Submitted to Building Research & Information
Manuscript ID 16BR0747-RE
Title COMPARING THE CARBON IMPACT OF BUILDINGS TO THAT OF INFRASTRUCTURES
Authors Butters, Chris Thomas, Terry
Date Submitted 16-Feb-2016

Submission to BRI Journal, Feb.2016

word count: abstract 219 + body 3910 + references 635

NB: items which may need to be "blinded" for review, are in RED

COMPARING THE CARBON IMPACT OF INDIVIDUAL BUILDINGS TO THAT OF THE SITE WORKS

(Authors …)

Abstract

The growing importance of the embodied, as opposed to operational, impacts of construction is well recognised. Simple examples comparing the carbon impact of individual buildings to that of the infrastructures and site works, illustrate the relative importance of the latter. This perspective is to date seldom addressed. Site works, especially in dense inner city contexts, are extensive, costly and energy and carbon intensive, involving mainly concrete and steel. The infrastructures including underground parking in particular also represent major land use interventions on almost the whole area of urban sites. It is shown that the urban infrastructures and site works can constitute a considerable fraction of the total carbon footprint. In addition, this fraction is likely to increase given that the buildings themselves will have considerably lower operational as well as embodied energy/carbon in future.

To date the impacts of the site works have been little focused in energy, carbon and LCA studies. This perspective has implications for sustainable building design as well as for urban policy and planning. The discussion highlights some potential advantages of low-dense typologies as regards embodied carbon, resilience and other qualities, and the significance of the urban infrastructures and site works in different climates and in low-income contexts. They need to be solved more sustainably, irrespective of urban density, transport systems or overall city contexts.

Keywords

(preliminary) Embodied impacts; low carbon; site works; sustainable building; sustainable urban form

Authors

1.Chris Butters (lead/corresponding author): Warwick University School of Engineering, email c.p.butters@warwick.ac.uk, phone: 07904 000051.
2.Dr.T.H.Thomas, same address, t.h.thomas@warwick.ac.uk phone: 07733 476418.

Acknowledgement

(as provided by EPSRC)
This document is an output from a project co-funded by UK aid from the UK Department for International Development (DFID), the Engineering & Physical Science Research Council (EPSRC) and the Department for Energy & Climate Change (DECC), for the benefit of developing countries. The views expressed are not necessarily those of DFID, EPSRC or DECC. Grant number: EPSRC EP/L002604/1.

1. Introduction

This paper illustrates, through simple examples, the importance of the environmental footprint of the site works and infrastructures that are associated with buildings and urban development. The indicator selected is that of embodied carbon. The findings which are then discussed briefly have implications for improving the sustainability of future building design as well as urban planning.

The largest energy requirement in buildings has normally been operational energy (OE) for space heating or cooling, in cold and hot climates respectively; but low energy buildings reduce this dramatically. As OE approaches *passivhaus* and similar very low levels in future, the *embodied* energy (EE) and carbon (EC) impacts become increasingly important. EC, in units of $kgCO_2e/m^2$ of floor area, already approaches or even exceeds 50% of the total lifetime carbon impacts in advanced sustainable buildings. This trend is comprehensively reviewed in (Ibn-Mohammed, Greenough, Taylor, Ozawa-Meida and Acquaye, 2013) and (Sartori and Hestnes, 2014). In a recent sustainable office building in Norway for example, the embodied carbon is very nearly equal to the operational carbon – 69 versus 75 tons CO_2/year respectively (Future Cities 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). In the following we discuss carbon only; the embodied energy implications are broadly similar as long as energy systems are largely fossil fuel based.

Many 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 a 4-storey office, concrete comprised 69.6% and steel 11.4% of the EC (Wallhagen, Glaumann and Malmqvist, 2011). Similarly, in an Italian apartment building these two comprised 76% of the EC (our analysis, from Blenghini, 2009). Cement products (reinforced concrete, mortar and blocks) and steel comprise over 70% of the total EC in a Chinese high-rise building case study (Xiaocun Zhang and Fenglai Wang, 2015). One can often substitute concrete and steel in buildings, for example with timber, lightweight panels or biomaterials, but this is far more challenging and seldom done in site works and infrastructures. Urban environments, which now house a majority of the world's population, require more of such "heavy" infrastructures than low-density settlements. In cities, even large green areas between buildings often consist only of a thin added green layer that covers extensive engineering works such as underground parking and infrastructural services. Reducing the impacts of these is a task for sustainable design. It can be of particular relevance for low-income contexts, also for cost and social reasons.

