred, or a thousand centuries. Therefore, the use of resources must be put on an entirely different level, one in which critical non-renewable resources are used in an endless pattern of recycling – much as natural systems already tend to operate. Their sustainability often spans millions of years – hence we would do well to take notes.

The "Triple Bottom Line" of Sustainability

Moreover, the matter of access to resources does not exist in a vacuum, but requires a social and technological system of delivery. Hence sustainability means that we must address the full social, economic and technological aspects of society. In that sense, sustainability requires accounting with a "triple bottom line:" not only ecological sustainability, but also social sustainability and economic sustainability. If one of these elements is missing, the other two will not be achievable either.

Therefore, social sustainability – the ability of a city or a region to maintain social organization, cooperation and well-being – is a critical dimension of sustainability too. If parts of the population are increasingly excluded and alienated, causing disruptive social problems, then this will increasingly distract from the capacity of the community to deal with other challenges. If the population is not well-educated, then they will be less able to respond politically to the real long-term challenges facing their society. (There is some evidence that this is occurring on the issue of climate change)

Similarly, economic sustainability is a necessary condition for a society to deal with its challenges. If an unsustainable economic activity depletes economic resources, then the society will be less able to apply those resources to other needs. Clearly, if an entire society is impoverished by unsustainable economic practices, then it is not able to deal with other challenges, and may not even remain viable as a society.

Moreover, all of these three "legs of the stool" of sustainability depend on each other. The depletion of ecological resources will certainly impoverish a society and contribute to economic unsustainability. In turn, a society that is economically unsustainable and impoverished can be expected to put greater pressure on ecological resources. Social unsustainability increases the likelihood of economic unsustainability, and the likelihood that the necessary steps to manage ecological sustainability will be taken. And of course, ecological unsustainability can also have a devastating effect on social sustainability ,as we have seen in parts of the world that have suffered ecological disasters.

Resilience, Capacity and Organic Growth

However, it should be noted that there is one important difference in ecological sustainability, putting it in a different class from the other two. Declines in both social sustainability and economic sustainability can be reversed relatively quickly. Economies can rebound, and populations can greatly improve their levels of education, organization and social well-being. But ecosystems can be damaged beyond repair – particularly when species become extinct. We do not understand all of the links between species, but we know that there are critical thresholds, beyond which, if too many species become extinct, entire ecosystems will collapse permanently – along with the resources and the services they provide to humans.

This ability to recover from damage is called ***resilience*** – and it is an important concept in sustainability theory. We recognize that we do not control, in a conventional sense, complex systems like ecologies or economies or social systems. Rather, we must recognize how we can facilitate their own internal ***capacity*** for renewal – how we can assist in promoting the "capacity-building" of these systems.

The tools required are not unlike the methods of biological science, or medical science. We need good measurements, and good analytical understanding of what is happening. We need to, in effect, "diagnose" this. Then we need tools to promote the health of the system – "prescriptions" of steps that can be taken. Finally we need qualitative and quantitative evaluation of the result, and refinements for further action.

Or, to use a related analogy, we need to act as "gardeners" as well as "carpenters." A carpenter has a design and executes it in a fairly linear process, and uses tools designed for this: hammers, saws etc. A gardener has to use tools and methods that respond to the complex phenomena of biological growth. The gardener might use a carpenter's techniques to build trellises and other structures to support growth. But the gardener will also plant seeds, fertilize, water, prune, weed – all the things needed to support the growth of the plants themselves.

The Complex Interrelationship of Sustainable Resources

Some of the key resources that are threatened by unsustainable practices:

Depletion of non-renewable resources:
- Fossil fuels
- Metals
- Fresh water

Depletion of renewable resources:
- Soil
- Fisheries
- Forests
- Other natural biological products (pharmaceutical products, etc)

These are fairly easy to understand. If we deplete the world's reservoirs of oil, for example, we make them unavailable to future generations.

Somewhat more complex, and therefore somewhat more difficult to anticipate, are cumulative changes to the environment from our practices that have damaging effects to the things on which living systems depend – and very likely, human beings will depend on them as well.

Damage to ecosystems:
- Pollution of air, water, soil (including ocean acidification)
- Destruction of habitat
- Destruction of "ecosystem services"

Most complex, and perhaps the most difficult to understand and anticipate, are so-called "systemic" effects of our actions: that is, things that happen to one part of the environment, that then trigger a problem, often unexpected, in another part.

Triggering of systemic effects:
- Extinction processes
- Climate change
- Other interactive effects

These effects are often the result of the other unsustainable practices mentioned previously – for example, climate change is caused by the depletion of oil and release of CO_2 in the atmosphere – and at the same time, they go on to make the other problems worse.

