IOP Conference Series: Earth and Environmental Science

Implementing climate impacts in road infrastructure in the design phase by combining BIM with LCA

To cite this article: R Slobodchikov *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012089

SUSTAINABLE BUILT ENVIRONMENT CONFERENCE 2019 (SBE19 Graz) IOP Publishing
IOP Conf. Series: Earth and Environmental Science **323** (2019) 012089 doi:10.1088/1755-1315/323/1/012089

Implementing climate impacts in road infrastructure in the design phase by combining BIM with LCA

Slobodchikov R, Lohne Bakke K, Ragnar Svennevig P, O'Born R
University of Agder, Jon Lilletuns vei 9, 4879 Grimstad, Norway

reyn.oborn@uia.no

Abstract. Building information modelling (BIM) software is increasingly being used in as a visual road design tool and offers real-time information on material demands as designs change. Life cycle assessment (LCA) is a tool that is used to measure the lifetime environmental impacts of systems, materials and processes. LCA data sets are organized according to process or product, which is ideal for implementation as a parameter in BIM. This paper seeks to explore how BIM and LCA can be used together in road design by analysing existing literature, creating a Norwegian test case on a road designed in a BIM model and adding LCA data to the model before comparing to a standard LCA study of the same road. Challenges such as including machinery emissions, uncertainty, data availability, and other insights gained will be discussed. The goal of this paper is to present a path forward for road builders to combine LCA and BIM to promote simplified LCA calculations.

1. Introduction

1.1. Background

Materials extraction and their associated processes contribute up to 50% of the global greenhouse gas (GHG) emissions and new infrastructure has outsized role in this growth [1]. Construction of infrastructure, and especially road infrastructure, is estimated to be a significant contributor to global GHG emissions [2]. As a road is designed and built, the most important decisions are made in the early design phase, which can have significant impacts on the overall GHG emissions of a project [3], [4]. The use of tools, such as life cycle assessment (LCA), can help determine environmental impacts in the early design phase, but use of such tools are often hindered due to lack of data, poor interface between road designs and LCA tools, and poor understanding of LCA as methodology [5]. This has been partially addressed by simplifying LCA for use in early decision making through tools such as CO_2CONSTRUCT, LICCER, CHANGER and JOULESAVE [6]–[9]. These models still require users to input data from one model (the road design) into a separate LCA model, requiring additional time, effort and expertise [10]. As the design of road infrastructure increasingly takes place within digital design tools as they become more sophisticated, integrating LCA with tools such as Builiding Information Modelling is becoming more attractive, although the use of Building Information Modelling (BIM) in road design is not widespread [11], [12]. BIM has several advantages over traditional modelling software and paper designs, namely that changes are shown visually in real-time [13], [14]. There have been several studies that have successfully integrated BIM and LCA in the construction sector [15]–[18] but still more work needs to be done for wider use. There have been few studies on integrating BIM with LCA for road construction but there has been some work on using spatial visualization and adopting BIM for road infrastructure projects [12], [19]. As road builders are increasingly forced to consider LCA and are increasingly moving towards digital tools for road design, it will be natural to combine BIM and LCA. This paper will show how it is possible for road planners to integrate BIM and LCA together for use in road planning and design.

1.2. Case study

The Norwegian government has set targets for greenhouse gas (GHG) emissions reductions in new road transport infrastructure in accordance with the signing of Paris Climate Agreement. The Norwegian government must reduce GHG emissions in new built transport infrastructure by 50% by the year 2030 [20]. This has meant that road planners, road builders, material producers and researchers have been forced to cooperate on developing strategies for reducing emissions in order to meet these targets [21]. The Norwegian Public Roads Administration (NPRA) is slowly mandating that LCA be used in assessing road projects and have their own simplified model for calculating emissions based on basic volumetric calculations and material requirements [22]. This model, like all LCA studies and models used in road construction, is not directly connected to the design process and requires users to input data from the road design model into an additional LCA model. The University of Agder and engineering consultant firm Sweco have been developing a BIM and LCA tool for road builders in Norway so that the design process and the LCA model are directly connected. The model is currently unnamed but can be called the BIM-LCA-ROAD (BLR) model for this paper.

