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EXPANDING THE USE OF LIFE-CYCLE ASSESSMENT TO CAPTURE INDUCED IMPACTS IN THE BUILT ENVIRONMENT

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ABSTRACT

The paper presents an expanded methodology for capturing and quantifying greenhouse gas emissions from the built environment. Current research concentrates on individual buildings or entire metropolitan regions. These frameworks are however limiting as they do not represent typical construction patterns – renovation and new construction of individual buildings within existing cities. In this paper we illustrate how life-cycle assessment can be used to evaluate the environmental impacts from induced impacts – the impacts resulting from the interaction of a building and its surrounding urban context. The results show the importance of induced impacts, particularly transportation and infrastructure, in capturing and quantifying all greenhouse gas emissions, and therefore for realizing climate mitigation.

INTRODUCTION

Life-cycle assessment is a proven method for the environmental evaluation of buildings (Ramesh, Prakash, & Shukla, 2010) (Sharma, Saxena, Sethi, Shree, & Varun, 2011) and infrastructure (Chester & Horvath, 2012). Research is increasingly focusing on the larger urban scale (Rickwood, Glazebrook, & Searle, 2008) (Glaeser & Kahn, 2010). However, individual buildings are not isolated objects, but rather integrated into the surrounding built environment. Alternatively focusing on an entire city ignores typical patterns of construction (i.e., renovations and new construction of buildings in existing cities). Thus analysis bridging the individual building scale and the urban scale is needed to assess actual construction patterns and to capture currently missing environmental outputs.

METHODOLOGY

In addition to embodied (i.e., material) and operational (i.e., electricity, heating) impacts for a building, we introduce a third category, induced impacts – the environmental impacts resulting from the interactions between an individual building and its urban surroundings. The paper presents results from the analysis of a six-story multi-family house in Munich, Germany constructed in 2011. Embodied (i.e., material production and end-of-life disposal), operational (i.e., heating, hot water, and electricity), and induced (i.e., personal mobility and road infrastructure) impact categories are analyzed for greenhouse gas emissions. The analysis uses process-based life-cycle assessment (LCA).

Analysis methodology and data sources

The process-based life-cycle assessment uses data from the Ecoinvent database (Swiss Centre for Life Cycle Inventories, 2010). Embodied impacts are calculated for the production and end-of-life disposal for twenty two structural and architectural materials for the case study building. Structural materials evaluated include concrete, concrete blocks, timber materials (oriented-strand board, sawn timber hardwood, and softwood). Architectural materials include flooring (natural stone, ceramic tile, cement plaster, and cement mortar), weather proofing, insulation, concrete roof tiles, gypsum plaster board, stucco, crushed gravel, window frames, and glazing.

The functional unit of analysis is carbon dioxide emissions per person per year. Based on the average living space per person in Munich, 36.5 m^2/person, the building would house 28 people (Bayerisches Landesamt für Statistik und Datenverarbeitung, 2011), (Statistisches Amt München, 2012). A life-span of 60 years is used for the analysis. Operational demands are determined for heating (5,470 kWh/yr-person), hot water (458 kWh/yr-person), and electricity (1,656 kWh/yr-person) (Nemeth & Lindauer, 2013) (Vereinigung der Bayerischen Wirtschaft, 2012) (Rheinisch-Westfälisches Institut für Wirtschaftsforschung, 2011) . Emissions for space heating are from gas (Kirchner & Matthes, 2009) (Schaechtele & Hertle, 2007). Hot water emissions are from generation by equal parts oil, gas, and electricity (Kirchner & Matthes, 2009), (Schaechtele & Hertle, 2007) (Umweltbundesamt, 2012).

Induced impacts expand upon the typical life-cycle assessment analysis to include results from transportation infrastructure and transportation use. Road infrastructure is based on typical road construction in Germany for a life-span of 30 years (Poxleitner, 2013) (Milachowski, Stengel, & Gehlen, 2011). Road construction is based on 4 cm asphalt surface layer, 8 cm asphalt binder layer, 22 cm asphalt base layer and a 51 cm frost blanket (Milachowski et al., 2011). Environmental outputs from the materials based on the Ecoinvent dataset; construction, maintenance, and end-of-life processes are not currently included. The allocation of road infrastructure to the case study building is based on the width of the building as per the payment scheme for public road funding as outlined by the Germany Building Code (Bundesministerium der Justiz, 2013).

Transportation use impacts include the embodied impacts for automobile and train vehicles and for operational use of both modes. Embodied emissions for automobiles (Helms et al., 2011) are calculated for the average automobile ownership rate for Munich (Landeshauptstadt Muenchen - Referat fuer Stadtplanung und Bauordnung, 2010). Embodied emissions are also included for the construction and maintenance of public transport railway vehicles (Stripple & Uppenberg, 2010) factored by the average travel distance in Munich (Landeshauptstadt Muenchen - Referat fuer Stadtplanung und Bauordnung, 2010). Emissions for automobile use (INFRAS, 2010) is combined with average travel patterns for Munich (Landeshauptstadt Muenchen - Referat fuer Stadtplanung und Bauordnung, 2010). The same travel survey is used for public transportation usage combined with the associated emission factors (IfEU - Institut fuer Energie- und Umweltforschung, 2011). Further detailed information regarding data sources can be found in (Anderson, Wulfhorst, & Lang, 2013).

RESULTS

The results of the expanded assessment for quantifying CO_2 impacts of the built environment are presented in Table 1.

Table 1. Emission results for the case study illustrate the importance of the operational and transportation phases (units are kg CO_2/yr-person).

Embodied		Operational			Infrastructure	Transportation			
Materials	Disposal	Heating	Hot water	Electricity	Road material	Car (embodied)	Car (use)	Train (embodied)	Train (use)
198	49	1105	526	937	8	227	1250	8	269
4.33%	1.07%	24.14%	11.49%	20.48%	0.17%	4.96%	27.31%	0.17%	5.88%

DISCUSSION AND CONCLUSION

The importance of transportation emissions (38%) is second only to operational emissions (56%). The second induced phase, road infrastructure, is very low (less than 1%) due to the density of the building location and the choice of the functional unit (i.e., per person). An alternative urban structure of single family homes would increase these emissions by 10 fold; however this would still result in fewer than 2% of total emissions. The embodied impacts from the building are also relatively low (5%).

The paper illustrates the importance of induced transportation impacts in capturing the full spectrum of greenhouse gas emissions for the built environment. Future research will explore the variance in transportation emissions due to the location of the building within the urban structure (i.e., city-center versus suburban locations).

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