For example, the deforestation in the Amazon basin may accelerate the effects of climate change, which may trigger diseases and infestations in trees, greatly accelerating the problem of deforestation.

The warming of the oceans from climate change may accelerate the release of methane sequestered in ocean beds, causing even greater warming. The same phenomenon of release through heating may happen to the methane sequestered in the peat beds that occur in vast stretches of the Northern Hemisphere.

These effects would tend to accelerate the effects of climate change. On the other hand, other effects might also serve to dampen climate change. For example, the increased levels of CO_2 might increase the growth of plants and ocean algae, which would then consume the CO_2 and release it back as oxygen.

The problem for those who study this phenomenon is that it is one that is exceedingly complex, and very hard to predict. Indeed, these effects are especially worrisome to those who study this subject, because they could create "runaway" effects that become severe – even catastrophic – in ways that we cannot understand.

The phenomenon of extinction is a similar problem. We might well wonder why we should care that a few species might go extinct. But beyond a certain threshold, the extinction of certain populations triggers the extinction, or the massive die-off, of other species on which they depend. The ripple effects could be enormous, and cause collapse of whole ecosystems.

Such ecosystems can recover if the key species are intact. But if those species are extinct, the ecosystem may not recover for many thousands or even millions of years – the time it may take for new species to evolve or adapt to the gap in the ecological system.

As the saying goes, "extinction is forever."

This could be a hugely important issue when it comes to the integrity of fisheries around the world, for example. A massive collapse in key fisheries due to the extinction of key species could lead to starvation and desperation in populations that rely on fishing. In turn they might be prompted to extract even more species of fish that had been considered inedible previously, threatening to cause more extinctions.

Or the extinction of a number of land creatures could trigger the explosion of very undesirable species that were held in check by them – perhaps crop pests that could greatly affect crop yields.

Once again, we see the complex effects of interactivity, making it difficult to predict the future consequences for human well-being. But we know the dangers are very real, and potentially catastrophic. That is why the question of sustainability – imprecise though it may be – has risen to the forefront of global awareness and action.

The particular challenge of climate change

It must be stressed that climate change is only one manifestation of the challenge of sustainability. It is a sad fact that if we could somehow solve the challenge of climate change tomorrow, we would still face almost all of the other serious challenges on the list above. Even without climate change, we would be severely compromising the ability of future generations to meet their own needs. We might very well be subjecting them to a world of increasing shortage, mass starvation, political instability, epidemic disease, and other consequences of a breakdown of the sustainable delivery functions on which our well-being depends.

And yet it must be said, the consequences of climate change in particular could be even more horrific. We could pass on a world wracked by massive disastrous weather events, widespread crop failures, the spread of epidemic diseases, loss of access to potable water, mass emigrations, enormous political instability, and worse.

Moreover, the challenge of climate change is closely linked to these other unsustainable activities and effects. In that sense, climate change does a remarkably good job as a "proxy," to represent all the other challenges of sustainability too.

For example, the depletion of oil and other fossil fuels is responsible for much of the increase in CO2 in the atmosphere. Deforestation and soil erosion also remove vegetative cover, which in turn tends to add to climate change. CO2 causes ocean acidification, which is predicted to cause the death of many shellfish and other ocean organisms. Activities such as construction and mining that damage habitat also contribute to climate change through their removal of vegetative cover, and through the use of non-reflective materials that absorb heat.

In turn, climate change makes many of these other issues much worse. Warming causes the death of species, including valuable forests, grasslands and crops. Storms and flooding damage access to fresh water. Climate change hastens the destruction of habitats and ecosystem services on which we depend, and very likely increases the rate of extinction greatly, even catastrophically.

So climate change, because it is both an urgent and a comprehensive issue, can serve as a kind of "lens" through which we can look at other, less urgent issues, that have therefore been ignored for too long.

Climate change: a summary of the science

The field of climate change research is a dynamic one, and it is important for professionals to keep themselves informed with updates in this rapidly changing field. Media coverage can be confusing and superficial, and interest groups can distort the true implications of new findings.

Broadly speaking, this is what is known in late 2009.

Human activities have introduced a number of so-called "greenhouse gases" into the atmosphere – so-called because they tend to trap heat in the Earth's atmosphere, much as the glass of a greenhouse traps heat entering from the Sun. Among the gases are carbon dioxide, methane, and various other hydrocarbon compounds.

These substances exist in the atmosphere naturally, but have risen markedly in the age of human industrial activity. One complication is that some of the gases act more strongly than others to produce solar heating. Therefore, scientists use a figure called a "carbon dioxide equivalent" or "CO2 equivalent," which expresses the equivalent concentration of CO2 if that were the only gas present, to produce the equivalent effect.

