**The role of Life Cycle Assessment in preparing built environment students for a career in industry**

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**Abstract**: Life Cycle Assessment (LCA) is growing in importance and significance since its introduction to the construction industry in the late 90s. Built environment students (those studying for a degree in Architectural Technology, Building Services Engineering, Building Surveying, Civil Engineering, Construction Management, Quantity Surveying and Real Estate Management) are starting to use LCA as an integral tool in decision making. The wider industry has used LCA for many years and the built environment is lagging behind. This paper details the role of LCA and key stages of learning required through a typical degree programme. In addition, the paper examines how sustainability is currently taught and provides recommendations for a national change through the introduction of LCA. From learning through to innovation, the use of LCA has significant importance in the built environment as low carbon design and zero carbon homes become mandatory.

**Keywords**: sustainability, life cycle assessment; low carbon; zero carbon

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1. **Introduction**

LCA is a procedure that can significantly influence decision making. In the late 1980s LCA emerged as a tool for understanding the true holistic life cycle impact and risk to products and in 1997 the International Organization for Standardization (ISO) developed the ISO 14040 standard, (ISO, 2006). Since that time additional standards have been developed including the World Resource Institute and World Business Council for Sustainable Development’s PAS 2050:2011.

In the construction industry the European Standards Technical Committee CEN/TC350 now provides the European standard of regulation and in the UK, the Building Research Establishment (BRE) has developed the Green Guide to Specification that is used in the BRE Environmental Assessment Method (BREEAM) and in the Code for Sustainable Homes (CSH). Both of which are based upon the principles of LCA.

When used correctly, LCA has been recognised as a way to increase profitability and engender sustainability and with this growing need for consideration this paper aims to identify and explain the role of LCA in preparing built environment students for industry. This paper identifies the changes that are required to existing curricula and provides a pathway of teaching through the three years of a typical degree program. For students currently studying for a degree in the built environment in the UK, LCA is not comprehensively taught and this paper serves as a guide to highlight transition from LCA theory into industrial practice. Most importantly it focuses on the modern necessity of LCA in both academia and industry.

1. **Life Cycle Assessment (LCA) in theory and practice**

Life Cycle Assessment (LCA) is the technique used for carrying out quantitative analysis of the environmental aspects of a product or service over its entire life cycle. It is a tool that allows for analysis of environmental aspects of a product and provides an assessment of the potential impacts on the environment. It has been used sparingly in the buildings sector since 1990 (Fava, 2006), (Ortiz et al., 2009), (Taborianski, 2004) and is based on the ISO 14040 methodology, from which additional standards have been developed. The assessment, as defined by ISO 14040, typically includes an assessment of production, use and disposal of a product. This list is not exhaustive and it is common to develop additional stages for use in different applications, (Finnegan, 2004), (CEN/TC 350, 2008).

 If one uses the ISO 14040 methodology and applies it to the building sector to compare for example the life cycle contribution of carbon for a typical commercial building. The results show that around 84% of the total carbon output is derived from the operational phase of the building over its lifetime use (Hue, 2010). Therefore one can use LCA to inform decision making and in this case focus efforts on reducing carbon in the operational stage.

 The UK government has set ambitious targets for all new residential and commercial buildings to be zero carbon by 2016 and 2019 respectively. If this is achieved will the total life cycle contribution at operation still be 84%? The answer is no, as when a buildings moves towards zero carbon (through better fabric energy efficiency and the use of low and zero carbon technologies), so the relative importance of the embodied carbon grows. In a low carbon building the carbon associated with materials and construction can be as high as 40% of the total lifetime impacts, (Battle, 2009).

 For new residential buildings the approach to become zero carbon is to initially focus on improving the building fabric and in particular achieve a Fabric Energy Efficiency Standard (FEES), the second stage is to then consider options for low and zero carbon technologies. Finally and if there are carbon emissions that remain, developers can use allowable solutions to effectively offset the remaining carbon. In essence this entails passive design and reducing the demand for heating and cooling; seeking low and zero carbon technologies and offsetting by generating renewable energy on or off site. All of which will result in a lowering on operational carbon and an increase in embodied carbon.

 For commercial buildings, the UK Green Building Council (CLG, 2014) has recently released a report on carbon reductions in new non-domestic buildings. This is first stage in setting out what is required to achieve a zero carbon commercial building in 2019. It is likely that the approach to achieve a zero carbon commercial building is similar to the residential buildings approach as outlined above.

