Preface

The objective of this thesis is to develop a conceptual visual tool and User Interface which enable architects to holistically integrate quantitative and qualitative assessments of GHG emissions in the decision-making process considering neighbourhood-oriented designs. This thesis is submitted as the result of my MSc project performed at the Norwegian University of Science and Technology (NTNU). The work was carried out at the Department of Energy and Process Engineering with Prof. Johan Berg Petterson as the main supervisor. Aoife Houlihan Wiberg who is a Professor at the Department of Architecture and Technology was co-supervisor.

Abstract

Building, transportation, and human activities are main sources to generate greenhouse gas (GHG) emissions in neighbourhood. In order to reduce GHG emissions in neighbourhoods, architects plays an important role particularly in the early design phase since this is when the architect has the greatest opportunity to make design decisions that directly lead to a reduction in the GHG associated with the consumption of energy and embodied emissions of materials used in zero emission neighbourhoods. However, it is not easy for architects to easily understand and visualise how their design contributes to the overall GHG emissions for the neighbourhood since the origin of the emission is out of architectural scope. Thus, this thesis develops a tool visualizing the relationship between the neighbourhood design and GHG emissions, which can be easily utilized by architects.

This thesis is aligned with the Research centre on Zero Emission Neighbourhoods in Smart Cities (FME-ZEN). A ZEN is defined as a group of interconnected buildings with associated infrastructure, located within a confined geographical area, aiming at reducing its direct and indirect greenhouse gas (GHG) emissions towards zero. Life cycle assessment (LCA) is used to estimate the potential environmental impacts of a product or service system throughout its life cycle. The methodology was initially developed and used for zero emission buildings and has now been expanded to include zero emission neighbourhoods (ZENs).
The FME-ZEN research centre has already developed a set of ZEN assessment criteria and key performance indicators (KPIs) that can quantify and qualify neighbourhood performance. This work defined the new criteria and indicators based on KPIs of ZEN and other assessment tools in order to apply to the visual tool developed in this work.

The main objective of this thesis is to develop a conceptual visual tool and User Interface which enable architects to holistically integrate quantitative and qualitative assessments of GHG emissions in the decision-making process considering neighbourhood-oriented designs based on the ZEN KPIs. The visual tool was developed in main two platforms (small-neighbourhood platform and large-neighbourhood platform). The small-neighbourhood platform visualises building energy performance and the GHG emissions as a quantitative assessment tool while the large-neighbourhood platform displays urban information related with the emissions as a qualitative assessment tool. The platforms of this thesis as a conceptual assessment tool do not develop the actual interconnection with the computing tools for the GHG emission assessment. However, as one of the contributions of this thesis, proper tools and database are selected and their detailed connection plan is established for practical use of the dashboard in near future.

Through the case study of Nidarvoll Skole in Trondheim region of Norway, this thesis shows how the new school design is associated with GHG emissions and how the relationships can be effectively visualised to help the decision-making process for architectural design toward zero-emission neighbourhoods. By using the visual tool developed in this thesis, the most environmentally friendly design option was able to be selected, which delivers less energy consumption and CO_2 emission, compared to the original school design. The savings in the two KPIs reached to 20,508 kWh/yr and 1,871 $kgCO_2eq$/yr respectively, compared to other design options.

Acknowledgements

First, I would like to thank my main supervisor Prof. Johan Berg Petterson. His support and valuable feedback were essential to my MSc thesis. He introduced me the topic of this thesis since he knew my architectural background and interesting. Thanks to his consideration, I was able to conduct this thesis passionately incorporating knowledge of the industrial ecology field into architectural field.

I would like to express my gratitude to my co-supervisor Prof. Aoife Houlihan Wiberg. Her enthusiasm encouraged me to participate in various activities such as an exhibit of ZEN Dashboard at Trondheim Science Exhibition and collaboration with students at the Sustainable Architecture programme for a case study. I also thank her for warm welcome whenever I visit her.

I would also like to thank Dr. Donghoi Kim at the Department of Energy and Process Engineering. I respect his in-depth knowledge, and his feedback on this thesis including proofreading was greatly valuable to me.

Special thanks to Meng-Shen Kan for our collaboration. She passionately participated in a case study for this thesis, and her feedback inspired me to design a dashboard.

Trondheim, July 2019

Daeyeon Cho

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Abbreviations

ZEN	Zero Emission Neighbourhoods
FME ZEN	The Research Centre on Zero Emissions Neighbourhoods in Smart Cities
ZEB	Zero Emission Buildings
LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
EPD	Environmental Product Declaration
GHG	Green House Gas
PV	Photo Voltaic
WP	Work Package
KPIs	Key Performance Indicators
BIM	Building Information Modelling
SWOT	Strengths, Weaknesses, Opportunities, and Threats
CBES	Commercial Building Energy Saver Toolkit
CityBES	City Building Energy Saver
CityGML	City Geography Markup Language
GIS	Geographic Information System
UI	User Interface
ICT	Information and Communications Technology
WWR	Wall-Window Ratio
MDF	Medium-density Fibreboard
ACH	Air Changes per Hour
LCC	Life Cycle Cost

1 Introduction

1.1 Motivation

Neighbourhood mainly consumes energy in residential, industry, and transport sectors. The use of energy generates greenhouse gases (GHGs) that impact on climate change. According to the International Energy Agency (2016), urban areas account for about two-thirds of primary energy demand and 70% of total energy-related carbon dioxide emissions.(IEA, 2016) In addition, more than 30% of global energy use and 20% of GHG emissions related with the energy are occupied in the building sector. (Polesello et al., 2016)