At present the level of CO2 equivalent gas in the atmosphere is approximately 380 parts per million. That is, if one separated out the molecules in the atmosphere, there would be an equivalent of 380 CO2 parts, and 999,620 non-CO2 parts.

This may not sound like much. But the historic level of CO2 parts per million is about 270, meaning that the world has seen roughly a 50% increase in concentration.

It is possible to examine evidence from ice cores and fossil records, and correlate the concentration of CO2 and other greenhouse gases with the Earth's average temperature. From this evidence, we can construct a fairly reliable model about the likely increase in temperature that will arise from corresponding increases in greenhouse gas concentrations. We now know that a rise to 450 parts per million is likely to be associated with a rise in average global temperature of two degrees centigrade.

This, too, sounds like a modest increase. But we know that its effects are likely to be profound. The fossil record indicates that a 6 degree centigrade increase in the Earth's temperature occurred some 56 million years ago, in a 20,000 year period known as the

Paleocene-Eocene Thermal Maximum. That rise resulted in the extinction of up to 50% of deep ocean life, and other dramatic biotic changes.

Current models suggest that we might reach the 6 degree rise in far shorter than 20,000 years – perhaps in as little as 100 years – with severe disruptions of the critical rainfall patterns and ecosystems on which humans depend.

The effects of climate change that are of most immediate concern to human populations are:

- Disruption of rainfall patterns for crop irrigation in large parts of the world;
- Inundation of coastal areas, making them uninhabitable;
- Severe storms, heat waves, wildfire breakouts and other highly disruptive weather events that will likely kill many thousands and destroy settlements;
- Severe disruption of fresh water supplies, through weather events and through contamination from flooding;
- Catastrophic collapse of species on which humans depend for food and other needs;
- Severe shortages of resources, prompting mass migrations of whole populations;
- Severe political instability and possibly catastrophic conflicts as a result of all of the above.

Climate change: Mitigation and adaptation

We know that some effects of climate change are already under way, and other effects are likely to be inevitable. For example, some coastal areas are likely to be inundated as sea levels rise. The steps we take to adapt to these changes – such as building dykes, or raising structures on piers, or removing people from coastal areas – are referred to as ***adaptation***, in contrast to steps we take to ***mitigate*** the factors that are causing climate change in the first place.

While some adaptation is inevitable, it must be understood that adaptation is often extremely expensive, and may even be ineffective. For example, it will simply be prohibitively expensive to protect many coastal settlements, and the cost of building new settlements will also be extremely high.

Urbanism and climate change

What is the role of urbanism in contributing to climate change? What does that imply for the role of urban designers?

(We have defined urbanism as the complex system of partial public and private realms that exist between buildings. Therefore large cities are not the only examples of urbanism – it can exist in the smallest town too, or even in some cases, in a rural farm complex.)

Let us consider two facts. First, it is in our homes and neighbourhoods that we first generate the demand for the world's resources. Here we eat most of our food, do much of our transportation, buy, use and dispose of most of the world's end products. Here we use much of the world's energy for heating and cooling, lighting and operating appliances.

So the question of whether these places increase or decrease demand for these resources is one we must examine carefully.

Second, it is already known that in our buildings, including homes, shops and offices (and not including manufacturing operations), we consume roughly half of the resources that contribute to climate change, in the activities, like heating and cooling and running lights and appliances, that are likely to trigger the release of greenhouse gases somewhere else. Moreover, we consume additional resources in the ways we furnish our houses, prepare and eat food, and go about our other activities of consuming goods. (There is a significant question of whether the design of the house and its neighbourhood have an effect on our tendency to consume in certain ways, such as purchasing large quantities of disposable goods; we will discuss this point later.)

So the shape of buildings, their efficiency of layout, their exposure to heat loss, their tendency to gain or lose heat energy, and their ability to accommodate our various habits of consumption – all have a significant effect on energy use and carbon emissions.

Add to that the energy we use to move between buildings, and a number of other patterns of consumption and energy efficiency (which we will discuss below) – and you come to roughly two-thirds of the demand for resources that cause climate change, coming from the built environment. (The other roughly one-third comes from commercial transportation, manufacture, and the production of the energy itself.)

So clearly, the built environment has a major role in generating the causes of climate change, and other unsustainable practices. It follows that built environment professionals must have a major role in making reforms.

But what are the specific factors that designers must take into account? Roughly speaking, they are factors at the scale of the building, and factors at the scale of the neighbourhood and region. And as we will see, these two sets of factors are more interrelated than they might appear.

Thus architects must think in terms of urban design, and urban designers must also think in terms of architecture. We will see this point emphasized as we go through the detailed factors.