After providing typical figures for buildings-related EC, the impacts of site works and urban infrastructures are considered. In addition to their *initial* embodied carbon they also require *recurrent* (operational phase) inputs, in particular for maintenance. To their advantage these works may have a longer lifetime than the buildings themselves; although in reality, in contexts of rapid urban development one sees rather frequent modification and remodelling of roads, piping systems and other infrastructures.

2. Carbon footprint of buildings

This field has been extensively researched. Table 1 gives typical examples from the literature ranging from large buildings to detached houses. The base measure applied is emissions per net floor area, since envelope thicknesses will vary greatly in different climates. Post-use EC value of timber or other materials is not considered here. Figures are however heavily dependent on primary energy mix; for example the Swedish energy system is less carbon intensive than that of China, hence materials manufactured in Sweden will result in a building with less embodied carbon. Building lifetime, an arguably rather short 50 years in many current studies, guidelines and codes, also greatly influences the outcome.

Heavy buildings are mainly of concrete and/or masonry. Typical lightweight ones are largely of timber and board products, but even in these, much of the EC is for concrete/steel items such as foundations and floor slab. Own EC estimates in this paper are based on the ICE Inventory (Hammond and Jones, 2011). Measured in kg CO_2e/m^2, large buildings can have EC well over 1000. The EC of smaller buildings may vary at least fivefold. Existing housing in heavy materials, such as (C) in table 1, lies in the range 400 to 600. The UK *passivhaus*-standard house (E) has EC of around 233, of which well over half is due to the concrete and steel - even though the design was developed to reduce the carbon footprint, includes low carbon concretes, and is "far lower than the average UK domestic dwelling". The lightweight Norwegian eco-house (F) by GAIA architects with a strong focus on eco-materials has EC below 150. Lightweight tropical buildings, such as the Thai example (G), generally have low EC.

Table 1: Embodied carbon – EC

No.	Building type	Main materials	EC $kgCO_2e/m^2$	% of which concrete+steel
A	Large buildings, UK	concrete, steel, glass	700-1200	60-80
B	Large buildings, China	concrete, steel, masonry	ca. 600	ca. 70
C	Typical low rise housing UK	concrete base, masonry	450-550	ca. 75
D	4 storey block, low energy, Sweden	concrete, blocks, timber	274	58
E	House, passivhaus, UK 2003	mix, low carbon	230	ca. 60
F	nZEB-eco house, Norway 2013	timber products, RC slab	140	40
G	Traditional houses, Thailand	lightweight on slab	70-100	ca 60

Sources: A, C, E, (RICS QS & Construction Standards, 2012); B, (Xiaocun Zhang and Fenglai Wang, 2015); D, (Dodoo, Gustavsson and Sathre, 2009); F, (Butters and Woodville, 2016); G, (Chiarakorn et al., 2015).

Despite differences in primary energy mixes and LCA methodologies, research comparing the EC resultant from five databases confirms the above tendencies, with figures (kg CO_2e/m^2) as follows: concrete buildings 600-870; heavy timber buildings 360-560; lightweight buildings around 270-450 (Takano, Winter, Hughes and Linkosalmi, 2014).

3. Carbon footprint of large urban developments

Lifecycle analyses seldom discuss exterior and site works as such. The examples whilst illustrative only, show that these may form a considerable part of the EC of building projects. A typical high-rise city block in Ningbo, China, has been studied within **our** ongoing research into low-impact housing and urban form (xxx authors, 2015). This mainly residential block, illustrated, contains some 3,000 apartments. It has 10 tower blocks of 23-30 floors set around landscaped areas. The urban density or floor area ratio (FAR), basically the site footprint multiplied by the number of storeys, is about 2.6. This is more than double the density of suburban typologies, but is similar to or lower than that in traditional European cities with urban blocks of 4 to 8 floors, where the FAR can exceed 4.0 (LSE Cities/EIFER, 2014); hence, high-rise does not necessarily offer higher population densities. The infrastructure implications however are considerable.