The BLR model was developed and tested using a real-world road design model from Sweco's design for a highway stretch on the European Highway 6 (E6) between Arnkern and Moelv in Norway as shown in Figure 1. Sweco chose this route for testing as there was an interest on determining GHG emissions in the project and because they had a design already built in a 3D BIM model. The model was designed in Trimble Novapoint according to Norwegian road standards and exported into the file format LandXML so that it be possible to import the models into Autodesk Civil 3D for further work.

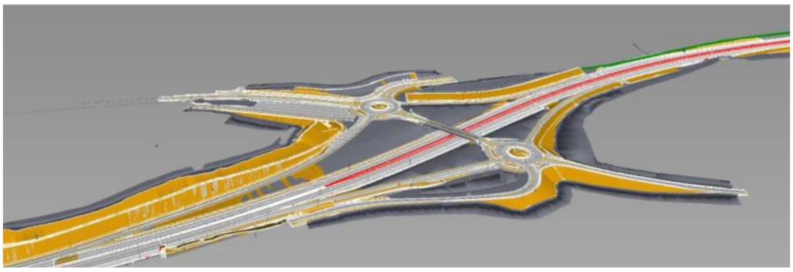


Figure 1. Sweco's Trimble Novapoint design for E6 route Arnkern-Moelv

2. Methods

2.1. Life cycle assessment

According to ISO 14040, a life cycle assessment study comprises of four main phases[23]:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

The *goal and scope definition* phase includes the definition of the system boundaries and processes covered, the functional unit, the impact categories to be included and a declaration on who the LCA study is for. The BLR model is intended to be used by road designers and has a functional unit of one road. The BLR model is a cradle-to-gate model and has system boundaries that include the material production, construction machinery and transportation of materials to the construction site. Road operation, maintenance, traffic and end-of-life are not included in the BLR model and currently only global warming potential (GWP) and cumulative energy demand (CED) are included, although the model framework can be expanded to include costs (in Norwegian Kroner) and other LCA impact categories. The *inventory analysis* phase involves the collection of data on resource and energy demand for each process and emissions from each process within the system boundary and calculated according to the functional unit. The data collected for the testing of the BLR model comes from the material requirements calculated in the BIM model while transport distances are from real world calculations from Sweco. The test analysis used in this paper only analyzed the road base layers and driving surface and associated material production, construction and transport processes. Fuel usage in machinery comes from the Norwegian EFFEKT model version 6.6 [22]. Additional material requirements come from an additional Norwegian case study and EcoInvent 3 [21], [24]. The *impact assessment* phase uses the results from the inventory analysis phase to present the environmental impacts of the system. This is accomplished by organizing emissions into impact categories and calculating their potential impact through characterized emissions factors. The emissions factors used in this version of the model also come from the EFFEKT model version 6.6. The BLR model calculates GWP using ReCiPe 2016 midpoint indicators [25] and expresses emissions in CO_2-equivalents. Finally, the *interpretation* phase presents the results of an LCA study and recommendations. There is often also a validation process for these results, usually via comparison to other studies found in literature or through data analysis, such as a sensitivity analysis on important model parameters. This paper presents the results of the BLR model for the case and compares it to the same calculations carried out in LCA software SimaPro. This comparative analysis was also performed to determine where the most uncertainty in the model occurs and to see where model improvements need to be made.

2.2. Programming and calculation procedure in BLR model

The programming of the BLR model took place using .NET framework with C# as the programming language in Microsoft Visual Studio. This code was then implemented in Autodesk Civil 3D to carry out calculations in the form of an add-on application. Autodesk Civil 3D is one of the two main programs for digital road design used in Norway (the other being Trimble Novapoint). Autodesk 3D has an advantage over Novapoint in that add-on applications can be implemented and that external programs can easily communicate with these applications. The BLR model use Dynamic Link Library (DLL) files to import external coding into Autodesk Civil 3D to the application programming interface (API), or application. In essence, the BLR model is actually an add-on application in Autodesk Civil 3D but is designed in the same way as a conventional LCA tool. The basic inventory analysis and emissions data were imported from an Excel file into the application. The BLR model has an additional module that shows the results in real-time color coding on the actual modelled road (See Figure 6). The code used in this model is currently has not been made public. The full calculation procedures for the BLR model are shown in Figures 2 and 3.