 One failing of both approaches is that the full life cycle of all materials and products is not considered and the zero carbon definition applies only to the operation of the building. Moreover, when new advanced energy saving zero carbon technologies are fitted to the building (such as solar panels) the full life cycle impact is not considered. This is fundamentally why LCA should be studied and used to calculate and evaluate the true holistic life cycle impact of all buildings. To date LCA is not fully used to calculate the true environmental impact of a zero carbon building and furthermore it is not a requirement of planning permission. These claims are supported by other growing evidence that LCA should be included in the assessment. A review of 60 case studies, where LCA had been performed, was carried out by (Sartori and Hestnes, 2007), highlighting the increasing importance and relevance of this type of analysis as we move towards ‘low-energy’ buildings. (Fay et al*.,* 2000)and (Cabeza et al., 2014) both comment on the fact that energy efficiency and other environmental strategies should be prioritised on a life-cycle basis. The (RICS, 2013) are also supporting the introduction of LCA through their methodology to calculate embodied carbon of materials.

 On the rare occasion that a full LCA is considered for a building, most users will use the ISO 14040 or PAS2050 methodology to develop their own basic model in Microsoft Excel with simple inputs/outputs at each stage, as used by (Hue, 2010). Experienced users will tend to select one of the more advanced industry standard LCA tools. In short there are three main types of tool. A more extensive list of LCA tools is provided by (Khasreen et al.,2009).

1. **Basic**: Basic calculations in Excel sheets with simple input and output only covering one or a few environmental impacts. Little or no experience is needed to develop a tool of this type.
2. **Medium:** LCA calculations can be made with help of building tools such as Ecosoft, EcoEffect, Equer, Legep, Envest and Beat (ENSLIC Building, 2010). These specific applications have been developed to facilitate the use of LCA in the building sector. Some experience and training beyond that of the basic assessment are required to use these tools.
3. **Advanced**: Those users with a detailed understanding of how to build an LCA model can use a more comprehensive LCA tool such as SimaPro or Gabi. Users will be training before they can use these types of tool and they must be able to handle these software applications on a building level (ENSLIC Building, 2010).

The industry is in agreement (Ortiz et al., 2009) that there is a growing need to focus on sustainability and to include LCA in the decision making and design process. (May et al., 2012) identified that early design decisions have a very significant impact on the products lifecycle. (Zhao et al.,2013) commented on the fact that the lack of sustainability information hampers the widespread adaptation of the best sustainability practices.

 Over the coming years we will therefore start to see LCA used more extensively. The (University of Northumbria, 2011) have already developed the Interoperable Carbon Information Model (iCIM) which feeds in Building Information Modelling (BIM) and presents a full LCA of both operational and embodied carbon for buildings. From 2016 all UK Government construction projects will require the use of BIM.

 The time to teach students about LCA is now and the first step is to consider how and if existing built environment degree programmes need to change. Secondly, one needs to then consider how LCA can be introduced.

**3 Existing Built Environment degree programmes**

If one examines a small selection of UK Universities[[1]](#footnote-1) who teach degree courses in the built environment, we find that they offer programmes in Architecture, Construction, Property and Commercial Management. Covering degrees such as Architectural Technology, Building Surveying, Construction Management, Civil Engineering and Real Estate Management. A review of the syllabus for a selection of these undergraduate and postgraduate degree programmes for the each University has revealed that LCA as a specific entity is not considered, (Liverpool John Moores University, 2014), (London South Bank University, 2014), (Northumbria University, 2014), (Oxford Brookes University, 2014), (University of Salford, 2014). Each degree course is typically accredited by a Chartered Institution such as the Chartered Institute of Architectural Technology (CIAT), Chartered Institute of Building Services Engineering (CIBSE), Chartered Institute of Building (CIOB), Chartered Institute of Civil Engineering Surveyors (ICES), Chartered Institute of Water and Environmental Management (CIWEM) or the Royal Institute of Chartered Surveyors (RICS). Through their accreditation, LCA is not considered to be a key component, unlike other areas such as building and construction technology, facilities management or valuation and law. Sustainability and life cycle thinking is left to the academic in question to consider how it should be taught for each specific degree programme.