In this situation, Norway and European countries have set the targets for reduction of energy use and GHG emissions in their societies. Following up Agenda 2030 (UN,2015), urban and local policy and strategy in Norway are implemented in a path to the sustainable energy and climate objectives. (Utenriksdepartementet, 2016) At the European level, the Energy Performance of Buildings (EPBD) requires that all new buildings should be almost net zero energy by 2020. (European Parliament, 2010)

In order to attain these goals, it is important for stakeholders to organize the policy, strategy, and design (Ouhajjou et al., 2017) since these form the basis of the entire system of society or a community. In particular, architect as a part of stakeholders can play a pivotal role as a bridge between strategic urban and building plans (Kallus & Law-Yone, 2000). Based on urban regulations, targets and strategies, urban planners define land use and establish the relationship between indoor and outdoor space in collaboration with architects. (Ingram, 1996) In addition, architectural drawings are essential in the practical process of urban planning. In the perspective of building energy planning, a building uses various technologies which include heating, cooling, ventilation, lighting, and plug loads, as well as, building materials that contains embodied energy and associated GHG emissions. In this process, architects collaborate with engineers to ensure the efficient energy use of the indoor environment. Therefore, architectural design acts as a mediator in the neighbourhood planning where it communicates with urban strategy and planning in the urban scale while co-works with engineering in the building scale. Thus, decisions made by architects during urban design can have a significant impact on climate-gas emissions of neighbourhood.

Energy planning involves various stakeholders, and it requires integrated assessments in various perspectives considering energy efficiency and climate impacts. (Ouhajjou et al., 2017) However, it is not easy to integrate the assessments in energy and climate change strategies since each stakeholder has different work scope and performance indicators to evaluate climate change drivers. This thesis addresses the problem for the integration of the performance assessments in neighbourhood design by architects. Thus, this thesis focuses on the study for the tool that can effectively integrate the neighbourhood assessments through the architecture-oriented visualisation.

1.2 Objective

The main objective of the thesis is to develop a visual platform in order to achieve net zero emission in neighbourhood. This study conducts how the platform can help architects in their early decision-making process to perform neighbourhood-oriented designs interrelated between urban planning and building design. Based on the role of architects in the urban planning and building design, this study analyses the relationship between urban planning and building design, and this thesis studies the way to visualise the relationship effectively in the platform.

Furthermore, the study shows how the visual platform can contribute to reducing energy use and GHG emissions in neighbourhood. The platform as a dashboard for architectural design identifies the relationship between architectural design in neighbourhood scale and GHG emissions. Thus, the platform provides the effective visualisation regarding the relationship.

The study also conducts how the platform can support architects to make effective decisions cooperating with other stakeholders in the early design phase. Since each stakeholder uses different KPIs for the neighbourhood assessment, the thesis develops the new KPIs and assessment criteria which can integrate different assessment methods used among the stakeholders. Based on the new KPIs and assessment criteria, the platform visualises the neighbourhood assessment.

The architectural background knowledges and experiences which the author of this thesis has contributed to understanding architectural design process and the collaboration with other stakeholders in this paper.

1.3 Work scope

This study focuses on GHG emissions, building energy efficiency, mobility, and spatial quality in neighbourhood scale as the key criteria to assess the neighbourhood performance for GHG emissions. Building and transportation are the main drivers that generate anthropogenic GHG emissions in neighbourhood. In 2010, building sector consumed over 30 % of global energy and emitted approximately 20 % of green-house gases in the energy, and it is reported that the energy consumption would be more than twice by 2050. (Graham, 2014) In the case of transportation, the emission accounted for 14% of 2010 global greenhouse gas emissions. (Fischedick, 2014) Spatial quality as the environmental features of neighbourhood directly or indirectly affects GHG emission in a long-term perspective. This study conducts the performance assessment based on materials and operational use which are the main sources of the energy consumption in building (Kristjansdottir, 2014). Mobility and spatial quality, focusing on qualitative assessment, is evaluated in the assessment scope related with architectural design.

This work is aligned with the Research centre on Zero Emission Neighbourhoods in Smart Cities (FME-ZEN). One of the projects in the ZEN centre is to develop visual tools for improved evaluation and decision-making toward zero-emission neighbourhoods. This work is closely related with the work package 1.3 in ZEN whose main objective is “The development of a user-centred architectural and urban toolbox for design and planning of ZEN, including visualization and decision support to improve stakeholder participation.” (Marianne et al., 2018) According to the work package objective, this thesis develops a visual dashboard to perform the neighbourhood assessment. The dashboard in this thesis has main two platforms in the urban and building scales. The platform in the urban scale addresses urban planning while the other in the building scale focused on building design for reducing GHG emissions. The platforms of this thesis as a conceptual assessment tool do not consider the actual interconnection with the computing tools for the GHG emission assessment. This thesis, however, shows the possibility of the interconnection with several calculation software and city data.

This study carries out a case study where the dashboard in this thesis is applied to an ongoing project in Sustainable Architecture programme in NTNU. By applying architectural alternatives to the dashboard, the case study identifies the emission performance of the designs in order to help to select the architectural alternative which can reduce GHG emissions the most effectively.

1.4 Research Questions

In order to develop the new dashboard and to apply the dashboard to the case study, the following tasks are to be considered in the thesis.

1. How can neighbourhood design be related with GHG emissions, and how can the GHG emission assessment of a neighbourhood be quantified and qualified for the emission reduction?

2. What are the drawbacks of existing visual tools for the neighbourhood assessment and how we can develop a new tool for the effective visualisation toward zero-emission neighbourhood?

3. How can a new tool be proposed and visualised for the understanding of the relationship between neighbourhood and GHG emissions and for the optimal architectural design with the emission reduction?