Figure 1. High-rise city block, Ningbo, China
(Photo: Butters)

The surface coverage (SC) of the Ningbo block is below 20%, meaning that 80% of the site is not built on – at least, not above ground. But a large part of such sites is in reality occupied by structures underground. Car ownership is increasing dramatically in developing countries. Although the Ningbo planning norms for parking, currently due for revision, are still set somewhat lower, a requirement for one parking place per dwelling is widespread in many countries (Rui Wang and Quan Yuan, 2013). On that basis the required parking garage would be nearly the same as the area of *the entire site*. Below we provide a rough estimate of the underground construction works for such parking. Other infrastructures including culverts, drains, roadways, lighting, paths, walling, etc., all add lesser but significant impacts. Waterproofing, not included here, is another energy and carbon intensive item which for a large underground parking structure is many times the waterproofing on the buildings themselves.

Table 2 provides a simplified comparison of the EC of the buildings and the site works in the high-rise block. As noted the share of concrete and steel in the overall EC of such buildings is typically 60-80%. It may be added that using low carbon concretes whilst beneficial would not reduce the *relative* importance of the site infrastructures.

Since the buildings are largely in concrete we adopt an EC figure of 750 kg CO_2e /m^2, in the middle range identified in studies such as those cited above. If one parking place (minimum 20 m^2 per vehicle) were provided for all 3,000 apartments this would require over 60,000 m^2 of RC slabs each for floor and deck, hence well over 120,000 m^2 of concrete; in addition come walls, columns and beams. The loadbearing deck carrying landscaping is considerably thicker than residential decks. Our addition of 7% of the building EC for all other exterior site works is tentative but is supported by figures in a detailed LCA study of a large urban development in Beijing (Han, Chen, Ling Shao, Li, Alsaedi, Ahmad et al., 2013) where external (municipal) civil, electrical, water supply, drainage and landscaping works together amount to some 6,6% of the total project EC.

Table 2: EC in a high-rise block, Ningbo

	t	CO_2e/kg	t CO_2e	kg CO_2e/m^2
The buildings:				
Total floor area 180,000 m^2			144,000	750
The site infrastructures:				per m^2 building
RC approx. 42,000 m^3 *	100,800	0.2	20,160	112
All other site works +7% of 750				53
Total (per m^2 of floor area)				165
*BoQ estimate 16,000 cubic metres (floor) + 23,000 (deck) + 1,400 (ext. and int. walls) + 1,000 (columns and beams) + 600 (ramps, shafts, stairwells, other). **Infrastructure as % of total EC: 165/(750+165): 18,03%**				

Hence, given carbon-intensive large buildings, the infrastructures and site works may constitute around 20% of the total embodied carbon in an urban block as a whole. Of this, approximately two-thirds is attributable to the underground parking. Further, one may note that with future low carbon buildings above ground, of even a moderately low carbon standard, say 350 kg CO_2e/m^2, the infrastructures fraction would become *well over 30%* of the total EC in this type of urban development.

It is difficult to establish the EC (or cost) of parking, ventilation systems or landscaping as such. The above mentioned Beijing study, one of few to address specifically the part played by exterior works, estimates these without underground parking, which is included in the buildings civil works. One can say that this unfairly “punishes” the building itself, in a carbon analysis, for what is actually a decision about parking at the level of the urban and site planning. Similarly, in the Beijing study HVAC, water and electrical services are analysed under separate headings; but the associated extra room heights, concrete shafts and plant rooms are “hidden” within the analysis of the building’s civil works. This is despite the fact that suspended ceilings, shafts and plant rooms (and their costs) are principally a part of the climatisation and building services. Seen in an LCA perspective, the above raises important issues of system boundaries and overlaps between “sectors” in building projects.

