Life cycle approach to sustainability in the construction and territorial development sector.

Andrea Campioli, Maria Chiara Torricelli** Ilda Mannino****

*Politecnico di Milano

** Università di Firenze

*** Venice International University

The frame of reference

The drive to bring the construction sector and the development of the built environment into line with the basic objectives of a green economy (1) entails a considerable degree of complexity owing to the different parameters requiring simultaneous consideration as well as to the diverse structures and differing timescales of such development, to the dispersed organisation of the operators involved and the profusion of mechanisms that can be applied to the analysis of sustainability.

A green economy is characterised by a concentration of investment in those sectors whose development strategies are focused on enhancing natural capital, rebuilding scarce resources and minimising environmental risks. The difficulty of evaluating the effectiveness of strategies employed in pursuing these objectives is an especially problematic issue in the construction and territorial development sector. It has often been the case in this area that, in the attempt to reduce the complexity of the processes, the theme of sustainability has ended up assuming fragmentary connotations, latching on, as the occasion offers, to different indicators, diverse phases, widely divergent interpretations of sustainability itself. Notable in this context has been the green economy experience in the field of renewable energy sources, where for example the impact of the production of the equipment used in exploiting the energy source is largely ignored; or in the field of brownfield site regeneration (2), where the impact at various levels of the reclamation operations is likewise overlooked; or again, in the field of the deep energy retrofitting (3) of existing building stock, where attention is concentrated on the reduction of energy consumption without considering the increased consumption of raw materials necessary for enhancing thermal performance.

The life cycle (LC) approach puts an emphasis on the need to go beyond the partiality with which the theme of sustainability is often pursued to instead frame it in a holistic perspective. The transformation of the built environment, from the single building to the urban planning level, is addressed taking full account of the social and economic repercussions, the flow of resources and environmental impact through every phase of a project's life cycle, from the extraction of the raw materials to their processing, from production through assembly to installation, from marketing to end use, from maintenance to management of obsolescence involving recycling, salvage, re-use or reconditioning. Each part of the process is scientifically traced, assessing relevant impacts, risks relative to the availability of resources, effects on the health of people and the environment, its social imprint. This makes it a good deal easier to understand where the best opportunities for reducing environmental, economic and social impact are located over a whole life cycle and for avoiding a shifting of the environmental burden from one phase, one impact category, one social grouping, to another, or between geographical areas in our now globalised economic system.

On the production side, the LC approach is emerging as an accepted framework for the development of innovative business models that are proving notably successful from an environmental point of view. The phenomenon of industrial symbiosis, where the waste from certain industrial activities is re-utilised as secondary raw material by others, including in the construction sector, can be seen as the outcome of a slow but inexorable assertion of this approach in European policy-making (4). By contrast, inserting the processes involved in territorial development into such a framework is evidently more complex. In this case it is a question of assessing the impact of human actions from an environmental, social and economic perspective, taking into consideration all the activities involved, over a not easily determinable arc of time and with regard to areas hard to circumscribe with any precision. None the less, we do not lack for studies testing ways of representing a given area and its development using models capable of identifying activities relating to consumption and production in that area, taking the whole life cycle into consideration and analysing direct and indirect impacts over its various phases.

Strategies and actions

Tools and methodology deployed by the LC approach are nowadays assimilated into the field of environmental studies, where indeed they originated in the 1960s and 70s (5) and deal principally with industry, focusing on products, services and organisations. Assessment and analysis bear on the «potential impact on the natural environment, human health or the depletion of natural resources, caused by the interventions between the technosphere and the ecosphere» (EC, JRC, IES, 2010: 22). International regulatory bodies, such as ISO, have proposed general standards for the conduct of Life Cycle Assessments (LCA) as well as standards for specific aspects of LCA based impact (ISO 14067:2012 Carbon Footprint of Product; ISO 14064: 2016 GHG Organisations; ISO 14046:2014 Water footprint products, processes and organisations). At EU level, too, standard methodologies for the assessment of cycle of life impact of both products and organisations are being developed. The current challenge is to widen environmental considerations to include sustainability and to increase the scale of application from products and industrial organisations to the meso- and macro-levels (Guinée et al., 2011). This is not just a question of spreading knowledge, but of tackling issues of values, vision and interpretation, with the contribution of a new "sustainability science" (Kates et al. 2001). The concept of sustainability is itself subject to differing interpretations. An initial sustainability model composed of three capitals: natural, social and economic (WCED, 1987) has been expanded to include two further capitals, financial capital and manufactured capital to arrive at a "five capitals" model (Parkin et al., 2003). However, as Jørgensen et al. have pointed out (2013: 1440), «the present level of knowledge about what creates and destroys social capital», the minimal consideration afforded to manufactured capital or to economic aspects in relation to social capital and poverty, make it still difficult at this point to assess impact in terms of the sustainability of the life cycles of products, services and processes. It none the less remains the case that the multidisciplinary, analytic and systematic approach of LC studies, especially at the impact analysis phase (Zamagni et al., 2012), suggest that it is worth continuing with, given its potential for further development in the direction of LCSA, Life Cycle Sustainability Assessment (Valdivia et al., 2011) and Analysis (Guinée et al., 2011) (6).

