



Life Cycle Assessment of Buildings and Road Pavements for Lower Environmental Impact –(A Review)

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ABSTRACT :

Buildings and roads are essential to everyday life, yet constructing and maintaining them consumes materials and energy and creates environmental impacts. Life Cycle Assessment (LCA) helps examine these impacts across a project's life, including material production, construction, use, maintenance, and end-of-life treatment. This review considers research on both buildings and road pavements discussed in the supplied report. For buildings, the studies highlight the importance of concrete, cement, steel, and the design of walls and roofs, alongside the energy used during occupation. Building Information Modelling (BIM) can help estimate quantities and compare design options, although the results depend on the quality of the environmental data used. For road pavements, material production, transport, recycling, and maintenance choices are recurring influences on energy use and carbon emissions. Reusing pavement materials and carrying out timely preventive maintenance can reduce demand for new resources, but the benefits vary with local conditions and the expected service life. Across both sectors, the literature points to the value of applying LCA early, explaining assumptions clearly, and comparing alternatives on a consistent basis. Environmental results should also be considered alongside cost, safety, durability, and practical performance. These considerations can help designers and infrastructure managers make better-informed decisions about reducing the impacts of construction.

Keywords: Life Cycle Assessment; buildings; road pavements; embodied carbon; BIM; recycling; sustainable construction

1. Introduction

Construction provides homes, schools, workplaces, and the roads that connect communities. At the same time, it draws heavily on natural resources. Buildings rely on materials such as concrete, steel, bricks, glass, and aluminium, while road projects use aggregates, bitumen, cement, fuel, and heavy equipment. Extracting, manufacturing, and transporting these materials requires energy and can generate greenhouse gas emissions. The impacts continue after a project is completed: buildings consume energy during use, and roads need regular inspection, maintenance, repair, and eventual renewal. Looking only at the initial cost or construction stage therefore gives an incomplete picture of a project's environmental performance.

Life Cycle Assessment (LCA) offers a systematic way to estimate environmental impacts over a product or system's life. In construction, this may mean examining raw-material extraction, manufacturing, transport, construction, operation, maintenance, replacement, demolition, and the reuse or disposal of materials. Not every study covers every stage; the selected boundaries should follow the purpose of the assessment and be stated clearly. An LCA generally defines its goal and scope, gathers information about material and energy inputs and emissions, evaluates potential impacts, and interprets the findings. These steps can help compare design options, but the comparison is meaningful only when the functional unit, assumptions, and included life-cycle stages are made clear.

In building projects, LCA can be used to compare structural systems, wall and roof assemblies, and material choices while the design can still be changed. Embodied impacts come from producing, transporting, and installing materials; operational impacts arise from the energy and resources used once the building is occupied. These stages can pull in different directions. For example, an option that lowers energy demand during use may require more materials at the start. Research discussed in the supplied report—including work on high-rise structures, social housing, and building envelopes—shows that quantities, manufacturing methods, climate, and operating energy all affect the result. The report also considers how BIM can connect design information and material quantities with environmental data.

Road pavements raise similar questions, but their life cycles are shaped by traffic, surface condition, haulage distances, construction methods, and the timing of maintenance. The way old pavement is handled also matters. Reclaimed materials can reduce the need for virgin resources, although processing, transport, and additional binder or energy may affect the overall benefit. Preventive maintenance can sometimes postpone more extensive rehabilitation. To judge whether it is the better option, however, the assessment needs to consider how often the treatment is repeated and how well it maintains the road over the period being studied.

This paper reviews studies on buildings and road pavements summarised in the supplied report. It outlines the factors that influence their environmental impacts, considers how material choices and digital tools can support design and maintenance decisions, and discusses limitations shared by many LCA studies. Its main argument is straightforward: LCA is most useful when it informs decisions early, covers the life-cycle stages relevant to the project, relies on suitable local data, and is considered alongside cost, safety, durability, and performance.

2. Literature Review

2.1 LCA in building design

Roberts, Allen, and Coley (2020) examined how LCA is used during building design. One concern raised in their review is timing: assessments may be completed after major choices about the building form, structure, or materials have already been made. At that point, responding to the findings can be difficult or expensive. Using LCA earlier gives designers more room to compare options and make changes. Early assessment is not always easy, because detailed project information may be unavailable and software tools or environmental databases may produce different results. Even so, the review supports treating LCA as part of the design process rather than as a check carried out at the end.

Ma, Azari, and Elnimeiri (2024) present a BIM-based LCA of a 60-storey office building. By using a digital model to estimate structural quantities, their study illustrates how design information can be linked to environmental assessment. As summarised in the supplied report, concrete accounts for much of the structure's mass, while both concrete and steel contribute to its environmental impacts. Possible ways to reduce these impacts include avoiding unnecessary material, improving structural efficiency, and considering lower-carbon concrete mixes or suitable recycled inputs. These options are not interchangeable in every project: any alternative must still meet requirements for strength, fire safety, durability, and applicable building codes.

