Sustainability of innovative urban surfaces – a new approach of assessment

To cite this article: K Henzler et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 323 012068

View the article online for updates and enhancements.
Sustainability of innovative urban surfaces – a new approach of assessment

Henzler K, Horn R, Jäger M, Maier S D

Department for Life Cycle Engineering (GaBi), Institute for Acoustics and Building Physics, University of Stuttgart, Pfaffenwaldring 7, 70569 Stuttgart, Germany

KristinaHenzler@gmx.de

Abstract. The physical design of urban surfaces determines the management processes that are required to ensure that their intended functions are fulfilled within a set period of time and influences their linked material flows. Those flows are causing numerous environmental, economic, and social impacts. In the field of urban surfaces, there is a broad variety of innovations available that has the potential to contribute to a more sustainable environment and quality of life in cities. However, before implementing any kind of innovation, it is important to quantitatively and qualitatively assess its sustainability impacts in a holistic manner. While current assessment methods provide a suitable framework for the sustainability assessment of products and services, without modification, they cannot be applied to urban surfaces and related management processes.

The herein introduced methodological approach is designed to overcome this problem by not only being tailored to the sustainability assessment of innovations in the field of urban surfaces but also by combining life cycle thinking with a holistic approach. By integrating SDGs, it will provide insight into the possible impacts of an innovation in all three dimensions of sustainability at the municipal level. This knowledge can be used to support the municipality in its decision on the design of urban surfaces and management processes by showing whether or not it is advisable to implement an innovation from a sustainability point of view. The focus of this publication is on the development of a general life cycle of urban surfaces and its interaction with product innovations.

1. Introduction
Leistner et al. [1] highlight the importance of the design of urban surfaces for the environmental quality in cities and their resilience to climate change. They show that urban surfaces have a considerable building physical and sustainability related potential and that innovations are essential for realising it [1]. It is pointed out by Leistner et al. that by conducting a Life Cycle Assessment (LCA) on the various management processes of urban surfaces, it is possible to determine their sustainability and to identify potential starting points for the optimisation of the partly large quantity of material flows in cities [1]. By systematically assessing the sustainability of urban surfaces, another perspective is taken as usually complete sustainability assessments of cities overlook their potential. All three dimensions of sustainability are essential for sustainable development [2], and not only environmental but also economic and social impacts are expected from the implementation of the aforementioned.
product innovations. Current sustainability assessment methods cannot unmodified be used for the analysis of innovations in the field of urban surfaces, as, e.g., they do not allow the practitioner to take into account the comprehensive use phase of the urban surface and the interaction of the life cycle of the innovation and the surface. Therefore here, a holistic approach for the sustainability assessment of innovations in the field of urban surfaces is proposed, using life-cycle thinking and indicators in line with and based on the Sustainable Development Goals (SDGs). Thus, such a method can be used to support municipal decision-makers with regard to potential sustainability impacts before implementing innovations for urban surfaces. The SDGs are accepted as a basis for the development of sustainability assessment methods and are used on a municipal level, e.g., by Maier et al. [3] and Wang et al. [4].

2. State-of-the-art of sustainability assessment methods
Several existing methods have been analysed regarding their suitability for the assessment of innovations in the field of urban surfaces.

The LCA uses the concept of life-cycle thinking [5], however, attempts to apply this to urban surfaces have shown that it is not sufficient to take into account the multitude of processes that occur during the use phase of urban surfaces. This leads to an entanglement of different processes and therefore, life cycles. This requires a new approach, different from the establishment of one general life cycle. Besides, various requirements are placed on urban surfaces concurrently [1], yet they cannot be considered with the concept of the functional unit provided in the ISO-LCA. Moreover, different stakeholder perspectives can be taken when assessing innovations in the field of urban surfaces, as, e.g., in the case of costs: on the one hand, there is the municipal budget and on the other hand, the income of the workers. Besides, as the LCA only allows for an assessment of possible environmental impacts [6], it is inevitable to go beyond this concept for a holistic assessment. Therefore, indicators must also be selected and adapted to the system of the urban surface to be investigated.

The concept of Life Cycle Sustainability Assessment (LCSA) presented by Klöpffer [7] allows the three dimensions of sustainability to be taken into account by combining the methods of LCA, LCC, and SCLA [6]. However, for the social dimension, there is no scientific agreement on indicators [8]. Hence, here, the SDGs are used to select indicators for a holistic assessment. Moreover, the methods of LCA, LCC, and SCLA are developed to different degrees, which can cause difficulties in the application of this approach [8]. Wang et al. [4] have shown that rather than the LCSA as presented by Klöpffer [7], the Life Cycle Sustainability Analysis (LCSA) Framework (hereinafter: LCSA Framework), which is one of the results of the CALCAS project [9], provides a good foundation for the development of a holistic sustainability assessment method.