Meanwhile, studies and regulatory initiatives continue to advance in the environmental field, both through their extension to other impact categories, relative to those codified (Sala et al. 2015), and through the fine tuning of methods of characterising impacts, notably: a geographical differentiation for certain indicators; causal models balancing determinants, impacts (midpoint level), and damage (endpoint level).

It is within this framework of knowledge and methodology that we need to locate any assessment of sustainability in the construction and transformation of the built environment sector, both at the individual building and at the wider territorial levels. There remain however many specific issues to be confronted and calibrated, even if we limit our studies to impacts on the natural environment and consequences for social capital.

A primary issue is how we interpret the life cycle model itself. In the construction sector the cycle of life moves from the industrial production of building materials, through design, construction use and management of a project, to its obsolescence (redevelopment, decommissioning, demolition, etc.). The environmental impact and sustainability of a building material depend necessarily on its eventual use, without considering which a judgement on sustainability is hardly conceivable. The same might be said of other product types (a car for instance), but in the building industry, as with civil projects generally, the useful life of a product is defined by the overall scheme which transforms the product into a contributing element in a "system" (a building, a public work) within a specific context. When we pass from the product (or service) level to the organisational level, if we confine ourselves to the industrial sector (supply and construction industries, but also design and planning companies) the cycle of life model may be assimilated to the "value chain" model which is utilised in the LCA approach to organisations, taking into consideration all the interconnected processes directly controlled by an organisation, or upstream or downstream from it. But when the organisations form a complex interlocking system operating over a whole territory (a city, a county, say), or administering it, it is the life cycle concept itself that needs reinterpreting, and it is not easy to define with any precision the system of processes, activities and functions present in that territory or in others with which it exchanges resources and emissions (Torricelli ed., 2015). The urban metabolism model, which has its roots in environmental studies as far back as the 1960s and took hold in the 1990s (7), can serve as a useful point of reference. This model interprets the city as a living organism, fed by a network of human activities, within which energy and diverse materials create movements whose direction is analysable and whose inflow, outflow and storage are quantifiable. Integrating LCA with this approach involves studying the life cycle of flows of natural, technological, social and economic resources and their associated impacts, which affect the territory to differing degrees.

Methods of applying environmental assessments to a given region have been put forward in compliance with legal directives and instruments which require evaluations of regional projects (VIA-AIA)(8), plans and programmes (VAS) (9) and other initiatives impacting on the natural heritage and biodiversity (10). Some indicators of environmental impact at the regional level have been put in place. We might mention such as Environmental Risk Assessment (ERA) or Human and Environmental Risk Assessment (HERA), which gauge risks deriving from natural events, procedures, processes, products, pollutants and industrial activities for human health and the environment at a specific site, and can be developed along LCA approach lines (EU Science for Environment Policy, 2015). Other mechanisms potentially open to a regional LC perspective are: Material and Energy Flows Analysis which maps the transfer of resources and emissions; 'Environmentally-Extended Input Output (EEIO) models which estimate energy consumption and greenhouse gas emissions; Exergy and Emergy analyses (EC, JRC, JES, 2010).

The issue of how to 'model' an LCA applied to construction and regional development links to the goals of a case-specific LCA study, having always at its centre the idea of the project as a process in time and space. In LCA studies applied to products, services and organisations we can distinguish between three archetypal goal situations: a. micro-level, product- or process-related decision support studies; b. meso-level and macro-level, strategic ("policy") decision support studies; c. monitoring type studies (EC, JRC, IES, 2010: 8-9). The identification of a goal situation of an LCA applied to product design, building design or to regional planning is a necessary step in defining the reference entities of the analysis (the what, how and when we are talking about), the limits of the system being examined, the provenance and quality of the data, their collection and storage methodology. At the level of buildings and building materials there is a good measure of agreement on how to proceed and the tools cited in the next chapter testify to as much; at the meso-level of industrial construction policy, and at the neighbourhood, city, metropolitan area or regional level, the situation is more open-ended and testing the validity of LC thinking still requires a good deal of interdisciplinary research work, particularly into case histories, to back up sustainability policies.