 If one considers a first year student studying for a degree at one of the Universities mentioned, it is common for that student to share modules with many other students on different degree programmes. For example Construction Technology would typically be taught to all students in the first year independent of whether they are studying for degree in Architecture Degree or Real Estate Management. The main reason for this integration of all students in one cohort is to enable them to have a basic understanding of all aspects of the built environment for residential and commercial buildings. Typically this would include lectures and seminars on foundations, basements, low and hire rise frames, internal and external walls, roof construction, services, remediation, refurbishment and sustainability. It is this later section on sustainability that requires further consideration. (Dawe et al., 2005) reviewed sustainable development teaching in higher education for the Higher Education Academy (HEA) and found that *holistic thinking and teaching* on sustainability is key. They noted two key barriers to teaching sustainability: (1) staff where limited in their own awareness and expertise and (2) institutional commitment was limited. Since 2005, a lot of change has occurred and most Universities now consider sustainability as a key core subject in teaching at all degree levels. However the majority of institutions still do not follow this 2005 HEA review guidance and consider *holistic thinking* in full. Instead they will tend to teach more general environmental science specific to the built environment. For example London South Bank University teach environment science as a first year module in their Construction Management degree and the University of Salford teach environmental science and services to all of their Architectural Design, Building Surveying, Construction Project Management and Property Management students. Each University will then, depending upon the skills and experience of the academic, teach their own specialism. Some may focus on construction and materials. Others may focus on assessment methods and tools such as the Building Research Establishment Environmental Assessment Method (BREEAM). This is insufficient and this paper provides a new approach and framework that all Universities could follow to improve *holistic thinking* and the teaching of sustainability.

 As identified by (Moore, 2010) there is no need to introduce new specific sustainability programmes to better prepare students for a career in industry; however there is a need to change the existing teaching of sustainability. This statement is also supported by (Hayles and Holdsworth, 2008) who comment that in order to keep up with industry demand, construction education programmes must incorporate modules in sustainability so that their students will be able to participate and be valued in the workplace. Furthermore they conclude by stating that students need the capabilities and skills to seek out and examine their own frameworks for thinking. One such skill that this paper proposes is the use of LCA. There are of course other methods that could be used to provide students with a holistic review of sustainability and (Ness et al*.,* 2007) undertook a review of tools for sustainability assessment. They concluded that LCA is the most established and well develop amongst all of the common product related assessment techniques that also include Life Cycle Costing, Product Material Flow Analysis and Product Energy Analysis. (Finnveden, 2000) supported this statement in his review on the limitations of LCA, stating that it would be difficult to imagine any other tool that could be used to assess the environmental performance of products.

 Since teaching in the built environment is focused on products and materials then LCA is the tool of choice. LCA also serves to provide an integrated approach to measuring environmental impact. These statements are strengthened by more recent work by (Finnveden and Moberg, 2005) and (Ortiz et al.,2009).

 The key question that follows this review of existing built environment degree programmes is how do we integrate LCA into the existing curriculum? As one is now aware, all Universities adopt different approaches to teaching sustainability and a review by (Holmberg et al., 2008) identified the five key success factors that are necessary to successfully integrate the teaching of general sustainability:

*(1) Legitimacy*: Is it seen as legitimate for lecturers to focus on environmental issues and sustainable development in research and in education?

*(2)* *Commitment in university management*: Is the university management determined to integrate educating sustainable development in the educational programmes?

*(3)* *Responsibility spread throughout organisation*: Is the responsibility to work with educating sustainable development spread between different departments and individuals – ideally a responsibility of all teachers?

*(4)* *Skilled teachers*: Are there many lecturers in the organisation that have a long experience of working with educating sustainable development?

*(5)* *Effective structure of organisation*: Is the educational organisation structured in such a way that it enables or facilitates educating sustainable development integration efforts?

 Of these five key success factors the Universities sampled in this study meet most of the criteria in that there is a general willingness to introduce and include sustainability into teaching across all degree programmes. The key success factor missing is number *(4) Skilled teachers.* Most academics in the UK do not teach LCA and as a result there is a need to strengthen this key area and include a component of LCA into teaching. Introducing holistic thinking through the use of LCA will then achieve the long standing objective of the HEA.

**4 Introducing LCA to a built environment degree**

Due to market demand, LCA is already incorporated into teaching in the built environment in a number of Universities across the US and Europe. If one considers an undergraduate in the UK starting a degree in the built environment in September 2014, they will typically graduate with a degree in 2017 and/or masters in 2018. By that time the industry will be looking for life cycle experts and those individuals with an understanding of the fundamentals. This is why it becomes important to consider the market in 2017 and use a management technique called backward strategic planning. This demonstrates how students can reach their goal and obtain the necessary knowledge and proficiency to use LCA in industry in 2017. Figure 1 shows a series of annual milestones from 2017 back to the present day. In order for students to reach their 2017 goal, there is a need to consider their annual progress and level of knowledge acquired.