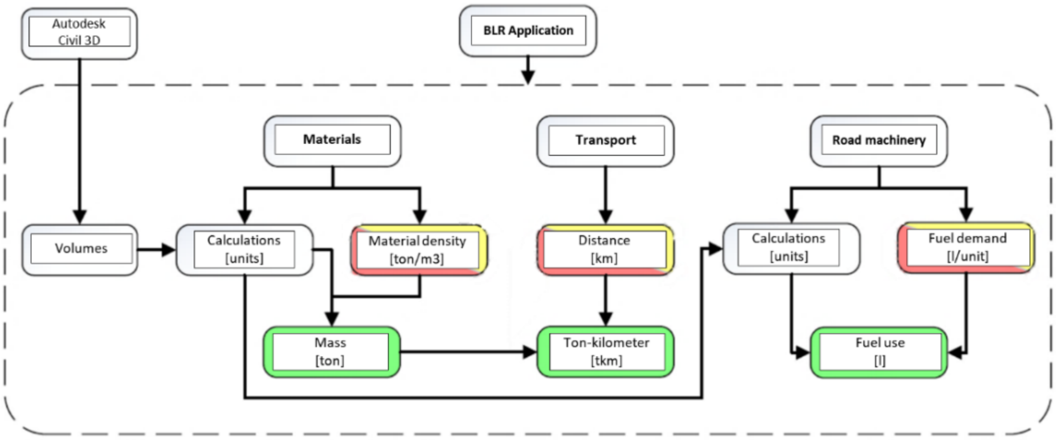


Figure 2. Calculation procedure for materials, transport and fuel in BLR model

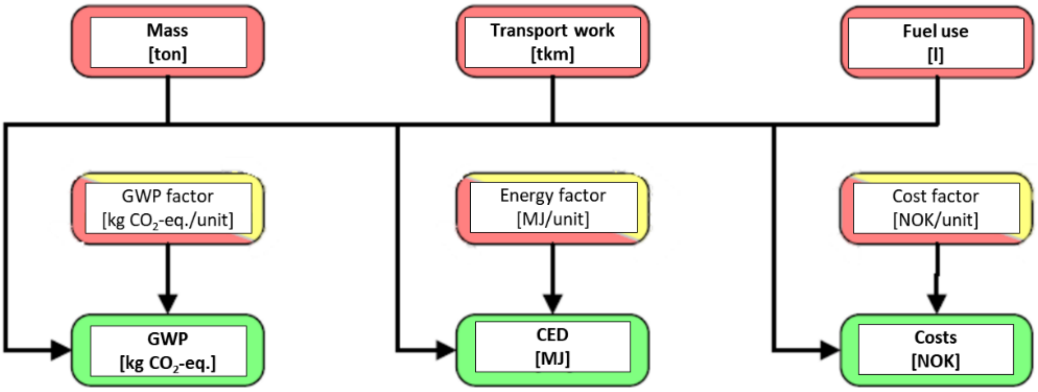


Figure 3. Calculation procedure for total GWP, CED and costs in BLR model

The BLR model calculates volumes according to the geometric volumes in the BIM model which are then converted into mass based on material density. The transport distance takes the mass calculations to calculate the overall transport work in ton-kilometers (tkm) which are used for calculating transport fuel demand. Road machinery processes also calculate based on volumetric mass calculations for earthworks and are combined with the transport fuel demand to determine the overall fuel demand in the road project. Once the fuel, mass and transport work are known, these are multiplied by GWP, Energy and Cost factors to determine the overall impact of the project. In Figures 2 and 3, the red boxes show which areas where the model does not allow for any changes in calculation parameters while the yellow boxes show where project-specific inputs can be added if the user so chooses, while the green boxes show the final calculated results.