Factors of low-carbon sustainability at the building scale

We begin this section with a caveat that every urbanist should know by heart: no building is an island. It does no good to have a low-carbon building that is located so remotely that the energy required to drive to it negates the savings. And it does no good to abandon a historic structure (as recently happened in a well-publicised case) to build anew a "green" structure that requires so much initial energy and resources that the owners have in effect dug themselves a "carbon hole" from which they will not even get back to even for some years. Far better, in that case, to retrofit the existing building.

Nonetheless, we know that there are a number of very important things that can be done at the building scale – particularly when it comes to heating, cooling and lighting, which account for a large portion of energy consumed by the built environment.

- Building energy systems: obviously these must be as efficient as possible, while remaining reliable over time and with changing conditions – a characteristic that is known as "resilience." Exotic technologies that may break down, or parts that may become unavailable, mean the system is non-resilient, and may not be sustainable under changing conditions. The more the systems can rely upon renewable energy (solar photovoltaic systems, solar hot water, passive solar heating) the better. Best of all are fully passive systems, that don't rely upon any technological inputs.

- Building envelope: high insulation value to maximize efficiency of heating and cooling, while retaining livable conditions. There is an optimal balance which may be hard to predict in practice. For example, greater window area often makes a building more livable, but fully glazed curtain walls may be too extravagant. (Ken Shuttleworth, the designer of London's "Gherkin," which is a full curtain wall building, has famously called curtain walls "a thing of the past."

Factors of low-carbon sustainability at the urban scale

These factors may be summarized as follows: infrastructure efficiencies, location efficiencies, efficiency of characteristic building types, ecosystem services, urban macro-effects, and behavioral effects.

Infrastructure efficiencies come from the pattern of the infrastructure, and the compactness of the functions it serves.

- Well-connected multi-modal transportation system, including public transit, walking, bicycle and car;
- Well-connected street network, facilitating shorter trips, and encouraging walking and biking;
- High density of end uses of energy, requiring shorter lengths of infrastructure, and lower operating, maintenance and embodied energy;
- Ability to capture waste heat and other forms of energy at a district level;
- Ability to reduce transmission losses.

Location efficiency comes from the well-distributed range of daily needs and activities:

- Jobs to housing balance;
- Optimal distribution of schools, shopping and other daily needs;
- Mixed use retail and commercial, with walking range of many residences;
- Optimally efficient regional distribution of large and small centers. Research shows that the most efficient patterns tend to follow a "power law," a distribution of many small centers, fewer medium centers, and very few large centers.

The efficiency of characteristic building types is closely connected to the efficiency of urban pattern. Again, no building is an island, and the size, shape and orientation of an individual building is closely related to the size, shape and orientation of the neighbourhood itself. The characteristic buildings that are likely to be built in a neighbourhood are in turn related to the neighbourhood's connectivity, density, characteristic appeal, market dynamics, and other factors.

The building characteristics include:

- Attached types, which tend to save heat from common walls;
- Buildings that are oriented to take maximum advantage of passive solar exposures;
  Buildings that are well-sheltered from the negative effects of sun and wind;
  Buildings that line the street and support an attractive streetscape, conducive t0 pedestrian activity;
- Buildings that make maximum use of small outdoor spaces, reducing wasted space around them, and the water, fertilizer and maintenance energy they require;

So-called "ecosystem services" are functions that the world's ecosystems perform for us, often unacknowledged, without which we would have to pay extravagant costs to perform them ourselves (if indeed that would even be possible). They include:

- Purification of water from wetlands, and from groundwater re-infiltration
- Purification of air from vegetation (especially conversion of CO_2 into O_2)
- Generation of soil nutrients from vegetation (especially conversion of nitrogen and CO_2 into soil nutrients)
- Pollination of crops by bees and other insects
- Natural pest management by predators within stable ecosystems
- Possible regulation of weather and atmospheric composition by ocean plankton and algae (damaged by marine pollution and waste)

Urban macro-effects are effects that are created by the urban pattern itself, rather than being created independently and merely being conditioned by the urban pattern. They include:

- Albedo effect. The tendency of darker buildings and paved surfaces to convert solar energy to heat energy, which increases the greenhouse effect, and adds to the heating of cities, and the cooling load for climates and seasons when cooling is required;
- Heat island effect. The tendency of air to become trapped between buildings – especially tall ones – and to become heated above ambient levels. Again, this increases the heating of cities and can exacerbate heat wave effects. It can also add to cooling load in climates and seasons when cooling is required.
- Negative effects of tall buildings. While higher density is generally more beneficial from a sustainability point of view, there can be a drop-off of benefits above about 100 persons per hectare, and as certain negative effects of tall buildings become significant.