Landscaping works, for example, are likely to be defined as an identifiable subcontract with its own bill of quantities, rather than as part of broader site impact. But they are only one part of site works; in addition to underground parking there are other quite large EC components in site works and infrastructures. More studies are needed which distinguish the various exterior site works that must be accumulated from within the bills of quantities of various subcontracts.

4. Discussion

Carbon is naturally only one consideration for sustainable infrastructure design and part of a broader picture. We therefore now briefly note a range of possible implications for design, energy policy and urban planning.

4.1. Sustainability Indicators

The indicator SC widely used in urban studies denotes the building footprint, and, inversely, indicates the extent of remaining open surface space on a site; this is useful as regards visual and social qualities especially. But as noted, urban infrastructures and underground parking can impact the entire site - whether above or below ground level is irrelevant. We also need to know how much of a site is undisturbed and its potential for biodiversity, microclimatic and other qualities including vegetation, soil, albedo and rainwater infiltration; and the potential for eventual restitution. This includes various categories:

- areas with removal of all topsoil without restitution,
- areas with subsurface civil works, parking, culverts etc.,
- coverage with constructions at surface level (paving, asphalt etc), especially if impermeable,
- coverage in the form of buildings and other structures
- surfaces that are given green (or blue) coverage subsequent to construction, including landscaping on top of underground spaces, artificial ponds and green roofs.

There is a growing requirement today to achieve a low ecological footprint and high biodiversity in site planning. SC alone provides an insufficient picture of the land use and degree of anthropogenic intervention. The opposite case is also illustrative: some “ecological” designs have raised buildings above ground in order to leave the natural soil and flora untouched underneath; these too may be unfairly “punished” by SC. Amongst examples of more holistic indicators is the Norwegian BGF (blue-green factor) system, based on evaluation of “ecologically effective areas” with a description of various qualities and parameters and a point system for evaluating outdoor spaces (Ardila and de Caprona 2014). This largely addresses the field of landscape engineering and evaluation, but even such systems do not fully account the carbon footprint of site works including underground parking; largely due to the overlaps in or non-correspondence of subsystems as these are normally delimited in contracts and BoQs.

4.2. Planning implications: the issue of density

Infrastructures and urban density are clearly related. Whilst not engaging in a detailed discussion of urban typologies, a general distinction is made here between fairly low-dense typologies, which range from cluster housing settlements to European type city blocks, and on the other hand typical inner city high-rise contexts. As typified in many traditional European towns, infrastructures in the low-dense variants can be fairly simple, and on-street parking provided. Dense inner cities on the contrary require far “heavier” types of infrastructures including for water supply, drainage, sanitation and wastes. They necessitate widespread underground parking as well as the complex mobility systems of multi-lane streets, bridges, flyovers and tunnels that are an integral feature of dense cities as a chosen - not inevitable - pattern of human settlement. It needs to be recalled that one of the ultimate aims of dense urban form is car free, high density living and working in walkable cities. This cannot be achieved in a “car city”. And, as is shown in several Norwegian studies (where transport associated with a building’s operational lifetime is, notably, often included in building LCA), transport has the largest impact on climate emissions; even more so as buildings themselves become low impact (Future Built Program, 2015).

Extremes of suburban sprawl and sites with very low density are obviously inefficient in resource use in many, though not all, ways. But high population density, as measured in dwellings per hectare (dph) or floor area ratio (FAR), can be achieved with relatively low-rise typologies (LSE Cities/EIFER, 2014; Jabareen, 2006). Greater density appears to offer efficient infrastructures as regards roads, energy, water supply and sanitation; however, “Other empirical studies have consistently found that lower operating costs in the suburbs more than offset the higher initial capital costs of installing new infrastructure”. (O’Toole, 1996). Surface parking in particular is immensely less demanding than underground, both in terms of technology and costs.