3. Results

3.1. Life cycle inventory results

The two cases were calculated with Autodesk Civil 3D to determine the overall material requirements for each road base. Case 1 is a theoretical road crossing made in Trimble Novapoint and exported to Autodesk Civil 3D while Case 2 is a real-world example of a 4-lane highway design.

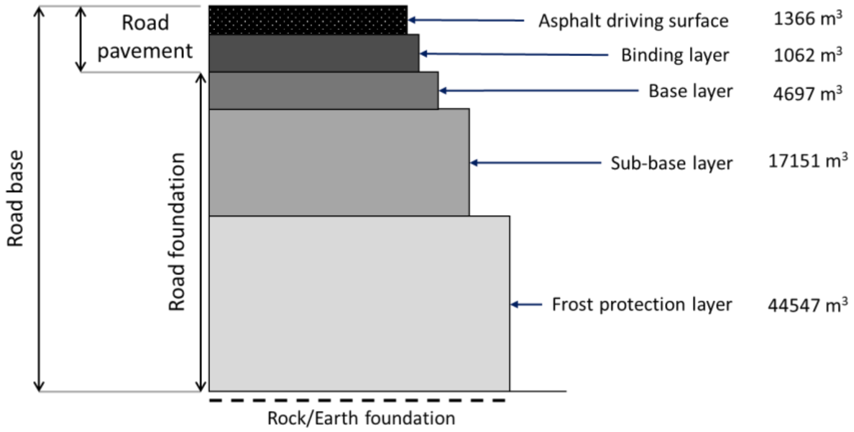


Figure 4. Material requirements for the test case

Figure 4 shows the volumetric material requirements for each component of the road base as modelled. These were calculated directly in Autodesk Civil 3D. The asphalt driving surface is a mix of gravel and bitumen while the other layers are layers of gravel and aggregates of various dimensions.

3.2. Life cycle global warming potential results

This case study is limited in that it only evaluates the GWP of the case and is used as an illustration of what is possible with a BIM model. Nevertheless, the aim of the BLR model is to calculate emissions as equally well as a standard LCA model thus the results were compared with an LCA model constructed in SimaPro. The model in SimaPro used the same impact factors and material demands as the initial BIM model. Figure 5 shows the relative emissions for each construction process and for material production for both the SimaPro LCA model and the BLR model while Table 1 shows the aggregated emissions for each of the main processes.

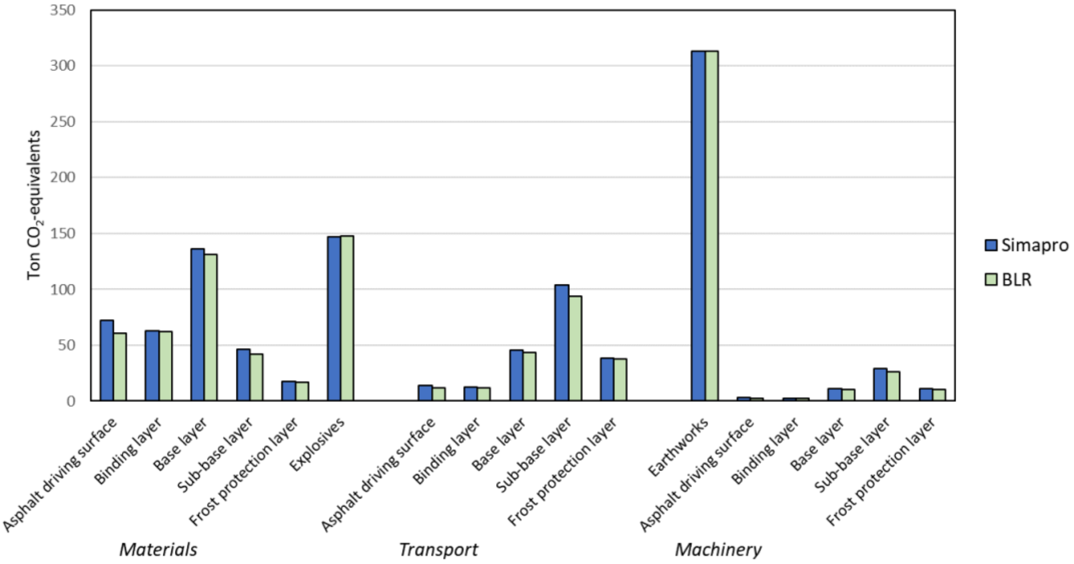


Figure 5. GWP life cycle impact assessment results (in tons CO_2-equivalents)