4. How can the proposed visual tool be applied to the case study of Nidarvoll Skole, and how can the tool contribute to the GHG emission reduction of the case study?

This paper is conducted according to the order of these questions.

1.5 Outline of Report

The thesis is mainly divided into eight chapters.

Chapter 1 explains the motivation and inspiration of this thesis objective including the objective, the work scope, and research questions.

Chapter 2 explains the relationship between neighbourhood and GHG emission with background knowledge and identifies the relationship between neighbourhood design and GHG emission with the analysis of various assessment criteria and KPIs and case reviews. This chapter develops KPIs for Dashboard based on KPIs of ZEN research centre and other assessment tools for sustainable neighbourhood.

Chapter 3 describes the methodology for the assessment of GHG emissions based on the KPIs developed in Chapter 2.

Chapter 4 describes recent design tools that can calculate energy performance in building scale and web-based platforms that provide information associated with GHG emission, energy efficiency, mobility, and spatial quality in neighbourhood scale.

Chapter 5 establishes the design concept of a dashboard and describes the structure and function of the dashboard as a user-interface design. The design concept shows how architectural design in neighbourhood scale can integrate various stakeholders in different scales – building and city. Dashboard design illustrates, based on the design concept, what the dashboard includes, what the functions are for, and how the functions are performed. The dashboard as a conceptual design, does not consider actual interconnection among software which enables to calculate and interact with itself in real time.

Chapter 6 carries out a case study which applies the dashboard developed in chapter 5 to the actual ZEN pilot project. By applying the project, Nidarvoll Skole in Sluppen region of Trondheim, to the dashboard, this study shows how the dashboard can be applied to practical projects.

Chapter 7 contains a response to the research questions mentioned in Chapter 1.4. The main methodologies and the case study for Nidarvoll Skole performed in the thesis are assessed in the basis on the research questions.

Chapter 8 describes the conclusion from the study in this thesis

2 Analytical approach to the relationship between Neighbourhood design and GHG emissions

In order to develop a visual tool for the design of zero-emission neighbourhoods, we need to understand the relationship between GHG emission and neighbourhood design. Thus, this chapter describes the relationship between a neighbourhood and GHG emission. In order to identify the relationship, this Chapter explains the hierarchy of neighbourhood system and shows the approaches to deal with GHG emission in different neighbourhood scales.

Moreover, The Key Performance Indicators (KPIs) which indicates the interconnection between the neighbourhood and GHG emission should be well defined to conduct the objective assessment of neighbourhood. The KPIs should be integrated in the well-organised assessment categories in order to conduct the quantitative and qualitative assessment of neighbourhoods for GHG emissions.

The Key Performance Indicators have been developed in various assessment tools for sustainable neighbourhood. This chapter analyses the key performance indicators (KPIs) used in ZEN and other tools and develops the developed KPIs for a neighbourhood-based platform.

2.1 Neighbourhood & GHG emission

2.1.1 Socio-ecological system of Neighbourhoods

Neighbourhood has been defined in perspectives of ecology, sociology, and design strategy. For example, Hallman defined “a limited territory with a larger urban area, where people inhabit dwellings and interact socially” (Hallman, 1984), George identified the characteristic as “the bundle of spatially based attributes associated with clusters of residences, sometimes in conjunction with other land uses” (Galster, 2001), and “neighbourhood is always a part of the whole and a system, having specific mechanisms and functions” was regarded by Kallus and Law-Yone (Kallus & Law-Yone, 2000). The theorical definitions include two common perceptions of neighbourhood: the potential of spatial extent and social interrelationships.

In line with the common perceptions, Kallus and Law-Yone articulated humanistic approach and instrumental approach as an urban and architectural planning idea. In the perspective of humanistic approach, neighbourhood is formed naturally, where the identity comes from human relationship. As the strength of human bonds, it can be expanded to the city or wider society. Although the traditional unit of human bond is family, the transition to nuclear family can forms another human bond as a social trend because human satisfaction in micro-neighbourhood is moved to the demand of broader-neighbourhood needs (John, 2010). On the other hand, instrumental approach is based on production mechanism as a purpose of neighbourhood. Within a systematic city, neighbourhood is a subsystem that supports the city. In this theory, neighbourhood can play a role as a basic planning tool to make urban strategy.

The two approaches indicate that social interrelationship in the perspectives of social function and structure has spatially extensibility toward upper system or sub-system of a society. In other words, we can identify the neighbourhood as a social interrelationship having two directionalities in the extensibility: urban system and building system as an upper system and a sub-system, respectively in the perspective of socio-ecology. Consequently, neighbourhood system is a part of urban system while building system is an entity of neighbourhood system as shown in Figure 2.1

As we can know the characteristics of neighbourhood above, we need to analysis the relationship between neighbourhood and GHG emission in the different directivities of neighbourhood since the interconnected two systems of neighbourhood have different approaches in urban planning or architectural design ideas (Kallus and Law-Yone, 2000).