They include:

- Embodied energy in steel, concrete and other high-energy materials
- Inefficient floorplates due to egress requirements, increasing the embodied energy per square meter even further;
- Higher exposures to sun and wind, especially when curtain wall assemblies are used;
- Shadowing effects on other buildings that may benefit from solar access;
- Ground effects that may damage the viability of low-carbon urban spaces. These include wind effects, shadowing, and "canyon effect" (trapping exhaust gases in higher concentrations);
- Social and psychological effects. More research is needed, but there is enough research to indicate some precaution is needed, both in the quality of life for residents of tall buildings (especially children) and in the psychological effects of tall buildings for the livability of the surrounding neighbourhood. There is also reason to be concerned that tall buildings can effectively serve as "vertical gated communities," isolating their residents from the street life below, to the detriment of both.

There are ways to mitigate many of these issues. But the key conclusion is that there are indeed significant issues to manage, and tall buildings must not be over-sold as a "green" building type.   The burden of proof must be on those who propose tall buildings as the most sustainable solution in a given context -- very carefully considering their true carbon footprint and their effect upon the surrounding urban structure.

The last category is the most difficult to assess, but may well be one of the most important: the effect of behavioural issues.   Evidence suggests that if we live in a neighbourhood in which it is very difficult or impossible to walk, and very much easier to drive to daily needs, then we are much more likely to get into the frequent habit of driving. The more we develop such a habit, the more we are very likely to avail ourselves of ever more of the resources it affords us – the big-box shopping, drive-through restaurants, and other more distant activities that might be only marginally better than closer ones.

Conversely, the evidence suggests, the more we live in an appealing urban neighborhood, with inviting walkable streets, well-distributed amenities and public spaces, the more we are likely to use these low-carbon activities, and interact with our neighbours who are doing the same. The more we live in a neighborhood with optimally distributed services (regular needs met with many small shops and services, less frequent needs met with fewer larger ones) the more we are likely to use a more efficient combination of large and small facilities.

Less clear is the effect upon consumption of other resources, like food, electronics and other household goods. But there does seem to be evidence that a more compact, urban lifestyle encourages a more selective consumption pattern – fewer household goods and electronics for smaller homes, and fresher market foods (which tend to be more available). Conversely, a lifestyle in a larger suburban home seems to encourage (or at least associate strongly with) more purchases of relatively disposable household goods and electronics, more purchases of highly packaged and processed foods, and more caloric intake per person (including more meat-based foods, which are much more energy-intensive to produce). But much more research is needed in this area.

It must be stressed that this is not behavioural determinism. The built environment does not force us to behave in one way, as opposed to another way. But it can certainly make it almost impossible to behave in certain ways – to walk to a neighbourhood farmer's market to buy fresh produce, for example -- or make it very much easier to behave in certain other ways. It can constrain our choices, or facilitate them. When it comes to sustainable patterns of activity, it is clear that this is a crucial topic.

Adding up the numbers

In dealing with sustainability, as we have just seen, many of the factors are inevitably qualitative: how appealing are low-carbon neighbourhoods and lifestyles? How well can we live in a more efficient lifestyle, in a more efficient urban pattern? To what extent will we value, care for, and take care of, buildings and urban spaces over many years?

How desirable, how livable, how beautiful, are our low-consumption neighbourhoods? These are inevitably important qualitative questions.

Nonetheless it is crucial to be able to measure the aggregate effects of various choices we might make, so as to optimise our choices, and to reach a much more sustainable condition. We can also measure the qualitative factors, by measuring the expression of human preferences and evaluations. Indeed we do this all the time when we count votes, or count rents, or count funds for socially important goals.

We must not let the quantitative information replace the qualitative information, but rather, serve as a complement to it. We must not be like those who, it is said, know the cost of everything and the value of nothing. This would be to misunderstand the value of qualitative information in its own right, and in combination with quantitative information.

What are metrics?

In the challenge of sustainability we speak of "metrics" as specific measurable dimensions. If we want a city to be sustainable, then we must ask, what is the rate of resource use, and the percentage of recycling versus waste? What is the period of time that pattern can be sustained?

What are the health statistics of the community – the longevity, well-being, mortality, morbidity (rates of sickness)? The social statistics, such as crime, poverty, social support and interaction? The economic statistics, like prosperity relative to resource use, jobs stability, local economic activity, stable trade patterns?

In the case of climate change, the numbers are particularly stark. How much carbon is each person generating, from their household back to the factories and farms that produce all that they consume? How much difference does it make to change the layout of a city? To change to a more efficient kind of automobile, like a hybrid? To change the availability of public transit?

There is a great deal of research on such metrics -- but it must be said, there is also a great deal of confusion. That is in part because it is possible to define such metrics in many different ways, which may or may not be consistent. And it is easy to overlook many important factors.

Moreover, it can be very difficult to get reliable and consistently defined information. As an old saying goes in computer science, "garbage in, garbage out." If our inputs are not clearly defined and accurately gathered, the results will likely be meaningless – or worse, misleading.