The LCSA Framework builds on the ISO 14040-standardised LCA, but goes beyond it in three dimensions of broadening and deepening, thus enabling the practitioner to conduct an assessment of impacts in the environmental, economic, and social dimension of sustainability [9]. However, it must be noted that it is not a guide [10]. Rather, it is described as “[ . . . ] a transdisciplinary integration framework of models rather than a model in itself” [9]. Consequently, it first needs to be made operational [9]. So far, the LCSA Framework has not been used for the evaluation of urban surfaces. Hence, the herein presented method adopts the fundamental structure of the LCSA Framework but relies on other methods and concepts in order to make it applicable to the case of urban surfaces.

The ex-ante sustainability assessment methodology for municipal solid waste management innovations developed by Wang et al. [4] provides a sound basis for the development of the new method. Its appealing features are the operationalisation of the LCSA Framework, the integration of the SDGs in the assessment, based on the approach by Maier et al. [3], and the sustainability assessment of innovations in a specific field before their implementation [4]. Thus the method of Wang et al. [4] plays a decisive role in the operationalisation of the LCSA Framework for innovations in the field of urban surfaces: its way of implementing the Framework and making it applicable to innovations serves as a basis for the design of the individual phases of the new approach. It needs to be modified to fit innovations in the field of urban surfaces and related management processes.
In conclusion, there is currently no method available that can directly be used for the sustainability assessment of innovations in the field of urban surfaces prior to their implementation. As has been shown above, not only the scope of application of existing methods but also the special features of urban surfaces, such as their extensive use phase, make it necessary to develop a new holistic methodological approach, which is tailored to the analysis of product innovations in this area. The method of Wang et al. [4] is used as a starting point for the development of the new approach. By this, the LCSA Framework is made operable for the assessment of urban surfaces. One of the main challenges in developing the new approach is the lack of application of life cycle thinking to the concept of urban surfaces. Thus, this newly developed framework serves as the underlying basis for the sustainability assessment of urban surfaces based on life cycle thinking and the SDGs.

3. Methodological Approach

The methodological approach for the sustainability assessment of urban surfaces is based on [3] and [4], depicted in figure 1. The adaptation of this framework allows the indirect assessment of SDGs across different impact category groups, including the selection and definition of appropriate SDG-based indicators. As the new methodological approach will allow a sustainability assessment of innovations in the field of urban surfaces, firstly the terms urban surface and innovation have to be defined in the context of sustainability assessments and life cycle thinking, and secondly, a general life cycle of urban surfaces must be developed. Thus the focus of this publication is on the introduction of a life cycle of urban surfaces and accordingly on the first stage of the methodology, the goal and scope definition. The generalised life cycle will make it possible to identify possible starting points for an innovation. Building on this first stage, a holistic sustainability assessment of an innovation can be conducted by proceeding with the phases of modelling and interpretation.

### Figure 1. Sustainability assessment of innovations in the field of urban surfaces, based on [3] and [4].

#### 3.1. System analysis

3.1.1. Urban surfaces, management processes and material flows. The term urban surfaces was coined by Leistner et al. [1]. This paper attempts to refine this concept by specifying the scope of its applicability and proposing a general categorisation of urban surfaces suitable for the herein proposed methodological approach for sustainability assessments of urban surfaces based on life cycle thinking.
Here urban surfaces are defined as surfaces that interact in public outdoor spaces within an urban context. Therefore areas such as public parks, streets, and facades are regarded as urban surfaces while indoor spaces and underground infrastructure, e.g., the municipal sewage system, are not included within this concept. A surface is considered as an urban surface as long as it keeps interacting in the same way as at the point under consideration, regardless of its geometrical dimension. As Leistner et al. [1] have shown, areas in cities are used for numerous purposes, amongst others, for buildings, traffic, and green spaces. Therefore urban surfaces are made of a variety of materials, such as concrete, grass, and cobblestone. Different requirements are placed on them, e.g., accessibility, usability, safety, and aesthetics [1]. Hence the combination of surface material, function, and requirements imposed on the surface by users or legal regulations is used here to differentiate between different types of urban surfaces. Figure 2 shows the combination of material, function, and requirements for the case of streets.

Figure 2. Triangular categorisation of streets.