Figure 5 shows the emissions for each of the different road layers according to the material production, transport of materials and construction machinery. The largest single impact for both versions of the model was emissions from earthworks machinery (primarily cutting and filling, digging of trenches and drainage), which amounted 313 tons CO_2-eq. for each analysis. Other high impacts were explosives (147 to 148 tons CO_2-equivalents), material production for gravel in the base layer (which require more crushing) and transport of materials for the sub-base layer (which have the greatest total mass of all materials produced). The frost protection layer is generally lower emissions for both production and transport as emissions from the production of these materials are included in cutting and filling, which are reflected in the earthworks emissions. Overall, there is a small difference for many of the processes in the SimaPro model versus the BLR model, where the SimaPro model in general has slightly higher emissions. Table 1 summarizes the differences between the three main processes of material production, material transport and construction machinery.

Table 1. GWP results based on SimaPro and BLR analysis

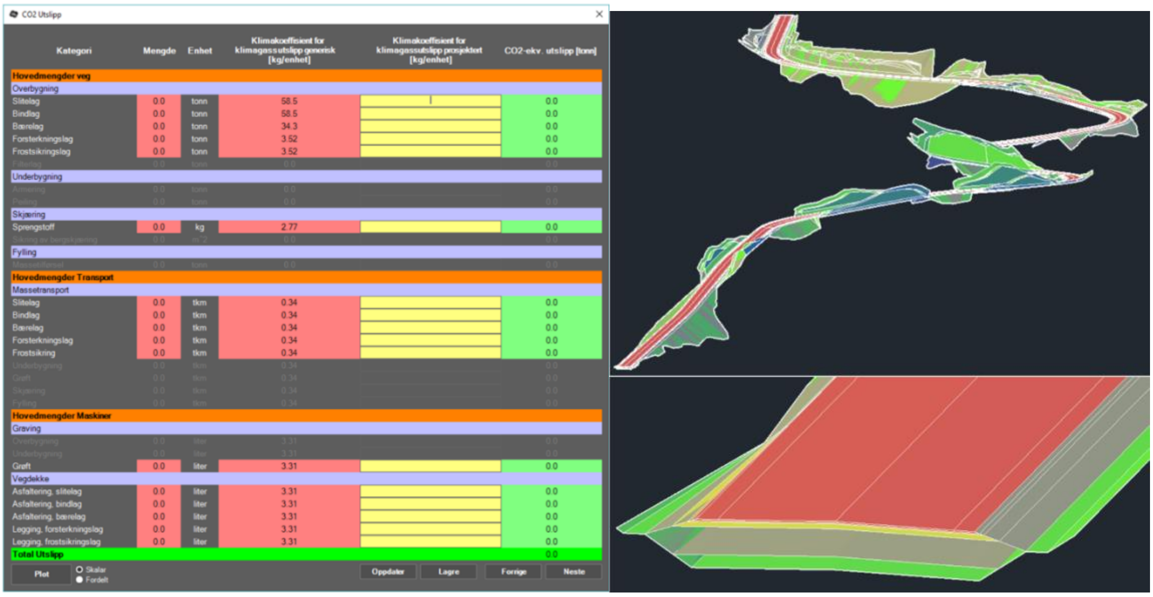
Item	SimaPro	BLR	Unit	Difference
Materials	482.24	461.53	Tons CO_2-eq	4.3 %
Transport	213.93	199.15	Tons CO_2-eq	6.9 %
Machinery	370.36	366.46	Tons CO_2-eq	1.1 %
Total	1066.53	1027.14	Tons CO_2-eq	3.7 %

The BLR model underestimates emissions by 3.7% compared to the SimaPro model. Most of this is due to material production emissions being underestimated although the highest uncertainty comes from transport of materials. This is largely due to calculation differences between the original Trimble

Novapoint design and the re-imported version in Autodesk Civil 3D. This variation issue can be solved by adding coordinates directly from the LandXML file, although this has not been implemented in the BLR model at this time.