And it is crucial to get a full picture, and not look only at one set of factors, which can be equally misleading. Part of the problem is in the nature of specialization: specialists are trained to look at only one set of factors, so as to try to make it as reliable as possible. But if that misses gaps between disciplines, the picture will not be complete..

For example, an urban sustainability researcher might assess a population that seems to be reducing carbon emissions, but might overlook one possibly crucial factor: the number of trips taken by jet aircraft, which contribute high levels of carbon, and in an especially detrimental part of the atmosphere.

Unfortunately, it is easy to manipulate statistics by making just these kinds of omissions, intentionally or through unconscious bias. The public discourse - as well as the scientific debate -- can be clouded by such incomplete statistics. In part that is the nature of the scientific process: to sift through such inaccuracies and gradually to correct them. In the case of public discourse, where those with particular interests may distort the process, it is more important to find a path through the thicket of inaccuracy and to develop a public consensus on the issue.

This is all the more difficult because the subject itself is a dynamic one, and the terms of reference themselves may change over time.

Thus it's crucial that professionals working on sustainable urban development strive to develop as comprehensive and accurate a picture as possible, presented with the clear outlines of a working consensus.

Our job is like that of doctors, who need to make a prescription to a patient on how best to improve their health. Our job is not to debate with the patient all the complexities of the latest medical research – though we shouldn't hide that wither. Rather, we should identify what, in our professional judgment, the preponderance of the evidence is telling us, about the best course of action available to deal with the condition at hand.

Specific Metrics of Climate Change

There are a number of well-established metrics that we can use to track the likely contribution of climate change from an urban settlement and its morphology. These include:

Vehicle Kilometers (or Miles) Traveled: This is the average distance each person drives in a given unit of time. If the average fleet vehicle efficiency is known, and such factors as idling and other contributions, it is relatively easy to work out form this the average CO_2 emitted per person from the driving activity.

Non-Tailpipe Vehicle Emissions per Person. As noted earlier, this includes vehicle manufacture, maintenance, extraction, refining and delivery of fuels, and all the other factors. They generally amount to 50% again of "tailpipe" energies, but will vary based on the rate of use of the vehicles and other factors.

Other Transportation Emissions per Person. This includes public transportation, which can vary greatly in efficiency, and other modes that are small but not negligible contributors. (For example, a person who rides a bicycle long distances every day and consumes a high-meat diet to do so may actually contribute significant CO_2 from that fact alone.)

Transportation Infrastructure Embodied, Operating and Maintenance Energy per Person. This is the share each person carries for the roads, bridges, lights, rails, and other infrastructure elements of the transportation system.

Domestic Energy Per Person: Again, this is relatively easy to work out for a given area, based on utility company statistics on delivered energy, and residential household composition. Once the use of energy in the various forms is known, it can be calculated what the extraction, refining, transportation, production and transmission energies and emissions are per unit of energy, and from there, per person.

Again it is vital to look beyond the energy and emissions at the building, and understand the hidden sources of energy and emissions in production and distribution.

Consumption of Water, and Use of Wastewater Per Person. This includes water for drinking, cooking, washing, human waste, plant irrigation and other uses. It may also include water for evaporation cooling units or other mechanical equipment.

Waste Versus Recycling Per Person. The degree to which resources are recovered from the waste stream, and the additional energy and resources required to so. Waste is also a problem in its own right as it can generate methane gas, a greenhouse gas that is over 20 times more effective in trapping solar heat than CO_2.

Other Infrastructure Embodied and Operating Energy Per Person. This includes pipe construction and repair, pumping, power line and telecom and cable construction and repair, and other utilities.

Transmissions Losses Per Person. These include electric power loss, and leakage from pipes. They can be significant percentages of total use, and they can be proportionally minimized with shorter distances per person.

Other Transportation Per Person, Including Inter-City. These include the very significant factor of air travel, as well as travel by car, rail and boat.

Embodied Energy in Materials in Buildings and Urbanism Per Person. This includes all the concrete, steel, glass, wood, brick, and other component of the built environment. There are great variations in the embodied energy and the potential for emissions in various materials. For example, wood is generally a low-energy material, and an excellent "carbon sink" – when harvested sustainably, it pulls CO_2 out of the atmosphere and locks it away in the building for its life. Concrete and steel, on the other hand, require comparatively high levels of energy and resources for their production.

The life span of a building is also highly relevant. A wood building that lasts ten years may be worse than a concrete or steel building that lasts 100 years.