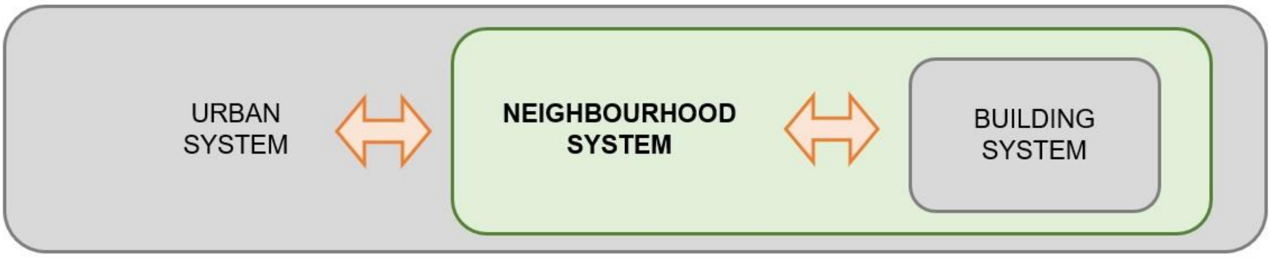


Figure 2.1 Hierarchy of Neighbourhood system

2.1.2 GHG emission in Urban system

Urban areas as intensive concentration of population and consumption are main hot spots that generate carbon emissions from world final energy use (Fischedick, 2014), and the top hundred cities emit around 20% in anthropogenic green-house gases. (Wood et al., 2018)

Since "a great amount of traded emissions beyond city boundaries impact on global emissions" (C40 Cities, 2018), city emissions can be divided into two categories: production-based emissions and consumption-based emissions. Production-based emissions include that of goods and services produced and consumed in a city as well as exported to the other cites but, the emission for goods and service imported from other cities is not included. Consumption-based emissions contain that of goods and serviced produced in a city as well as imported into the city but, goods and service exported to other cities are not accounted in the emission.

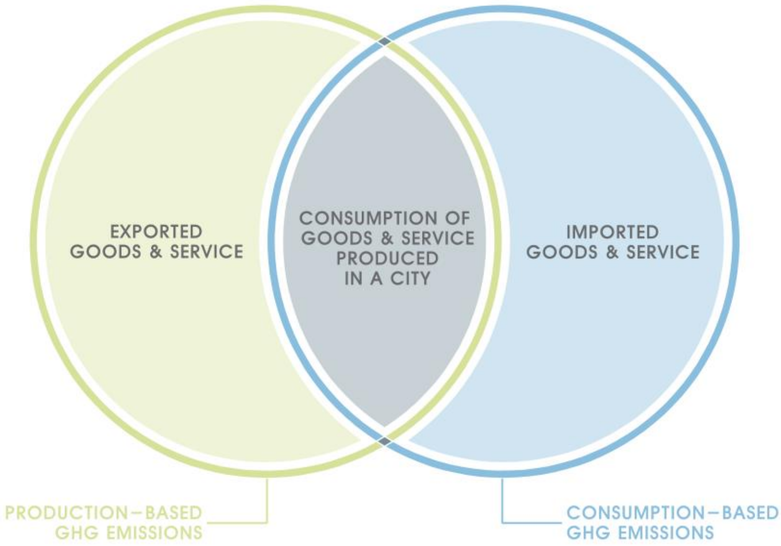


Figure 2.2 The concept of production-based & consumption-based GHG emissions

It is important to consider both emission concepts when evaluating urban GHG emissions. However, this work focuses on the consumption-based emission due to the following reasons. Many cities rely on imports, and especially most in Europe and North America, the size in consumption-based emission is three-fold of that in production-based emission. (C40 Cities, 2018) It means that cities should consider the innovation for product chain and value chain of products and service that they have utilized from mining material to wasting or recycling in order to achieve the emission reduction.

2.1.3 GHG emission in Building system

Buildings represent a critical sector for climate change mitigation. In 2010, the building sector is reported that it consumed 32 % of total global energy and emitted 19 % of energy-related GHG emission, and it is expected that it would double or triple by 2050 (Graham et al., 2014). In the life cycle of the building, the phase of the manufacture of building materials and the building operational use occupies the most of energy consumption in the building.

Embodied energy is the energy used at the stage of building material manufacturing. The manufacturing stage includes raw material mining, material production, transport, and construction. (Ramesh, 2010) Thus, embodied emission means the GHG emissions generated by embodied energy at the stages from mining to construction. However, since GHG emissions mean 'CO2 equivalent' gas emission, embodied emission also includes CO2 emissions generated in the process of material production as a non-energy-related process. For example, since cement emits CO2 during the calcination of limestone, the embodied emission of cement involves the calcinated CO2 as well as the emissions from the embodied energy. (Kristjansdottir, 2014) Embodied emission can be categorised according to the building life cycle based on NS-EN15987, and the level of embodied emission is explained in ZEB ambition levels of Chapter 2.2

In the perspective of building operational energy use, the increasing trend of the building energy use is attributed to the change of lifestyle- improved housing, electricity, and facilities in household of developing countries that have the high rate of population growth.

Buildings use various technologies in order to maintain the comfort indoor environment and lives of occupants. The demands for heating, cooling, lighting, cooking, and appliance, are main factors of building energy consumption.

As the distribution of final energy consumption, A half of energy use in residential buildings and commercial building is associated with thermal conditions of building indoor space. Besides equipment performance for heating and cooling, building envelope is closely related with indoor thermal condition since building envelope, such as wall, roof, floor, window, and door plays a role to transfer thermal energy. Therefore, the energy-efficient envelope considered by architectural design can reduce energy consumption in buildings. Total energy saving in building sector is significantly achieved in the indoor conditions that architects can design and consider. Figure 2.1 shows that the potential of thermal conditions and lighting which can be improved by architectural design represents over 30 % in total energy saving. (Diczfalusy & Taylor, 2011)