Figure 1: backward strategic planning

2014

2015

2016

2017

**Backward Strategic Planning**

**Time**

**LCA Knowledge**

1st year

2nd year

3rd year

At the end of the 1st year of a typical degree program in the built environment there are certain levels of LCA knowledge that need to be obtained. Furthermore, this knowledge provides the foundation for further learning for successful completion of the 2nd year and so on to the end of the degree program.

 When teaching LCA in the built environment, it is best to integrate LCA design into existing modules. There is no need to develop new specific modules. There are a number of universally accepted techniques and a number of academics have already integrated LCA into their teaching. Assistant Professor Erin Moore has added LCA as a topic to her undergraduate program at the University of Oregon's Architecture Department. She begins with lifecycle thinking which is first introduced to undergraduates as a means to get students thinking about the ecological connection of the products and processes used during the assembly and life of a building. They are encouraged to "re-think the lifecycle of construction materials to account for the embodied energy, embodied water, and ecological and human health impacts of their production, use, and disposal (or re-use)". Moore teaches hands on practice using LCA tools (in this case SimaPro) and believes that LCA is an important concept for architecture students to understand for two main reasons; so that in the future they can easily evaluate and make better design decisions as well as be able to competently work and discuss analyses with LCA consultants, (Moore, 2010). At Arizona State University (Brundiers et al.,2010) introduces sustainability teaching in years 1 and 2 around simulating the real world and evaluating how sustainability impacts a real world problem. In the later years of the degree program he engages with the real world focusing on case studies linking theory to practice. (Sullivan and Walters, 2013) teach LCA, life cycle costing, Building Information Modelling and Leadership in Energy and Environmental Design (LEED) as part of their construction management degree at the University of Florida. This is in response to a growing industry demand for skills and knowledge in this area from the US Green Buildings Council (USGBC). Not only is there industry demand, students are also beginning to recognise the importance of developing such skills to equip them ready for industry. A report by the Higher Education Academy (Drayson et al*.,* 2012) demonstrates this with 80% of first-year students surveyed reporting they believe sustainability skills are going to be important to their future employers with the majority believing that it is the role of universities and courses to prepare them for graduate employment.

*4.1 Framework for teaching*

In order to prepare students correctly it is necessary to consider the approach from other academics and the industry need. Year 1 in Table 1 refers to the first year of an undergraduate program and Year 4 refers to a postgraduate masters degree level student. For each year, through a typical degree program in a school of the built environment, an explanation of the key themes that should be taught is highlighted together with an explanation.

Table 1: LCA teaching framework

|  |  |  |  |
| --- | --- | --- | --- |
| Year 1 **Learning**  | Year 2 **Methodologies**  | Year 3 **Applications**  | Year 4 **Innovation**  |
| Sustainability in the built environment.  | Methods of Sustainability Assessment.  | Real work application of sustainability.  | Future direction and innovation.  |
| LCA theory and thinking  | LCA tools, methodologies  | Use of LCA tools in industry | Future of LCA tools  |

*4.2 Year 1 (Learning)*

The first year of an undergraduate program is about learning and in order to improve decision making in sustainable development it is important to start with the right foundation. Sustainability in the built environment should be focused on a number of key themes as follows:

 - *Environmental and impact* – applied learning linked to resources, consumption and quality focusing on why LCA is important in assessing the impact the built environment has in relation to other sectors. The inputs (energy use) and resultant outputs (emissions) and how they impact society. Understanding the true life cycle environmental impact of particular building materials and choices made at the design stage. The BRE Green Guide should be covered along with the basics of BREEAM and LEED.

 - *Regulation and legislation* – what is the current regulation and legislation? How robust are they and how will they change in the future? Focusing on issues such as: Zero Carbon Buildings Standards; Carbon Costing, EU Emissions Trading Schemes (ETS) and Climate Change Agreements (CCAs).

 - *LCA theory* – lecture materials should cover what is a LCA and how does it work? What are the fundamental building blocks? Why is it important to the built environment and how is it used? How is LCA used in the BRE Green Guide?

 The type of assessment and examination should be focused on the level of knowledge attained. Examples of typical exam question could be: What the main materials used in the construction of a commercial building and what are the resultant carbon impacts? If we changed the type of material, what are the resultant carbon and financial impacts? Other questions could focus on future regulation, were the student could be asked if new legislation would change the way construction industry assesses sustainability. Finally, a series of tutorials could be used to help students build a simplistic LCA model, starting with mindmaps and moving into more detailed analysis.