Consumption of Food Per Person. This is a very large component of energy and emissions per person. It includes the production of energy required to grow, harvest, process, transport, refrigerate and deliver foods, including fertilizers, farm equipment, irrigation and pumping, trucks, rail, stores, restaurants, refrigerators, and other equipment and processes. The range of food types varies greatly, with meat products estimated to consume as much as five times more per calorie than vegetable foods. In addition, foods requiring extensive transportation and/or extensive processing and storage also require more energy and emissions per calorie than foods grown locally, or delivered more quickly with minimal refrigeration. Finally, the waste factor is significant: the more foods can be used without wasting a significant percentage (by spoilage, or from rejected cosmetic blemishes, or from restaurant over-production) the lower will be the consumption per person.

Consumption of Goods Per Person. This include all the other goods one consumes, together with all the goods required to make that possible. In the former category are the clothes, furnishings, paper, tools, appliances, electronics and other end-user goods of our daily life. In the latter category are all the things needed to produce and deliver them: the mining equipment, machines, factories, offices, trucks, railroads, aircraft, stores, and other parts of the manufacturing and deliver system.

Of course this system is a global one, and components of even a rather ordinary household electronic device may come from many parts of the world. The question is to what extent this supply chain uses energy and resources, and to what extent it uses other unsustainable methods – a question that is increasingly hard to answer in a complex, global-scale production system.

All Other Resources Per Person. In this category are all the incidental acts of consumption of resources and/or energy: burning of waste piles, flaring of excessive industrial gases, burning of campfires,

Other Metrics – Human Impacts

In a distinct category are the other so-called "footprint" activities: the disruption of ecosystems and the services they may provide us.

Deforestation and loss of vegetative cover per person. Vegetative cover removes CO2 and reduces albedo effects, by converting solar energy to biomass. It is important to emphasise that this metric is measured per person. Thus a compact city that has little greenery within it, but leaves the surrounding land undisturbed, may actually be better per person than a sprawling city with significant greenery. Of course, a compact city may also feature greenery (such as street trees and green roofs) and that may confer many other benefits as well.

Deforestation and loss of vegetative cover is usually measured in hectares or square km (or acres or square miles), and graphed over time.

Loss of infiltration, recharge and wetland areas. This can lead to drastic decline in water quality and other negative effects, requiring energy-intensive (and expensive) systems to mitigate the problem.

Loss of wetland and recharge areas is usually measured in hectares or square km (or acres or square miles), and graphed over time. Growth of impermeable cover (e.g. pavement that does not allow infiltration) is also measured in area over time.

Loss of animal services. These include pollination from insects and birds; predation of pests by other species; consumption of undesirable "weed" species by various grazing animals; and other services performed that economically benefit humans.

Beyond the Specifics of Climate Change: Other Ecological Metrics of Sustainability

In addition to the resource depletion issues described earlier, other ecological metrics include:

Pollution. A very broad and important category, and one that includes air, water and soil pollution. Metrics typically specify parts per million (pollutants to contaminated media). In soil, it might be measured in the cubic volume of contaminated material, in meters or yards.

Ironically, some air pollutants may actually reduce the effects of climate change, by creating a reflective layer of haze in the atmosphere. But they often come with other pollutants that greatly increase the effects. (For example, vehicle exhaust contains particulates that help to shield from the effects of climate change, but also contains CO_2 and other greenhouse gases.)

Erosion of Soil. Given its role in supporting crops, a healthy soil system is a critical resource for the welfare of humanity. But erosion and depletion have reached the point that roughly half the historic level of soil has been eroded away and flushed into the oceans. This half-way mark has led some to term the challenge "Peak Soil." Soil depletion is usually measured in depth of soil (cm or inches) and graphed over time.

Destruction of habitat. This can be from one of the specific human impacts above, like deforestation, or it can be from other less direct sources, such as climate change. Or it can be simply from the displacement of ecosystems by human structures such as roads, buildings, houses and the like. This is usually measured in area (hectares or acres).

Depletion of fisheries and other wildlife stocks. This can happen from over-fishing, or from other impacts such as pollution or climate change. This is measured in number of animals, or else in weight of the animals, and percentage of change.

Social and Economic Metrics of Sustainability

It is important to remember that sustainability is not just about sustaining the natural environment, but about sustaining the human one as well. For the following variables, it may matter less how high the variable is in absolute terms, than that the variable is not dropping over time. It is also important to determine a minimum threshold at which we consider a sustainable society must provide for its members.

For example, hunter-gatherer societies were sustainable over hundreds of thousands of years. But they included aspects of society that we would probably not accept today: levels of disease, sanitation, infant and childbirth mortality, and other factors.

The built environment does not directly control these factors, but it does shape them. For example, improper shelter in a cold climate will affect levels of morbidity (illness). Similarly, we can use diagnostics of other health and social well-being to identify factors that may be contributors within the built environment.