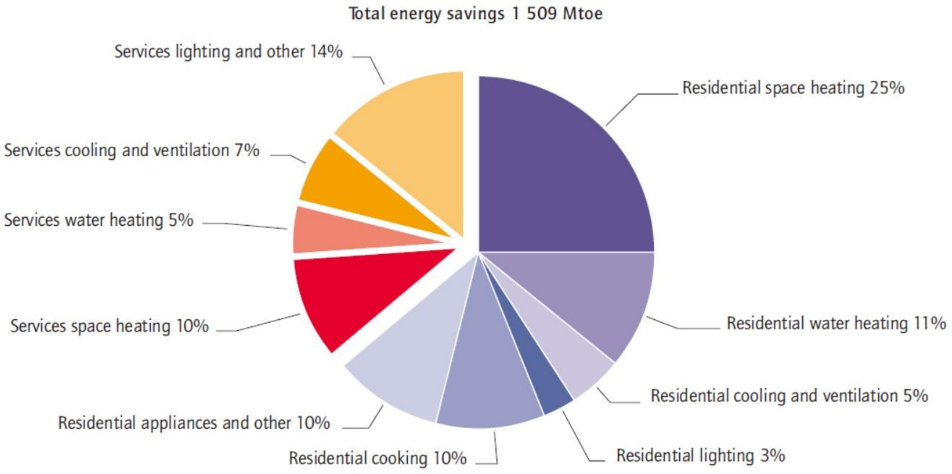


Figure 2.3 Building sector energy savings by sector and end-use (Diczfalusy & Taylor, 2011)

The GHG emissions in building system can be mainly divided into the embodied emissions from building materials and the emissions from building operational energy use. Embodied emissions can be analysed according to the building life cycle stages while the emissions from the building energy use can be analysed by the energy consumption factors and building elements.

2.2 ZEB & ZEN

The Research Centre on Zero Emission Buildings (ZEB) established by the Research Council of Norway, collaborating with NTNU and SINTEF, to develop technical solutions to reduce GHG emissions in the building sector (Kristjansdottir et al., 2014). ZEB projects have succeeded in minimizing negative environmental impact during production, use, and demolition of buildings through the ZEB pilot projects such as the ZEB pilot building Powerhouse 1 and the residential building ZEB living laboratory.

The ZEB definition guideline includes ZEB ambition levels as shown below. (Kristjansdottir et al., 2014)

1. ZEB-O÷EQ: Emissions related with operational energy use except for equipment and appliance.
2. ZEB-O: Emissions related with all operational energy use.
3. ZEB-OM: Emissions related with all operational energy use plus embodied emissions from materials.
4. ZEB-COM: Emissions of ZEB-OM plus emissions related with the construction phase.
5. ZEB-COME: Emissions of ZEB-OM plus emissions related with the end of life phase.
6. ZEB-COMPLETE: Emissions related with a complete lifecycle.

As an expanded concept from the ZEB, The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME-ZEN Centre, ZEN) was established in 2017. The main goal of ZEN is to develop solutions for buildings and neighbourhoods without greenhouse gas emissions. In order to achieve the goal, the ZEN is conducted in the neighbourhood scale for design, planning, technology, and solutions of buildings. (Marianne et al., 2018) Furthermore, the research has visions which creates new business models, roles and services with flexible market strategy as well as a decision-support tool for optimizing energy systems. The ZEN Research Centre is hosted and organized by joint unit of NTNU and SINTEF.

The ZEN Centre mainly has six Work Packages (WP). The thesis is developed in WP1 where the framework for ZEN design focuses on the development of neighbourhood design instruments. To be specific, the thesis is aligned with the main objective of WP1.3 to develop ZEN toolbox for neighbourhood design supporting to encourage stakeholder participation (Bremvåg et al., 2017).

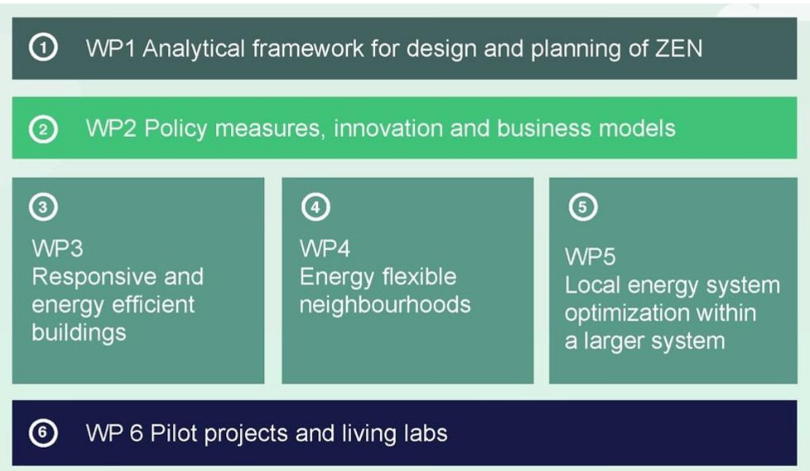


Figure 2.4 The six work packages of the ZEN Centre (Marianne et al., 2018)

The ZEN defines neighbourhood as “a group of interconnected buildings with associated infrastructure, located within a confined geographical area” (Marianne et al., 2018). The buildings mean various types of architectural work such as new, existing, retrofitted, or the complex type. The infrastructure defined in the ZEN do not include only grids and technologies for energy production and delivery but, also technologies for building resources flows such as water, waste, and information and communications technology (ICT). Furthermore, the geographical boundary concludes external grids for building energy such as electricity and district heating. Based on the definition of neighbourhood, ZEN research has developed the criteria of assessment tool and key performance indicators (KPIs).