Looking beyond the scale of individual sites, a factor that greatly determines infrastructure needs with their associated space use, materials and environmental impacts, is the overall urban transport picture (Sorensen and Hess, 2007). In general, low to medium density developments with surface parking will have a low proportion of site-related EC; this can be a significant argument in favour of low-dense development. And as noted the Ningbo high-rise example illustrated above has FAR of around 2.6, not very much higher than the low-dense models. In acclaimed state of the art, walkable low-dense ecocity districts such as Vauban in Freiburg or Western Harbour in Malmo (Butters, 2011), the FAR seldom exceeds 2,0 but there are many qualities including low cost, diversity, social inclusivity and genuine (as opposed to artificial) landscape, green space and ecological habitats.

Naturally this relates in turn to broader questions of balancing quantitative and qualitative considerations in urban development. However, the focus here is the on-site infrastructures; these need to be solved more sustainably, irrespective of the transport systems or urban density in question.

4.3. Broader lifecycle considerations

Whilst we have focused on *carbon*, as noted the implications are broadly similar for embodied *energy*. Embodied energy may be reduced by various means, notably substitution with less energy-intensive materials. However, the carbon impact of site works, heavy urban ones and underground parking in particular, will be more difficult to reduce. This is partly due to the high carbon emissions that are related not to energy but to the basic *chemical* process of cement manufacture from calcium carbonate; this is the case for all cements of Portland type and amounts to well over 0.5 tons of carbon per ton of cement, even taking subsequent recarbonation into account (SangHyun Lee, WonJun Park and HanSeung Lee, 2013; Pade and Guimaraes, 2007). This again argues for increased attention to the site works.

As has been discussed elsewhere (Cheshmehzangi and Butters, 2016), "heavy" urban infrastructures have some disadvantages when one examines the whole lifecycle picture:

- Their *recurrent embodied energy/carbon* for ongoing maintenance is probably more onerous than in low-rise infrastructure solutions, not least due to difficult (i.e. high-rise, underground, and/or multi-layer) accessibility,
- The impacts of *materials transport* and of *on-site construction*, although relatively minor in the LCA balance, are also higher,
- The *post use impacts* can be far higher due to complicated demolition and recycling or disposal of more complex and polluting materials and technical components,

The recurrent energy/carbon inputs into buildings as well as infrastructures demand particular attention: This includes repair, upgrading, extension, replacement and so on throughout their lifetime. "Over a very long life-span this has been shown to exceed the waste flow from simple demolition" (Thomsen. Schultmann and Kohler, 2011). They may amount to *more than* the initial embodied impacts.

In comparison to solutions that are feasible in low-dense and rural contexts, the post-use phase of such infrastructures will almost invariably be both onerous and costly, as well as quite energy intensive. It may be noted for example that recycling concretes, for use as aggregates in new mixes, requires *more energy* than producing fresh aggregates (Weijun Gao et al., 2001).

In addition, other sustainability considerations – important ones – may be linked to the type of site works. For example, being both massive and expensive, dense urban infrastructures offer less flexibility or "generality", hence less *resilience* – a keyword in sustainability discussions – for future modification and adaptation that may be needed over time. Resilience reaches far beyond technical considerations alone. Re-engineering of heavy urban infrastructures is very onerous not only in technical and carbon terms but equally in terms of process: "the capability to be able to mobilize coherently, and in a coordinated way, the stakeholders necessary to develop and operationalize strategies …" (Eames et al., 2013) – hence involving a very high level of organisational, financial and strategic complexity. This again suggests advantages in smaller scale cities and low-dense building typologies.

4.4. Policy implications: climatic contexts

Some interesting points also emerge regarding the relative importance of the site works and infrastructures in different climates. Since space heating and space cooling require energy inputs of a similar order, in hot climates (both hot-dry and hot-humid) OC will tend to be similar to cold climate OC. In both cases one assumes that the *operational* part will reduce in future energy-efficient buildings. Whilst this underlines the growing importance of the *embodied* impacts generally, the site works picture will in fact vary considerably depending on the climatic context:

- in hot-humid climates, where buildings are often lightweight, the EC of the buildings will be lower, hence the EC of the site works will tend to be of greater relative importance than in hot-dry or cold climates,
- in moderately warm climates where there is little need for space heating or cooling at all, operational energy/carbon is far lower so the embodied aspect (of both the buildings and the site works) will tend to be even more significant,
- and finally, the relative importance of the site works is likely to be large in *any* building, whether in hot or cold climates, that is without significant space heating or cooling; hence in particular in low-income contexts.