The scenario

The life style approach constitutes therefore an important support for progress towards a green economy in the construction and territorial development sector. As we have seen it can be applied at a variety of levels and can be integrated into a number of different instruments and methodologies. A further boost to its spread and development is inherent in the concept of the "circular economy" (11), promoted so vigorously in recent European policy, culminating in the 2015 Circular Economy Package (12). The circular economy is rooted in an economic model foregrounding the regeneration of resources through the use of renewable energy, cutting back on the use of chemical substances that hamper the re-use of raw materials, and waste elimination, and prescribes the designing of materials, products' systems and business models to take account from the outset of the need to set up circular flows in the deployment of resources within the technosphere, and reduce the burden offloaded into the biosphere.

From this perspective three main themes emerge for future construction and territorial development. First of all, "regeneration". This means launching strategies and promoting initiatives that involve the recovery, re-use and enhancement of what already exists, the exploitation of renewable energy sources to cater for regions that become in their turn energy producers, or again pursuing a planning policy that promotes land recovery, favouring the reclamation and re-use of brownfield sites over encroachment on greenfield areas. Secondly, "optimisation". This is a question of seeking solutions which aim at achieving maximum functionality using the minimum resources possible, reducing waste and impact over the whole life cycle. New building should focus on strategies for limiting land consumption and mitigating impacts both at the local and regional level, and the construction sector be encouraged to reduce waste produced in the extraction, production, building and obsolescence phases, and aim for the "lean production" pursued in other industrial contexts. Finally, "circularity". This means setting up virtuous cycles that envisage treating infrastructure, buildings, materials and products at the end of their useful life as resources to be reutilised in a new cycle rather than as waste matter. Of particular importance here is 'urban mining', in the sense of the whole range of operations and technologies aimed at the recovery of secondary raw materials from all kinds of man-made assets inherent in buildings and infrastructure (Baccini and Brunner, 2012; Cossu, 2013; Lederer et al., 2014).

The degree of effectiveness that the introduction of a circular economy aspire to, in relation particularly to the wider objectives of the green economy will largely depend on our ability to consider in their entirety the life cycles of processes of transformation involving the built environment and regional development as a whole, and to ground ourselves in a territorial planning strategy specifically aimed at facilitating a circular use of resources over time and in a building and infrastructure design that envisages from the outset the re-use and recycling of the materials used and the efficient management of waste products from both construction and demolition.

The uncertain state of policies bearing on regional development and the built environment, the fragmentation of the processes, the dispersion of the players involved, mean that a considerable effort will be required to make progress in the direction outlined. At the planning and design level we need to carefully assess all the economic, social and environmental implications of decisions involving projects extending over long periods of time and a sometimes extensive geographical area. On the production level, we need a new transversality based on cooperation rather than competition. At the commissioning level – public or private – a prior definition of life cycle phases and their duration will be crucial to a proper evaluation of the effectiveness of actions undertaken in the direction of sustainability.

Notes

(1) There is no internationally agreed definition of the green economy. UNEP defines a green economy as one founded on «improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In a green economy, growth in income and employment are driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services». (UNEP, 2011).

(2) In 1995 the Environmental Protection Agency launched the Brownfields program and defined a "brownfield" site as an area occupied by decommissioned industries, usually in urban areas, whose re-use may be complicated by the presence of pollutants or contaminants. "Greenfield" sites are previously undeveloped areas generally situated on the fringe of urban areas or in a suburban context.

(3) Deep energy retrofit operations are defined as those aiming for energy savings of between 30% and 60% of the pre-existing situation.

(4) Of significance in this context are product-oriented policies defined in COM (2003) 302 and circular economy policies defined in COM(2014) 398, and COM(2015) 614.

(5)Originally conceived as a management tool at the industrial organisation level for efficiency in the use of resources and of energy and subsequently in waste management, it has evolved over time into an instrument employed by political decision makers and standard framing organisations (McManus and Taylor, 2015).

(6)Life Cycle Sustainability Assessment (LCSA) applies three LC approach methods: Life Cycle Assessmment (LCA), evaluating environmental performance; Life Cycle Costing (LCC) assessing costs or Environmental Life Cycle Costing (ELCC) assessing costs with the inclusion of external impacts; Social Life Cycle Assessment, evaluating social impact. The three measures may be applied separately. Life Cycle Sustainability Analysis (LCSA) framework denotes instead a holistic approach to embrace the relationships between the various aspects of sustainability while also giving due weight to ethical and broader value considerations. LCSA Analysis envisages unifying the inventorying and the analysis of impacts, broadens the range of indicators and their field of application and studies interconnecting causal mechanisms linking the activities under review.

(7)VIA Valutazione di Impatto Ambientale Dir. 1985/337/CEE, modified by Dir. 1997/11/CE and executive orders; AIA Autorizzazione Ambientale Integrata Direttiva 2010/75/UE concerning industrial emissions (prevention and integrated reduction of contamination), and executive orders.

(8)VAS Valutazione Ambientale Strategica Dir. 2001/42/CE and executive orders.