On completion of the year 1 the students should have attained the following:

Figure 2: Year 1 (Learning)



**LCA knowledge attained**

- Understanding of the complete life cycle impact of buildings

- Understand LCA theory and importance for industry

- Appreciation of driving forces and regulatory requirements

*4.3 Year 2 (Methodologies)*

Following the first year of learning, the undergraduate should shift their focus to understanding LCA methodologies. They should be presented with a clearer understanding of how and why sustainability assessments are carried out. This will begin with lectures and discussions on the various and numerous methods of sustainability assessment. There is then a requirement to link these methods to LCA thinking and start to discuss typical LCA tools that can be used to assess the full life cycle of a product.

 In this second year of study, there are a number of key themes areas to explore:

 - *Sustainability assessment* – methodologies for carrying out sustainability assessment should be understood using examples such as BREEAM and LEED together with an explanation of why they are important, what are their shortcomings and how can they be improved. A review of any other related methods should also be explored.

 - *LCA tools and methodologies* – linked to the sustainability assessment above, LCA tools such as those identified by (ENSLIC Building, 2010) and (Khasreen et al*.,* 2009) should be introduced. A review of each tool, its main features, pros and cons should be covered. On completion this will enable the undergraduate to have a clearer understanding of the methodologies and applications.

 Assessment and examination should focus on methodologies. Which method is best and why? What are the shortcomings of current methods? What stage in the construction of a typical building do we introduce LCA thinking and design? Tutorials should again be used to allow the students to build their own basic models and test their own theories and ideas.

Figure 3: Year 2 (Methodologies)



**LCA knowledge attained**

- Methods of sustainability assessment

- Knowledge of models and techniques

- Ability to build a basic LCA model

*4.4 Year 3 (Applications)*

The final year of an undergraduate degree program in the built environment is focused on application of knowledge and should cover both sustainability and the use of tools in the real world. The students should be able to use the applied learning from year one and their knowledge of methodologies in year two to understand how they can be used in real world applications.

 This final year should cover a number of key themes as follows:

 - *Sustainability in the real world* – as early as possible the students should be exposed to particular case studies and/or site visits to existing or new construction projects that consider sustainability to be an important aspect of the project. This should be supported with further detail and explanation of how sustainability and LCA fits within the design and build of construction projects. Particular focus on the contribution and importance sustainability makes in the design, construction, use and demolition phases.

 - *LCA tools in the real world* – One of the most common types of LCA tool used in the industry is GaBi. At this final year level the students should understand why this is the case. How is it used in practice? What data is required? What does it provide as output? Further understanding of its interaction (amongst others such as iCIM) with BIM is also necessary. Finally it will be necessary to review the cost implications of using LCA.

 Year 3 examination and testing should be focused on the real world and if possible the final year dissertation should be undertaken on a real world case study. At this stage the students should be able to link the applied learning and tutorial work of year 1 and 2 to the production of a professionally written dissertation and completion of an end of year examination. The examination questions should be focused on practical application of LCA in industry.

Figure 4: Year 3 (Applications)



**LCA knowledge attained**

- Sustainability in live case studies

- Use of LCA tools in real world applications

- Practical application of LCA

*4.5 Year 4 (Innovation)*

At Masters level, the students should be leading on innovation. They should have a sound knowledge of the principles behind LCA, the methodologies that are commonly used and most importantly how each tool is used in industry. The next step (innovation), should be examining the future direction of LCA and its integration with other processes.

 This Year 4 should be focused on a number of key themes as follows:

 - *Future direction –* How will LCA be used in the future and what is the best platform for its use in the built environment? The postgraduate students at this level should be investigating new methods of integrating LCA with design. Researching new techniques to assess whole life sustainability at the design stage and assessing the holistic impacts that zero carbon buildings face.

 - *Market drivers –* Future regulation and legislation is key and the students should be lectured and undertake research on the impact of the market drivers. Will LCA become a part of planning law or a legal requirement for new developers? How will the Governments use LCA in providing guidance on construction projects?

 At Masters level, innovation is key and the students should be tested on the future direction of LCA. Focusing on the major changes forecast for the industry and how LCA will be introduced.

**5 Conclusion**

As the construction industry is required to be more sustainable and government legislation becomes more stringent; it is imperative that those educated within built environment are leading the way. Graduates must be able to enter industry with the skills, knowledge and awareness to help sustain business and improve design. Building LCA into undergraduate and postgraduate built environment courses will ensure that upon entering industry, the professionals of the future are ready. As more employers are demanding more from graduates; those trained on aspects such as LCA will undoubtedly gain an advantage in the jobs market.

There is no requirement for wholesale change of typical built environment degree programmes, just a necessity to redefine the way sustainability is taught. This paper provides a framework upon which this change could be made following a process of learning, methodologies and application.

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