The supplied report also discusses research comparing wall and roof options for social housing, taking account of both embodied impacts and energy use during occupation. This is important because materials cannot be judged on production emissions alone. Insulation and envelope design can influence heating and cooling needs for many years, while options that perform well in use may carry higher initial impacts. The balance depends on the building, climate, energy supply, and assumptions used in the assessment. Findings from one location should therefore be applied elsewhere only after those conditions have been considered.

2.2 BIM and digital support for building LCA

BIM can bring together information about building components, dimensions, and material quantities. When this information is linked to environmental data, teams can estimate embodied impacts and compare design alternatives more efficiently. The supplied report describes the use of automated quantity take-off and visualisation to examine different materials and construction options. These features can help engineers and clients understand the results, but a digital model does not make an assessment accurate by itself. The quantities, specifications, environmental datasets, and system boundaries still need to be checked. Pairing LCA with life-cycle costing can provide a broader basis for decisions by showing environmental effects alongside construction, maintenance, and replacement costs.

2.3 LCA in road pavement construction and maintenance

For road pavements, Huang, Bird, and Heidrich (2009) developed a tool for assessing the life-cycle impacts of asphalt pavement construction and maintenance. Their work illustrates why a pavement should be assessed over its service life, rather than only at the point of construction. Li et al. (2019) reviewed LCA and life-cycle cost studies involving recycled waste materials in highway pavements. Their review indicates that recycling can help conserve resources, but the result depends on how materials are processed and transported, how well they perform, and what alternative they are compared with.

The supplied report describes comparisons between conventional pavement reconstruction and several recycling approaches. In one case, full-depth reclamation using Portland cement had lower energy use and carbon dioxide emissions than removal and reconstruction or cold central plant recycling. This finding applies to the methods and assumptions examined in that study; it does not establish that the same method will always perform best. The amount of cement used, transport distances, local material availability, and the condition of the existing pavement can all change the comparison.

Maintenance timing also affects a pavement's total environmental impact. The report summarises a framework that considers material quantities, transport, equipment, energy use, emissions, and pavement structural response. In that particular study, producing materials was the largest contributor to estimated embodied energy and carbon emissions. Preventive treatments may reduce impacts when they extend pavement life and delay major rehabilitation. Their value should nevertheless be assessed over the full period being considered. A treatment with a relatively small impact each time it is applied may need to be repeated often, increasing its total impact.

2.4 Whole-life impacts, uncertainty, and research gaps

Studies of buildings and pavements face many of the same methodological challenges. Their results may not be directly comparable because they use different functional units, include different life-cycle stages, or draw on data from different regions. For example, a building study may report embodied carbon but leave out operational energy or end-of-life treatment. A pavement study may assess one maintenance treatment without covering the entire road life. These narrower studies can still answer useful questions, provided their scope is made clear. Without checking boundaries and assumptions, however, comparisons can give a misleading impression of which option is environmentally preferable.

Digital tools, including BIM and GIS, can link design or route information with environmental calculations. In building projects, BIM can support quantity take-off and comparisons of structural and envelope options. In road projects, digital infrastructure models can help connect pavement condition with maintenance options, quantities, and costs, while GIS can support the assessment of terrain and earthworks during route planning. These tools are useful only when the information behind them is dependable. Future studies would benefit from stronger regional databases, clearer reporting of uncertainty, and sensitivity checks showing how results change when assumptions change. Environmental impacts should also be considered alongside durability, safety, cost, and service life.

3. Conclusion

The studies reviewed here show that LCA can help guide environmental decisions for both buildings and road pavements. For buildings, the choice and

quantity of materials, structural design, wall and roof systems, and energy use during occupation all matter. For pavements, material production, transport, recycling methods, and maintenance schedules are important. In both sectors, decisions made early in a project can shape its impacts for years, which makes early assessment especially valuable.

BIM and other digital tools can make LCA more practical by improving quantity estimates and helping teams compare alternatives. They cannot, however, compensate for incomplete data or poorly explained assumptions. Recycled materials and lower-carbon products should be evaluated in their local context and checked against technical requirements, rather than treated as automatically better choices. Maintenance options also need to be compared over a realistic service period, not by looking at the impact of a single treatment alone.

Further research should make system boundaries more transparent, improve local environmental datasets, and explain uncertainty more clearly. Where the study's purpose allows, assessments should cover the relevant stages from construction through use and maintenance to end-of-life. Considering environmental findings together with cost, safety, structural performance, and durability would make LCA results more useful in practice. Used carefully, LCA can help project teams identify realistic ways to reduce resource use and emissions across the built environment.

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