(9)Valutazione di Incidenza, Dir. Habitat 1992/43/CEE & DPR and executive orders.

(10) The idea of the circular economy is based on a vision of an economy designed to auto-regenerate. Within it we can identify the flow of two different types of material: biological, that can be reintegrated into the biosphere, and man-made, intended to be recycled, limiting negative impact on the biosphere. While efficient use of resources and the limiting/management of waste are at the centre of the circular economy, the green economy situates these measures in a wider framework which also considers human wellbeing and the long-term resilience of the ecosystem.

(11)The Circular Economy Package outlines a series of legislative proposals to stimulate movement towards a circular economy, encouraging sustainable economic growth. The key document is COM(2015) 614, which was followed by COM (2017) 33.

References

Baccini, P., Brunner, P. (2012), *Metabolism of the Anthroposphere: Analysis, Evaluation, Design*, The MIT Press, Massachusetts Institute of Technology, Cambridge.

Cheshire, D. (2016), *Building Revolutions: applying the Circular Economy to the Built Environment*, RIBA Publishing, London.

Cossu, R. (2013), "The Urban Mining concept", *Waste Management*, Vol. 33 No. 3, pp. 497–498.

EC, JRC, IES (2010), *International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance*, EUR 24708 EN. Luxembourg. Publications Office of the European Union.

European Environment Agency (2016), *Circular Economy in Europe. Developing the knowledge base*, EEA Report, n. 2, 2016.

Guinée, J., Heijungs , R., Huppes, G., Zamagni, A., Masoni, P., Ekvalland, T. and Rydberg, T. (2011), "Life Cycle Assessment: Past, Present, And Future", *Environ. Sci. Technol.*, Vol. 45, pp. 90–96.

Jørgensen, A., Hermann, I.T. and Bjørn, A. (2013), "Analysis of the link between a definition of sustainability and the life cycle methodologies", *International Journal of Life Cycle Assessment*, vol.18, pp. 1440-1449.

Lederer, J., Laner, D., Fellner, J. and Recheberger, H. (2014), "A framework for the evaluation of anthropogenic resources based on natural resource evaluation concepts", *Proceedings SUM 2014 of the 2nd Symposium on Urban Mining*, Bergamo, Italy; IWWG International Waste Working Group.

Loiseau, E., Junqua ,G., Roux, P. and Bellon-Maurel, V. (2012), "Environmental assessment of a territory: An Overview of existing tools and methods", *Journal of Environmental Management*, vol. 112, pp. 213-225.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grubler, A., Huntley, B., Jager, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore, B., O'Riordan, T. and Svedin, U. (2001), "Environment and development: sustainability science", *Science*, Vol. 292, pp. 641–642.

McManus, M.C. and Taylor, C.M. (2015), "The changing nature of life cycle assessment", *Biomass and bioenergy*, Vol. 82, pp. pp.13-26.

Newman, P. (1999), "Sustainability and cities: Extending the metabolism model", *Landscape and Urban Planning*, Vol. 44, pp. 219-226.

Organisation for Economic and Cooperation Development (2015), *Material Resources, Productivity and the Environment*, OECD Green Growth Studies, OECD Publishing, Paris.

Parkin, S., Sommer, F. and Uren, S. (2003), "Sustainable development: understanding the concept and practical challenge", *Proceedings of the institution of Civil Engineers, Engineering Sustainability*, Vol. 156 N. 1.

Sala, S., Dewulf, J., Benini, L., Fazio, S. and Pant, R., (2015), *Recommended impact assessment methods for ILCD and Environmental Footprint: challenges, opportunities and updates*, SETAC JRC92930.

Science for Environment Policy (2015), "Integrating Environmental Risk Assesssment", Thematic Issue 53, Issue produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol, available at: http://ec.europa.eu/science-environment-policy.

Torricelli M.C. (ed.) (2015), *ES-LCA e patrimonio naturale. Life Cycle Analisi ambientale e sociale di un'area protetta*, Firenze University Press, Firenze.

UNEP (2011), *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*.

UNEP/SETAC Life Cycle Initiative (2011), *Greening the Economy Through Life Cycle Thinking*.

Valdivia, S., Ugaya, C.M.L., Snnemann, G. and Hildebrandd, J. (eds.) (2011), *Towards a Life Cycle Sustaibnability Assessment. Making informed choices on products*, UNEP/SETAC Life Cycle Initiative.

Zamagni, A. , Masoni, P., Buttol, P., Raggi, A. and Buonamici , R. (2012), "Finding Life Cycle Assessment Research Direction with the Aid of Metha-Analysis", *Journal of Industrial Ecology*, Vol. 16 N. 1, pp. S39-S52.

WCED (World Commission on Environment and Development) (1987), *Our common future,* Oxford University Press, Oxford.