3.3. *Model results and model functionality*

This section outlines the functionality of the model beyond the LCA results. The BLR model was developed in this study is designed so that the user has the ability to comprehensively calculate environmental impacts in real-time during the design process. This is useful for users who are familiar with designing roads in BIM but lack the time or expertise to do a separate LCA analysis. The calculations are shown both in numerical form as tables and visually on a color-coded scalar plot as shown in Figure 6.



Kategori	Mengde	Enhet	Klimakoeffisient for klimagassutslipp generisk [kg/enhet]	Klimakoeffisient for klimagassutslipp prosjektert [kg/enhet]	CO2-ekv. utslipp [tonn]
Hovedmengder veg					
Overbygning					
Slitelag	0.0	tonn	58.5		0.0
Bindlag	0.0	tonn	58.5		0.0
Bærelag	0.0	tonn	34.3		0.0
Forsterkningslag	0.0	tonn	3.52		0.0
Frostsikringslag	0.0	tonn	3.52		0.0
Filterlag	0.0	tonn	0.0		0.0
Underbygning					
Armering	0.0	tonn	0.0		0.0
Peiling	0.0	tonn	0.0		0.0
Skjæring					
Sprengstoff	0.0	kg	2.77		0.0
Sikring av bergskjæring	0.0	m^2	0.0		0.0
Fylling					
Massetilførsel	0.0	tonn	0.0		0.0
Hovedmengder Transport					
Massetransport					
Slitelag	0.0	tkm	0.34		0.0
Bindlag	0.0	tkm	0.34		0.0
Bærelag	0.0	tkm	0.34		0.0
Forsterkningslag	0.0	tkm	0.34		0.0
Frostsikring	0.0	tkm	0.34		0.0
Underbygning	0.0	tkm	0.34		0.0
Grøft	0.0	tkm	0.34		0.0
Skjæring	0.0	tkm	0.34		0.0
Fylling	0.0	tkm	0.34		0.0
Hovedmengder Maskiner					
Graving					
Overbygning	0.0	liter	3.31		0.0
Underbygning	0.0	liter	3.31		0.0
Grøft	0.0	liter	3.31		0.0
Vegdekke					
Asfaltering, slitelag	0.0	liter	3.31		0.0
Asfaltering, bindlag	0.0	liter	3.31		0.0
Asfaltering, bærelag	0.0	liter	3.31		0.0
Legging, forsterkningslag	0.0	liter	3.31		0.0
Legging, frostsikringslag	0.0	liter	3.31		0.0
Total Utslipp					0.0

Figure 6. Example of GWP results presentation in BLR model

The table shows the calculated amounts for each material/process in the second column and the emissions factors (GWP per unit in this figure) for each material/process in the fourth column. The fifth yellow column allows for the user to add a project specific emissions factor if they choose while the sixth green column shows the total calculated emissions. The scalar plot on the right shows the overall project emissions color coded, where red has the highest emission and green has the lowest emissions. Grey colors signify elements that are not included in the current BLR model. The user can also zoom in or out on the project in the same way as any other BIM model shown Autodesk Civil 3D.

4. Discussion

Researchers have been working for many years to try and develop models that combine LCA with road project designs as customers and road authorities demand emissions reductions in new infrastructure. The overall goal of the development of BLR was to make LCA calculations as simple as possible while also being robust enough to compare well with more standard LCA road models. BLR differs from existing LCA models in that the road design and impact calculations are carried out simultaneously within the same model while other models typically require information from finished road designs as inputs. The BLR model is advantageous for road builders and designers as they can evaluate emissions and make decisions to reduce emissions in real-time. The visual aspects of the BLR model also help to easily see which sections of the road require efforts to reduce emissions.