2.2.1 ZEN assessment criteria and key performance indicators (KPIs)

The ZEN is split into six main categories to reduce GHG emissions in neighbourhood scale. Each category has assessment criteria and key performance indicators. (Figure 2.5)

a. GHG emissions

The main purpose of the ZEN is to reduce GHG emissions of neighbourhoods in the phase of building and infrastructure life cycle. The GHG emissions category is divided into two assessment criteria: Total GHG emissions and GHG emission reduction. In line with the goal to minimize GHG emission in the building and infrastructure life cycle, the emission should be calculated according to the life cycle assessment methodology.

b. Energy

Energy category focuses on the operational energy use since the embodied energy in included in the GHG emission category. The energy category is divided into two assessment criteria: Energy efficiency in buildings and Energy carriers. The KPIs of Energy efficiency in buildings are calculated in building scale. It includes building energy use such as heating, cooling, ventilation, domestic hot water, humidification, lighting, and plug load. The KPIs of Energy carriers are calculated in neighbourhood scale. It includes all energy flows in the neighbourhood.

c. Power/load

Power/load category focuses on power peaks in the energy flows with smart energy grids. The category is split into Power/load performance and Power/load flexibility. The assessment criteria of Power/load performance and Power/load flexibility are calculated in the neighbourhood scale.

d. Mobility

Mobility category promotes sustainable transport patterns. In line with the promotion, it is divided into two assessment criteria: Mode of transport and Access to public transport. The KPI of Mode of transport is calculated as the percentage share of eco-friendly transport modes. Access to public transport includes the linkage to public transport nodes, local city centre, and the way to travel. The KPIs of Mobility are evaluated in neighbourhood level.

e. Economy

Economy category originated in life cycle costing methodology has one assessment criteria: Life cycle cost (LCC). Life cycle costing is a methodology to evaluate building and construction cost in the whole life cycle.

f. Spatial qualities

Spatial quality category promotes good places to live with eco-friendly lifestyle in neighbourhood. The spatial quality category is divided into three assessment criteria: Demographic needs and consultation plan, Delivery and proximity to amenities, and Public space. Demographic needs and consultation plan are evaluated for the need of the occupancy and the process to ensure the needs, ideas, and knowledge of the community. Delivery and proximity to amenities covers the accessibility between amenities and users. Public space as a key dimension of spatial quality is to encourage social interaction.

Category	Assessment criteria	Key performance indicators (KPIs)
GHG emission	• Total GHG emissions • GHG emission reduction	• Total GHG emissions in tCO_{2eq}; tCO_{2eq}/m^2 heated floor area (BRA)/yr; $kgCO_{2eq}/m^2$ outdoor space (BAU)/yr; tCO_{2eq}/capita • % reduction compared to a base case
Energy	• Energy efficiency in buildings • Energy carriers	• Net energy need in kWh/m^2BRA/yr; Gross energy need in kWh/m^2 BRA/yr; Total energy need in kWh/m^2 BRA/yr • Energy use in kWh/yr; Energy generation in kWh/yr; Delivered energy in kWh/yr; Exported energy in kWh/yr; Self-consumption in %; Self-generation in %; Colour coded carpet plot in kWh/yr
Power/Load	• Power/load performance • Power/load Flexibility	• Net load yearly profile in kWh; Net load duration curve in kWh; Peak load in kWh; Peak export in kWh; Utilisation factor in % • Daily net load profile in kWh
Mobility	• Mode of transport • Access to public transport	• % share • Meters; Frequency
Economy	• Life cycle cost (LCC)	• NOK; NOK/m^2 heated floor area (BRA)/yr; NOK/m^2 outdoor space (BAU)/yr; NOK/capita
Spatial qualities	• Demographic needs and consultation plan • Delivery and proximity to amenities • Public Space	• Qualitative • No. of amenities; Meters (distance from buildings) • Qualitative

Figure 2.5 ZEN assessment criteria and KPIs (Marianne et al., 2018)

This thesis will define the scope of assessment criteria and indicators for the development of Dashboard, based on ZEN assessment criteria and KPIs. However, ZEN KPIs is a tool to evaluate the comprehensive performance of neighbourhood while this work requires new assessment criteria for architect-oriented dashboard. Therefore, we need to develop KPIs for effective assessments of neighbourhood scale for architectural works.

2.3 KPIs for Dashboard

The main goal of this study is to develop a dashboard for architects, and the dashboard is to reduce GHG emissions in neighbourhoods. Based on the main purpose of dashboard in this study, this chapter 2.3 analyses the KPIs of various performance measurement systems in order to figure out the KPIs which can be assessed by architects. Besides, this chapter reviews the approaches to address GHG emissions in order to comprehend the assessment categories implemented in different neighbourhood levels. Through the analysis for various KPIs and the review of neighbourhood assessment categories, this study develops the KPIs for Dashboard.

2.3.1 KPIs in the neighbourhood performance measurement systems

The following performance measurement systems are to achieve sustainable society and they have well-organised KPIs for the purpose of the systems. ZEN KPIs have been also defined and developed based on the following tools (Marianne et al., 2018).

The aim of BREEAM Communities is to provide the standards for the improvement of social, environmental, and economic benefits in neighbourhoods. the assessment criteria and the KPIs are categorised by Governance, Social and economic wellbeing, Resources and energy, Land use and ecology, Transport and movement, and innovation. (BREEAM, 2012)

The goal of CITYkeys is to support the development of smart city solutions and services, dealing with the challenges related with the growth, energy, and climate targets of cities. The assessment criteria and the KPIs are categorised by the themes such as People, Planet, Prosperity, Governance, and Propagation. (Bosch, 2017)

The goal of Smart Cities Information System is to promote sustainable improvement of urban areas, focusing on energy, transport, and Information and Communications Technology (ICT). The assessment criteria and the KPIs are mainly categorised by Energy performance, Environmental performance, economic performance, ICT, mobility. (Möller, 2016)

PI-SEC as a Norwegian research project has a main goal to provide knowledge for moving towards smart and sustainable energy use in urban areas and planning. The assessment criteria and the KPIs are categorised by CO2-reduction, Increased use of renewable energy, Increased energy efficiency, Increased use of local energy sources, and Green mobility. (Walnum, 2017)

The analysis for neighbourhood performance measurement systems

In order to analyse the performance measurement systems, the assessment criteria of the measurement systems were rearranged according to the categories of ZEN assessment criteria since the dashboard of this study was based on the context of ZEN assessment criteria. Next, the criteria and KPIs were analysed for the relevance to architectural works. They were also classified by the methodology of assessment: quantitative and qualitative methodologies. The recategorized criteria are shown in Table 2.1.