From this, a categorization of urban surfaces is derived. For example, the categories of green spaces, building spaces (roofs/ facades), traffic areas, squares, and barriers are distinguished. Those can be further disaggregated into subcategories, e.g., in the case of green spaces into playgrounds, parks, and nature reserves or in the case of traffic areas into roads, cycleways, and footways. Thorough management is required in order to ensure that urban surfaces fulfil their functions within a set period. While the necessary management processes depend on the type of surface, it is common that most surfaces require several processes with varying frequencies during a year. The following is a brief, non-exhaustive overview of management processes in the field of urban surfaces. The maintenance of green spaces involves processes such as the removal of weed and foliage, watering, fertilising, and lawn mowing. Traffic areas require processes such as cleaning, winter service (gritting and snow clearance), and road marking works as well as repair, replacement, and modernisation processes. For other surfaces, e.g., barriers, repair and cleaning processes need to be performed. Derived from Leistner et al. [1], material flows that are applied to a surface during a management process, such as gritting salt, water, and fertiliser, are called input flows. Output flows are considered in this paper as a result of management processes and include, e.g., green waste and dust.

3.1.2. Life cycle of urban surfaces. As urban surfaces are considered as infrastructure, the building life cycle in DIN EN 15978 [11] is transferred to urban surfaces to design their life cycle. For this purpose, a building is considered as consisting of several urban surfaces. Consequently, the surface material is understood as equivalent to the construction product/ component in the standard DIN EN 15978 [11] and the surface as equivalent to a part of a building. The adapted life cycle does justice to the complex use phase of urban surfaces, in which, as is the case with buildings, several management processes for their maintenance, repair, and so on are carried out. It should be noted that for the assessment of urban surfaces a functional equivalent shall be formulated in accordance with DIN EN 15978 [11] in order to be able to take into account the fact that as aforementioned several requirements are placed on urban
surfaces simultaneously, such as usability, safety, and aesthetics, and to ensure the comparability of the assessment results [1, 11]. It could be defined, e.g., as ‘Providing 1m² of footway for 1 year that meets its functional and technical requirements’, with the reference unit [m²·a]. It reflects the previously introduced categorisation of urban surfaces based on their material, function, and requirements. Figure 3 shows, based on DIN EN 15978 [11], a proposal for the modules of the life cycle of a new urban surface, for which information should be provided to assess its sustainability. The four phases of its life cycle are briefly explained below.

![Figure 3: Information on the life cycle of an urban surface, based on DIN EN 15978 [11], technical terms adapted from [12].](image)

A 1-5: Analogous to DIN EN 15978 [11], the processes leading to the installable surface product, e.g., wooden battens, should be taken into account in the production phase. The construction phase should contain processes for the surface materials from their production site to the completion of the construction of the surface, such as the transport of the wooden battens to the construction site and their installation [11].

B 1-7: Adapting the boundaries set in DIN EN 15978 [11], here the use phase comprises the time between the construction and the dismantling/demolition of the urban surface. In module B1, it is taken into account that substances can be released into the environment during the use of the urban surface [11]. As previously pointed out, various management processes are performed in the use phase of an urban surface. These processes can be assigned to different modules within this phase. Following the standard DIN EN 15978 [11], the boundary of the module B2 should contain processes such as street cleaning, and lawn mowing. The repair processes necessary in the event of damage are considered in the module B3 [11]. While a replacement with the same surface material (even if it is undamaged) is taken into account in module B4, a replacement with another material should be considered in module B5 [11]. Analogous to DIN EN 15978 [11], energy and water flows that occur in the use phase of the surface, e.g., in the process cleaning, are assessed in the modules B6 and B7.
3.2 Scenario building

3.2.1. Innovations for urban surfaces. In order to optimise urban surfaces from a sustainability point of view, different types of innovations can be introduced in the city. This study relies on Rogers [13] to define an innovation as: “[... an idea, practice, or object that is perceived as new by an individual or other unit of adoption”. With regard to urban surfaces, the idea, practice or object is related to an innovation that has the potential to optimize urban surfaces and the unit of adoption refers to the municipality. Thus, based on the work done by Leistner et al. [1], in this publication we differentiate between three different types of innovations in the field of urban surfaces: a) innovative surface materials, e.g., sound-absorbing facades [1]. This type of innovation directly influences the material composition and structure of the urban surface itself; b) innovative machines/technologies, such as gritting vehicles with a hybrid drive or battery-powered hedge trimmers. This type of innovation is related to the technology that is used to manage an urban surface; c) innovations regarding the management processes of urban surfaces, e.g., a new weed removal process. This type of innovation refers to an innovative way in which a particular management process is carried out. In any case, it is necessary to assess the potential sustainability impacts of an innovation before its implementation to facilitate an informed decision regarding its introduction [4]. In this paper, the focus is on the assessment of surface material innovations and innovative machines, both product innovations, since process innovations are not considered as tangible. The innovations are used for designing a comparison scenario which can be compared to a baseline scenario reflecting the state of the art of the urban surface and its management in the respective municipality [4]. The delta between the baseline scenario and the comparison scenario is calculated to assess the sustainability impact.