The BLR model is a proof of concept showing that it is possible to include emissions in BIM for road designs but the model has several shortcomings in its current form and in relation to traditional

LCA models and methods. The first major shortcoming is that the scope of the model is extremely limited compared to other LCA studies as only CED and GWP are included. Other LCA studies and even Environmental Product Declarations (EPDs) have far more impact categories included. As the BLR model was only designed as a proof of concept, these impacts were not included but space for additional impact categories has been included as road authorities prioritize GHG reduction over all other impact categories [26]. Other impact categories such as eutrophication, acidification, and photochemical oxidation that are usually included in road LCA studies should be prioritized [27], [28]. The BLR model is also limited in that it does not include the full depth and breadth of materials and construction processes used in road construction in its current form. As the model continues to be developed, more information will be added to it which will improve the model quality and LCA results and could be expanded to included maintenance and end-of-life processes in the future. This will require better data inputs, which could be improved by linking up to existing LCA inventories for roads in Norway, by implementing EPDs and by using project specific data when available [29], [30].

5. Conclusion

This paper presented an integrated BIM and LCA model for road design and tested the model through the use of a case study in Norway. The results of the testing showed that it was indeed possible to combine emissions calculations in a BIM model through the use of C# to develop an Autodesk Civil 3D application. Future work should improve the robustness of the model by adding emissions factors for more construction processes and materials, by expanding the model to include more impact categories and additional life cycle phases, and by linking the BLR model to existing LCA datasets.

References

[1] B. Oberle *et al.*, “Global Resources Outlook 2019,” Nairobi, 2019.
[2] L. Huang, G. Krigsvoll, F. Johansen, Y. Liu, and X. Zhang, “Carbon emission of global construction sector,” *Renew. Sustain. Energy Rev.*, vol. 81, no. June 2016, pp. 1906–1916, 2018.
[3] G. K. Booto *et al.*, “Road Planning and Route Alignment Selection Criteria in the Norwegian Context,” in *Proceedings of the 3rd World Multidisciplinary Civil Engineering - Architecture - Urban Planning Symposium*, 2018.
[4] J. Hammervold, “Towards greener road infrastructure: life cycle assessment of case studies and recommendations for impact reductions and planning of road infrastructure,” NTNU, Trondheim, 2014.
[5] S. Miliutenko *et al.*, “Life cycle impacts during early stages of road infrastructure planning: a case study in Sweden,” in *TRA 2014 Proceedings*, 2014.
[6] B. Ebrahimi, “Performance Measures of Road Infrastructures: Preliminary environmental and lifetime estimation of Norwegian pavements,” Chalmers University of Technology, 2017.
[7] D. Reger, S. Madanat, and A. Horvath, “Economically and environmentally informed policy for road resurfacing: tradeoffs between costs and greenhouse gas emissions,” *Environ. Res. Lett.*, vol. 9, no. 10, p. 104020, 2014.
[8] J. M. Barandica, G. Fernández-Sánchez, Á. Berzosa, J. a. Delgado, and F. J. Acosta, “Applying life cycle thinking to reduce greenhouse gas emissions from road projects,” *J. Clean. Prod.*, vol. 57, pp. 79–91, 2013.
[9] B. Ebrahimi, H. Wallbaum, H. Brattebø, H. R. Vignisdottir, R. A. Bohne, and G. K. Booto, “Environmental Life Cycle Assessment (LCA) of Road Pavements : Comparing the Quality and Point of Application of Existing Software Tools on the basis of a Norwegian Case Study,” *CIB World Build. Congr. 2016 Vol. V - Adv. Prod. Serv.*, pp. 749–760, 2016.
[10] R. D. Schlanbusch, S. M. Fufa, T. Häkkinen, S. Vares, H. Birgisdottir, and P. Ylmén, “Experiences with LCA in the Nordic Building Industry - Challenges, Needs and Solutions,” *Energy Procedia*, vol. 96, no. 1876, pp. 82–93, 2016.
[11] A. Costin, A. Adibfar, H. Hu, and S. S. Chen, “Automation in Construction Building Information Modeling (BIM) for transportation infrastructure – Literature review , applications , challenges , and recommendations,” *Autom. Constr.*, vol. 94, no. July, pp. 257–281, 2018.
[12] H. Y. Chong, R. Lopez, J. Wang, X. Wang, and Z. Zhao, “Comparative Analysis on the Adoption