Does the environment offer shelter, security, comfort? Does it facilitate social interaction, or make it difficult to achieve (for example, by isolating people)? Does it facilitate healthy levels of commerce, close-by shopping, a variety of healthy foods? Often the metrics we use to determine this are not in themselves conclusive, but are "indicators" of the need for further research and prescriptive action.

Some of the "indicator" metrics we can use to "diagnose" possible problems in the built environment that affect its social and economic sustainability:

- Longevity
- Morbidity
- Rates of suicide
- Rates of treatment for depression
- Rates of other psychological disorders
- Rates of substance abuse
- Rates of crime
- Rates of poverty
- Indicators of social capital, including
    - Numbers of social groups
    - Percentages of membership in social groups
    - Ability of strangers to cooperate and share resources
- Self-reported well-being
- Economic vitality

The factors of so-called "social capital" are particularly important. It appears that higher social capital is closely associated with higher resilience. People in distress are more able to rely upon each other to meet needs, and more likely to work cooperatively to solve problems and recover from adversity. Research shows that the built environment does play a role in facilitating the formation of social capital. Environments that isolate people do a poor job of facilitating social capital. Environments that allow people to share public spaces safely, and to interact in moderated ways, seem to facilitate the growth of social capital.

Research is painting a clearer picture about the comparative advantages of a walkable environment with a well-designed, functional public realm.

Qualitative and "Biophilic" Components of Urban Sustainability

Finally, we must remember that sustainability is about being physically and mentally well, as much as it is about merely surviving. If we are not well, then by definition something is going wrong, something that may well rise to the level of a threat to sustainability. From an evolutionary point of view, our ability to feel well or unwell is a biological capacity to recognize these factors, even when we do not do so consciously or rationally.

It used to be thought that our qualitative evaluation of an environment didn't matter much: it might add to our pleasure, but it didn't seriously affect our well-being. We now know, through evidence-based research, that the perceived quality of our environments can have a measurable effect on our psychological health, and even our physical health.

In particular, the characteristics of what is called "biophilia" – our innate love of natural and biological forms – are now well-known to have a marked effect on well-being. For that reason, biophilia is now a major trend in the design of hospital and patient care environments, which incorporate water, vegetation, sunlight, and other characteristics of "natural" environments.

By contrast, sparse, antiseptic environments can have a negative effect on well-being and health. In one famous study, patients on a recovery ward with a view of a blank wall healed more slowly than those with a view of a natural scene with trees. Other studies show similar results for alien, unfamiliar kinds of environments.

There are likely to be important implications for the creation of sustainable environments.

Putting It All Together

As we saw with the topic of resilience, there is one more vitally important characteristic of urban sustainability, and of sustainability in general: it is a complex product of many factors working together. It is not a mere addition of parts, but has the characteristics of a system. The system includes our urban systems, but also includes behavior and consumption patterns that extend beyond the urban system. (If we buy goods from overseas, or ship our waste overseas, we need to assess these overseas impacts too.)

What this means is that, as designers, we are not able to simply add up numbers by themselves, and satisfy ourselves that our work is "sustainable." Sustainability is not a formula. Rather, it is a state like health, that is dynamic and complex. It has to be continuously measured, and the factors that promote it will very likely need to be continuously adjusted.

But like health, sustainability is also a characteristic that develops under its own laws of resilience and equilibrium. Sometimes the best thing we can do is to know when to do nothing, and let people or places develop on their own. Sometimes we can give just a nudge, and the environment will do the rest. Sometimes we will have to take more aggressive action.

In any case, we need the tools to be able to manage this complex condition. We need to be able to diagnose what is happening, using the metrics and the tools that are appropriate for a given region. We need prescriptive tools too, including new technologies, new designs, and new economic and social tools.

Sustainability plans have become important tools to assess and improve the sustainability of a city, neighborhood or other area. A detailed discussion of such tools is beyond the scope of this overview, but following are the kinds of elements they might include:

- Diagnostic assessment tools
    - Ecological metrics
    - Economic metrics
    - Social metrics
    - Qualitative metrics
- Prescriptive tools
    - Master plans
    - Regulations
    - Codes
    - Economic incentives
    - Social incentives (e.g. certification systems)
    - Social capacity-building resources

As designers, we need to be able to work with other specialists – economists, social scientists, ecologists, engineers and others – to be able to develop designs and design approaches that will enhance the sustainability of a place. As consultants, we need to be able to develop framework approaches, combining analytical tools, diagnostic assessments, prescriptive tools and other resources to enhance the capacity of the community to improve its own sustainability.

Additional Reading (Optional):

Van der Ryn, S and Cowan, S. *Ecological Design*. Island Press, New York, (2005).

Farr, D. *Sustainable Urbanism: Urban Design with Nature.* New York: Wiley (2007).

Condon, P. Seven Rules for Sustainable Cities. New York: Island Press (2005).