3.2.2. Life cycles of innovations. Depending on the type, the innovations intervene in different modules within the use phase of an urban surface. As in Maier et al. [3], the system boundary of the innovation is based on the concept of life cycle thinking in order to be able to consider the sustainability impacts along the entire life cycle of the innovation – this makes it possible to identify a shift of burden in all three dimensions of sustainability between the life cycle phases or processes and to take countermeasures prior to their implementation [5]. Therefore, the life cycle of a surface material innovation or innovative machine, both product innovations, should be designed after ISO 14040 [5]. For the life cycle of products and their innovative versions, respectively, a cradle-to-grave approach is chosen; consequently, impacts are assessed in the raw material and fuel acquisition, the production of precursors and the final product as well as in its use and end-of-life phases [6, 14].

An (innovative) machine is used in the respective management process of the urban surface, which in turn is performed in the use phase of the surface. For example, a common gritting vehicle and an innovative road sweeper would be used in module B2 (maintenance) of the urban surface. An innovative surface material, such as easy-to-clean cladding, would be installed in module B5 (modernisation) of the surface. As a result, the life cycle of a product and product innovation, respectively, and the life cycle of the urban surface interact. This finding is illustrated in a greatly simplified manner in figure 4. This relation reminds of the interactive life cycles introduced by Labuschagne and Brent [15]. Figure 4 shows that in the use phase of an urban surface, in addition to modernisation processes, such as process 2, also several other management processes, for example, the maintenance processes 1 and 3, are carried out, in which different products or product innovations can be used.
4. Application

This section gives an example of the application of the sustainability assessment framework and the life cycles shown in figures 3 and 4 to a highway. It also makes clear how the SDGs are integrated into the assessment. In the first step of the goal and scope definition, the road is characterised, following figure 2. The highway is made of concrete and serves as a space for movement of non-pedestrian traffic. It needs to meet requirements such as safety, usability, and durability. Based on this information, it is possible to design the life cycle of the highway in question. Following figure 3, the phases of production and construction contain processes concerning the provision of concrete and the building of the road. In the use phase, maintenance processes such as winter service (gritting and snow clearance), road cleaning and repair processes are carried out (non-exhaustive list). In the end-of-life phase, besides the demolition of the highway itself, the processing and final disposal or recovery of the demolition waste and output flows, e.g., sweepings and dust, need to be included. In the scenario building, suitable innovations are identified and selected for the assessment. An innovative snow plough was chosen to improve the sustainability of the process of snow clearance. The life cycle of the innovation is built using the life cycle thinking in ISO 14040. Then the interacting life cycles of the highway and the currently used and innovative snow plough, respectively, are designed.
Figure 5 illustrates for the case of the innovative snow plough the embedding of the introduced life cycle scheme in an LCSA Framework operationalising assessment system and the integration of the SDGs into the latter. Thus it is possible to conduct a holistic sustainability assessment of the innovative snow plough. To make the assessment system easier to follow, the life cycle of the highway is not fully depicted in this figure. Looking at figure 5, it is essential that the practitioner analyses the sustainability impacts of the highway’s use phase with (comparison scenario) and without (baseline scenario) the application of the innovation and additionally the entire life cycle of both ploughs. In this way, it can be determined if the potential advantages of the innovation regarding the sustainability impacts of the road’s use phase outweigh the impacts linked to the innovation’s provision. As shown in figure 5, the herein presented assessment system is built on the SDG-integrating approaches by Maier et al. [3] and Wang et al. [4]. Their SDG-based indicator systems are adapted to the assessment of innovations in the field of urban surfaces because as Maier et al. [3] point out, it is crucial that the indicators fit the innovation under question. Hence impact category groups from the indicator systems of Maier et al. and Wang et al. that are thematically uniting the SDGs, e.g., poverty, climate and health and safety, as well as suitable indicators are used to assess the potential impacts of an innovation in the three dimensions of sustainability [3, 4]. Amongst the criteria guiding the selection process of the indicators is their ability to assess likely impacts caused by innovations in the field of urban surfaces.