The above indicates three contexts where the carbon-related implications of the infrastructures necessary for different urban solutions might be particularly significant for city planning, energy and climate policy.

4.5. Policy implications: low income contexts

Our research program addresses energy use and climate emissions in low-income contexts. We need to look beyond the buildings alone and include site works and infrastructures. Whilst the topic of this paper applies broadly, this study suggests that the specific context of low-income areas is particularly relevant. The largest increases in energy use and emissions globally are amongst the upwardly mobile populations of the developing world's cities. Energy amenities including air conditioning in urban contexts such as Thailand and China are spreading at rates of up to 10% every year in typical cases (Bureau of Social Statistics 2014; Jian Yao and Neng Zhua, 2011). In developing country cities these are relatively low-income, upwardly mobile, sectors. Below them, the approximately one billion at the bottom of the pyramid have even fewer amenities. It is not those lowest income groups, who still lack such basics as lighting and space cooling, who can or should reduce their energy and climate impacts, which are still very small. Yet many of their basic needs relate to site works and infrastructural amenities: energy, water, sanitation, drainage, air and green space. Are dense, compact cities a good answer?

"Advanced" green solutions for buildings as well as for urban infrastructures exist, but they are expensive; so they are not likely to be accessible for the poorest groups that most need those amenities. The kind, and cost, of infrastructures is dependent on what models of settlement we choose, whether low-dense or high-rise. If low-dense is both socially favourable, cheaper, and allows for lower carbon infrastructures then this might be prioritised, especially in low-cost contexts. *High quality* dense cities may be very liveable, but low quality ones may be little better than "vertical slums".

5. Conclusions

The embodied energy and carbon of site works and urban infrastructures, where concrete and steel are almost unavoidable, have been highlighted. The relative importance of this varies depending on climatic and economic context and on settlement typology. This has implications for urban planning and policy choices in different regions. Low-dense solutions offer some inherent advantages. There are considerable sustainability impacts but equally opportunities in the field of site planning and green infrastructures; this paper underlines once again the importance of a holistic/integrated approach at a strategic design level.

Whilst there is rapid progress in our understanding of individual buildings as regards both operational and embodied impacts of construction, to date the impacts of the site works and infrastructures have been little focused in energy, carbon and LCA studies. These need to be solved more sustainably, irrespective of the transport systems or urban density in question. Their impacts are often "hidden" within other parts of building energy/carbon analysis. Their impacts are considerable, and may steadily become a larger part of the overall picture.

References

Ardila, P., de Caprona, M. (2014). *Blågrønn Faktor, Veileder Byggesak*, (Blue-green factor, guidelines), Framtidens Byer, Oslo, http://www.miljodirektoratet.no/Global/klimatilpasning/Bl%C3%A5gr%C3%B8nn%20faktor/BGF%20Veileder%20byggesak%20Hoveddelen%202014.01.28.pdf.

Blenghini, G. (2009). Life cycle of buildings, demolition and recycling potential: A case study in Turin, Italy. *Building and Environment* 44:319–330.

Bureau of Social Statistics. (2014). *Major Findings on the 2013 Household Energy Consumption*. National Statistical Office, Ministry of Information and Communication Technology, Royal Thai Government.

Butters, C. (Ed.). (2011). *Signals – Local Action, Success Stories in Sustainability*. Stiftelsen Idebanken / The Ideas Bank Foundation, Oslo. http://solutions2011.ubcsustainable.net/download.php/dms/sol2011/material/other/SIGNALS.pdf?inline=1

Butters, C., Woodville, P. (2016). *Analysis of a very low embodied energy house in Norway*. Interim report, xxxx research program, Warwick, UK. (in preparation - how to reference this?) Nb shows authors

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*. Incheon, South Korea.