In the case of the relevance to architectural works, the assessment categories of GHG emissions, Energy, Mobility, and Spatial quality can be affected by building design and site planning. The embodied energy form building materials and building operational energy are main drivers to generate GHG emissions. The envelope of building as a medium to deliver energy between inside and outside of building affects the loss of indoor energy such as heating, cooling, ventilation, and lighting. In the Mobility category, the building location and orientation design can affect the assessment of accessibility from building to public transportation and amenities. Moreover, the assessment criteria of Spatial quality are interrelated with architectural works. Demographic need as a user demand is an essential factor to be incorporated to building design. Consultant plan includes the participation of architects. Amenities and public space in neighbourhood are considered in the site plan and building space programme plan. The Quality of housing and the built environment in the Spatial quality category is also an essential part of architectural works. Therefore, architectural works are related with the assessment for GHG emission, Energy, Mobility, and Spatial quality categories and for the related criteria and KPIs (blue marked in Table 2.1).

In the perspective of the assessment methodology, the categories of GHG emission, Energy, Power/load, and Economy are calculated in the assessments of performance measurement systems. Mobility and Spatial quality categories are evaluated with quantitative and qualitative methodologies in the measurement systems. In the case of Mobility, the ZEN measures the access to public transport with a metric while the BREEAM and CITYkeys evaluate the accessibility criteria with a Likert scale. Delivery and proximity to amenities and Quality of housing and the built environment in Spatial quality category use the metric while the criteria of Demographic need and consultant plan and Public space evaluate the neighbourhood performance with the Likert scale. Accordingly, we can know that the neighbourhood performance measurement systems use quantitative and qualitative methodologies in order to assess the neighbourhood criteria. Besides, the assessment criteria which cannot be calculated directly use the Likert scale as the KPIs.

ZEN Category	the Assessment criteria and KPIs		Unit	Method		Performance Measurement Systems	Architectural Scope
GHG emissions	Total GHG emissions		kgCO2eq/m2 heated floor area (BRA)/yr tCO2eq	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
	GHG emission reduction		% reduction	QUANTITATIVE	Calculation	ZEN	Yes
	Energy and mitigation	Carbon dioxide emission reduction	% in tonnes	QUANTITATIVE	Calculation	CITYkeys	Yes
		Reduction in lifecycle CO2 emissions	% in tonnes	QUANTITATIVE	Calculation	CITYkeys	Yes
	CO2 emissions	Materials	Tonnes CO2 eqv./yr	QUANTITATIVE	Calculation	PI-SEC	Yes
		Stationary Energy	Tonnes CO2 eqv./yr	QUANTITATIVE	Calculation	PI-SEC	Yes
	Greenhouse Gas Emissions		kg CO2eq/ (m2 *month); kg CO2eq/ (m2 *year)	QUANTITATIVE	Calculation	SCIS	Yes
	Carbon dioxide Emission Reduction		tones/(year)	QUANTITATIVE	Calculation	SCIS	Yes
Energy	Energy efficiency in buildings	Net energy need	kWh/m2 heated floor area (BRA)/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Gross energy need	kWh/m2 heated floor area (BRA)/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Total energy need	kWh/m2 heated floor area (BRA)/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
	Energy carriers	Energy use	kWh/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Energy generation	kWh/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Delivered energy	kWh/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Exported energy	kWh/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Self consumption	%	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Self generation	%	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
		Colour coded carpet plot	kWh/yr	QUANTITATIVE	Calculation	ZEB / ZEN	Yes
	Energy and mitigation	Reduction in annual final energy consumption	% in kWh	QUANTITATIVE	Calculation	CITYkeys	Yes
		Reduction in lifcycle energy use	% in kWh	QUANTITATIVE	Calculation	CITYkeys	Yes
		Reduction of embodied energy of products and services used in the project	Likert scale	QUALITATIVE	Evaluation	CITYkeys	Yes
	Energy Use	Electric	MWh/yr	QUANTITATIVE	Calculation	PI-SEC	Yes
		Thermal	MWh/yr	QUANTITATIVE	Calculation	PI-SEC	Yes
	% of different kinds of RES in district heating	Electricity	%	QUANTITATIVE	Calculation	PI-SEC	No
		Heat pump	%	QUANTITATIVE	Calculation	PI-SEC	No
		Solar	%	QUANTITATIVE	Calculation	PI-SEC	No
		Biofuel	%	QUANTITATIVE	Calculation	PI-SEC	No
		Waste	%	QUANTITATIVE	Calculation	PI-SEC	No
	Energy demand and consumption		kWh/ (m2 month); kWh/(m2 year)	QUANTITATIVE	Calculation	SCIS	Yes
	Energy savings		%	QUANTITATIVE	Calculation	SCIS	Yes
	Degree of energetic self-supply by RES		%	QUANTITATIVE	Calculation	SCIS	Yes
	Primary Energy Demand and Consumption		kWh/(m2 * Year)	QUANTITATIVE	Calculation	SCIS	Yes
Power/load	Power/load performance	Yearly net load profile	kW	QUANTITATIVE	Calculation	ZEB / ZEN	No
		Peak load	kW	QUANTITATIVE	Calculation	ZEB / ZEN	No
		Peak Load Consumption	kW	QUANTITATIVE	Calculation	PI-SEC	No
		Peak Load Production	kW	QUANTITATIVE	Calculation	PI-SEC	No
		Peak load reduction	%	QUANTITATIVE	Calculation	SCIS	Yes
Mobility	Mode of transport		% share	QUANTITATIVE	Research	ZEN	No
	Access to public transport		Meters	QUANTITATIVE	Calculation	ZEN	Yes
	Transport assessment	Reduce the need for travel	BREEAM credit	QUALITATIVE	Evaluation	BREEAM	No
		Promote multi-purpose or linked trips	BREEAM credit	QUALITATIVE	Evaluation	BREEAM	No
		Promote a more sustainable pattern of development	BREEAM credit	QUALITATIVE	Evaluation	BREEAM	No
		Reduce distances from buildings to public transport nodes	BREEAM credit	QUANTITATIVE	Calculation	BREEAM	Yes
		Improve sustainable transport choices	BREEAM credit	QUALITATIVE	Evaluation	BREEAM	No
	Access to (other) services	Access to public transport	Likert scale	QUALITATIVE	Coverage	CITYkeys	Yes
		Improved access to vehicle sharing solutions	Likert scale	QUALITATIVE	Evaluation	CITYkeys	Yes
		Access to public amenities	Likert scale	QUALITATIVE	Coverage	CITYkeys	Yes
		Access to commercial amenities	Likert scale	QUALITATIVE	Coverage	CITYkeys	Yes
Economy	Life cycle cost (LCC)		NOK/m2 heated floor area (BRA)/yrNOK	QUANTITATIVE	Calculation	ZEB / ZEN	No
	Green economy	CO2 reduction cost efficiency	€/ton CO2saved/year	QUANTITATIVE	Calculation	CITYkeys	No
	Total Investments		€/m2 (building company); €/kW (energy company)	QUANTITATIVE	Calculation	SCIS	No
	Total Annual costs		€/year	QUANTITATIVE	Calculation	SCIS	No
	Payback		Years	QUANTITATIVE	Calculation	SCIS	No
	Return on Investment (ROI)		%	QUANTITATIVE	Calculation	SCIS	No
	Reduction of energy cost		[%]	QUANTITATIVE	Calculation	SCIS	No
Spatial Qualities	Demographic needs and consultation plan		BREEAM credit	QUALITATIVE	Evaluation	ZEB / ZEN	Yes
	Delivery and proximity to amenities		No. of amenities Meters (distance from buildings)	QUANTITATIVE	Calculation	ZEN / BREEAM	Yes
	Public Space		Public-life Analysis	QUALITATIVE	Evaluation	ZEN	Yes
	Public Space		BREEAM credit	QUALITATIVE	Evaluation	BREEAM	Yes
	Quality of housing and the built environment	Local parking	BREEAM credit	QUALITATIVE	Evaluation	BREEAM	Yes
		Increased use of ground floors	% in m2	QUANTITATIVE	Calculation	CITYkeys	Yes
		Increased access to green space	m2	QUANTITATIVE	Calculation	CITYkeys	Yes