and Use of BIM in Road Infrastructure Projects," *J. Manag. Eng.*, vol. 32, no. 6, pp. 1–13, 2016.
[13] D. Clarke-Hagan and J. P. Spillane, "A QUALITATIVE REVIEW OF BIM, SUSTAINABILITY AND LEAN CONSTRUCTION: Is There A Future For Lean Construction?," in *Proceedings of ARCOM Doctoral Workshop Sustainability and BIM ARCOM Doctoral Workshop Sustainability and BIM*, 2016.
[14] B. Soust-Verdaguer, C. Llatas, and A. García-Martínez, "Critical review of bim-based LCA method to buildings," *Energy Build.*, vol. 136, pp. 110–120, 2017.
[15] S. Eleftheriadis, D. Mumovic, and P. Greening, "Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 811–825, 2017.
[16] F. Shadram, T. D. Johansson, W. Lu, J. Schade, and T. Olofsson, "An integrated BIM-based framework for minimizing embodied energy during building design," *Energy Build.*, vol. 128, pp. 592–604, 2016.
[17] M. Röck, A. Hollberg, G. Habert, and A. Passer, "LCA and BIM: Visualization of environmental potentials in building construction at early design stages," *Build. Environ.*, vol. 140, no. December 2017, pp. 153–161, 2018.
[18] M. Röck, A. Hollberg, G. Habert, and A. Passer, "LCA and BIM: Integrated assessment and visualization of building elements' embodied impacts for design guidance in early stages," *Procedia CIRP 69*, pp. 218–223, 2018.
[19] C. S. J. Karlsson, S. Miliutenko, A. Björklund, U. Mörtberg, B. Olofsson, and S. Toller, "Life cycle assessment in road infrastructure planning using spatial geological data," *Int. J. Life Cycle Assess.*, vol. 22, no. 8, pp. 1302–1317, 2017.
[20] Avinor, Jernbaneverket, Kystverket, and Statens Vegvesen, "Nasjonal Transport Plan 2018-2029 Vedlegg 1 - Grunnlag for klimastrategi," Oslo, 2016.
[21] R. O'Born, G. K. Booto, B. Ebrahimi, H. R. Vignisdóttir, H. Wallbaum, and R. A. Bohne, "Sustainability review of Norwegian road construction and infrastructure," in *Proceedings of the 1st International Conference on Sustainable Mega Infrastructure*, 2018.
[22] A. Straume and D. Bertelsen, "Dokumentasjon av beregningsmoduler i EFFEKT 6.6," Oslo, 2015.
[23] ISO, "ISO14040: Environmental management-life cycle assessment principles and frameworks." British Standards Institution, London, 2006.
[24] G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, "The ecoinvent database version 3 (part 1): overview and methodology," *Int. J. Life Cycle Assess.*, vol. 21, no. 9, pp. 1218–1230, 2016.
[25] M. A. J. Huijbregts *et al.*, "ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and enpoint level - Report 1: characterization," Bilthoven, The Netherlands, 2016.
[26] J. I. Arntsen, "Klimakrav – hva gjør Statens vegvesen," 2015.
[27] B. Ebrahimi, H. R. Vignisdottir, H. Wallbaum, and R. A. Bohne, "Review Paper on the Current Status of Environmental Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) of Road Projects," in *Proceedings from the 12th Urban Environment Symposium*, 2015, pp. 1–16.
[28] S. T. Muench, "Roadway Construction Sustainability Impacts," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2151, pp. 36–45, 2010.
[29] J. Krantz, J. Larsson, W. Lu, and T. Olofsson, "Assessing Embodied Energy and Greenhouse Gas Emissions in Infrastructure Projects," *Buildings*, vol. 5, pp. 1156–1170, 2015.
[30] J. Hammervold, "Dokumentasjon VegLCA v2.01," Trondheim, 2018.