Cheshmehzangi, A., Butters, C. (2016). *Sustainable Living and Urban Density: the Choices are Wide Open*. Paper presented at CUE2015-Applied Energy, Low-carbon Cities and Urban Energy systems, Fuzhou, China 15-17.11.2015, www.applied-energy.org/cue2015. (forthcoming in proceedings)

Chiarakorn S. et al. (2015). *Alternative Building Models for Low-income Housing in Thailand: BOQ, Embedded Energy, and GHG Emissions*. Interim report, ELITH program). School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, Thailand.

Cole, Raymond J. (2012) Regenerative design and development: current theory and practice, *Building Research & Information*, 40:1, 1-6, DOI:10.1080/09613218.2012.617516

Dodoo, A., Gustavsson, L., Sathre, R. (2009). Carbon implications of end-of-life management of building materials. *Resources, Conservation and Recycling* 53:276–286.

Eames, M., Tim Dixon, Tim May & Miriam Hunt (2013). City futures: exploring urban retrofit and sustainable transitions, *Building Research & Information*, 41:5, 504-516, DOI: 10.1080/09613218.2013.805063.

Future Built program. (2015). *Ostensjoveien 27, Hovedresultater og Sammenligning av Alternativer*. (Emissions analysis of a new office block), http://www.futurebuilt.no/prosjektvisning?projectID=207426), Norway.

Future Cities program. (2014), http://www.futurebuilt.no/prosjektvisning?projectID=207426 (report, in Norwegian, analyses of a new low impact office block). Norway.

Hammond, G., Jones, C. (2011). *ICE Inventory of Carbon and Energy, version 2.0*. University of Bath, UK.

Han, M. Y., Chen, G. Q., Ling Shao, Li, J. S., Alsaedi, A., Ahmad, B. et al. (2013). Embodied energy consumption of building construction engineering: Case study in E-town, Beijing. *Energy and Buildings* 64:62-72.

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.

Jabareen, Y. R. (2006). Sustainable Urban Forms, Their Typologies, Models, and Concepts. *Journal of Planning Education and Research* 26:38-52, Association of Collegiate Schools of Planning, MIT, USA.

Jian Yao, Neng Zhua. (2011). Enhanced supervision strategies for effective reduction of building energy consumption – a case study of Ningbo. *Energy and Buildings* 43:2197–2202.

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

O'Toole, R. *The vanishing automobile and other urban myths*. Different Drummer, The Thoreau Institute, USA, Spring 1996.

Pade, C., Guimaraes, M. (2007). The CO2 uptake of concrete in a 100 year perspective. *Cement Concrete Research* 37(9).

RICS QS & Construction Standards. (2012). *Methodology to Calculate Embodied Carbon of Materials*. RICS Professional Information, IP 32/2012, Coventry, UK.

Rui Wang, Quan Yuan. (2013). Parking practices and policies under rapid motorization: The case of China. *Transport Policy* 30:109–116.

SangHyun Lee, WonJun Park, HanSeung Lee. (2013). Life cycle CO2 assessment method for concrete using CO2 balance and suggestion to decrease LCCO2 of concrete in South-Korean apartment. *Energy and Buildings* 58; 93-102.

Sartori, I., Hestnes. A-G. (2014) (2007). Energy use in the life cycle of conventional and low energy buildings: a review article. *Energy and Buildings* 39 (3):249–257.

Sorensen, A., Hess, P. (2007). *Metropolitan Form, Density, Transportation*. Neptis, Toronto.

Takano, A., Winter, S., Hughes, M., Linkosalmi, L. (2014). Comparison of life cycle assessment databases: A case study on building assessment. *Building and Environment* 79:20-30.

Thomsen A., Frank Schultmann & Niklaus Kohler (2011). Deconstruction, demolition and destruction, *Building Research & Information*, 39:4, 327-332

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.

Weijun Gao, Takahiro Ariyama, Toshio Ojima, Alan Meier (2001), Energy Impacts of Recycling Disassembly Material in Residential Buildings, Energy and Buildings 33 553-562.

Xiaocun Zhang, Fenglai Wang (2015). Life-cycle assessment and control measures for carbon emissions of typical buildings in China. *Building and Environment* 86;89-97.