5. Discussion and conclusions
The herein introduced generalised life cycle of urban surfaces and its proposed interaction with the life cycles of product innovations provide a good starting point for a life-cycle based sustainability assessment of innovations in the field of urban surfaces. However, there is still a need to extend the proposed life cycles to make it possible to assess process innovations and to consider potential interdependencies between different management processes. Furthermore, while the methodology can be used for the assessment of innovations that optimise existing functions, it needs to be further developed so that it can be used, e.g., for the evaluation of innovations that change the functions of an urban surface, such as multifunctional materials. The next steps are to select and adapt indicators from the SDG framework to the urban surface system and to illustrate the practical applicability of the newly developed methodology by applying it to a case study concerning a specific innovation.
Acknowledgments
This research is funded by the Federal Ministry of Education and Research – BMBF as part of the BUOLUS project (Bauphysikalische Gestaltung urbaner Oberflächen für nachhaltige Lebens- und Umweltqualität in Städten – BUOLUS).

Author Contributions
conceptualization, K.H.; methodology, K.H.; validation, K.H.; formal analysis, K.H.; investigation, K.H.; writing—original draft preparation, K.H.; writing—review and editing, K.H., R.H., S.M.; visualization, K.H.; supervision, R.H., S.M.; project administration, S.M., M.J.; funding acquisition, R.H., S.M., M.J.

References
[1] Leistner P, Kaufmann A, Koehler M, Würth M, Hofbauer W K, Dittrich S, Maier S, Gordt A and Jäger M 2018 Bauphysik urbaner Oberflächen Bauphysik 40 358–68
[2] Weinberger K, Rankine H, Amanuma N, Surendra L, van Hull H V, Foran T, Reyes R, Malik A and Murray J 2015 Integrating the three dimensions of sustainable development: A framework and tools (United Nations) p 7
[3] Maier S, Beck T, Francisco Vallejo J, Horn R, Söhlemann J-H and Nguyen T 2016 Methodological approach for the sustainability assessment of development cooperation projects for built innovations based on the SDGs and life cycle thinking Sustainability 8 1006
[4] Wang J, Maier S, Horn R, Holländer R and Aschemann R 2018 Development of an ex-ante sustainability assessment methodology for municipal solid waste management innovations Sustainability 10 3208
[5] EN/ISO 2009 DIN EN ISO 14040:2009-11 Umweltmanagement - Ökobilanz - Grundsätze und Rahmenbedingungen (Berlin: Beuth Verlag)
[6] Klöpffer W and Grahl B 2009 Ökobilanz (LCA): Ein Leitfaden für Ausbildung und Beruf (Weinheim: WILEY-VCH) pp 1–386
[7] Klöpffer W 2003 Life-Cycle based methods for sustainable product development Int J LCA 8 157–9
[8] Finkbeiner M, Schau E M, Lehmann A and Traverso M 2010 Towards life cycle sustainability assessment Sustainability 2 3309–22
[9] Guinée J B, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonomici R, Ekvall T and Rydberg T 2011 Life cycle assessment: Past, present, and future Environ. Sci. Technol. 45 90–6
[10] Pannekeet C, Kleijn C, Kramer G J and Guinée J 2013 Towards application of life cycle sustainability analysis Rev. Metall. 110 31–38
[11] Pannekeet C, Kleijn C, Kramer G J and Guinée J 2013 Towards application of life cycle sustainability analysis Rev. Metall. 110 31–38
[12] EN 2012 DIN EN 15978:2012-10 Nachhaltigkeit von Bauwerken - Bewertung der umweltbezogenen Qualität von Gebäuden – Berechnungsmethode (Berlin: Beuth Verlag)
[13] DGNB GmbH 2018 DGNB system – New buildings criteria set: Environmental quality ENV1.1 / Building life cycle assessment p 52
[14] Rogers E M 1983 Diffusion of Innovations 3rd edn (New York, NY: Free Press) p 11
[15] Fraunhofer-Institut für Bauphysik IBP 2019 Ökobilanzierung Available online: https://www.ibp.fraunhofer.de/de/kompetenzen/ganzheitliche-bilanzierung/methoden-ganzheitliche-bilanzierung/oeokobilanzierung.html (accessed 07.03.2019)
[16] Labuschagne C and Brent A C 2005 Sustainable project life cycle management: The need to integrate life cycles in the manufacturing sector Int. J. Proj. Manag. 23 159–68
[17] Maier S 2016 Methodological approach based on life cycle thinking for sustainability assessments of development cooperation projects: Analyzing a case study within the GIZ program Renewable Energies and Energy Efficiency Master Thesis (M.Sc.) (Bayreuth: University of Bayreuth) p 38