Table 2.1 The analysis of neighbourhood performance measurement systems

2.3.2 Review for the approach to address GHG emissions in different levels

Since neighbourhood system with regard to GHG emission is closely associated with the entire city and even a single house, this study needs to research how the emissions can be dealt with in the different perspectives of both urban and building scale. Thus, this thesis reviews various case studies to see how they handle the different level problems when evaluating GHG emissions of neighbourhood.

This is based on the case studies conducted in C40 Cities Climate Leadership Group (C40 Cities, 2019) as a network of the world megacities engaged in dealing with climate change. Thirty cases with different levels (urban, neighbourhood, and building) are selected for the review, and analysed according to the following criteria.

+ The scope of topics: Energy, Buildings, Transportation and Urban Planning
+ What is the project?
+ What is the background problem?
+ What are the actions to address the problem focused on?
+ What is the main benefit and impact from the actions?

No.	Project	Location
1	Sustainable Energy Action Plan	Seoul
2	Comprehensive Parking Management System	Chennai
3	Electrification of the Bus Fleet	Warsaw
4	Circular Economy Roadmap	Amsterdam
5	Metrobüs System	Istanbul
6	Iconic Buses real-time Airquality Alerts	London
7	Practice guide : the expansion of district heating	Oslo
8	Big Data to Promote Eco-friendly Freight Transport	Tokyo
9	Smart LED Retrofit Optimizes Resources	Buenos Aires
10	Demand and Supply side CO2 reductions	Dubai
11	The Superblocks programme	Barcelona
12	Sustainable Neighbourhood Area	Basel-Stadt
13	Biggest Landfill	Hanoi
14	Transition to a Clean Heating Network	Rotterdam
15	Mapping real-time energy consumption	Copenhagen
16	Walkable City drives	Stockholm
17	Low-Carbon Park	Dalian
18	The Green Traveler Reward Platform	Beijing
19	International resorts zone central gas distributed energy station	Shanghai
20	Pioneering Sustainability in Schools	Rio de Janeiro
21	Energy Retrofits Protecting the Cultural Heritage	Heidelberg
22	Hıdayet Turkoğlu Sports Complex	Istanbul
23	Zero Emissions From New Buildings	Vancouver
24	The Madrid Recupera Plan	Madrid
25	RE:FIT Progrmme from public buildings	London
26	Megenagna Smart Parking	Addis Ababa
27	Energy Office Sloar Project	Durban
28	Customised training and awareness raising	Cape town
29	Quadplex quaranteed energy savings project	Philadelphia
30	Energy-saving Retrofits for Aging Housing Stock	Chicago

Table 2.2 The list of Review

No.	Scale	Action Area				Impact			
		Electricity grid	Mobility	Spatial Quality	Building energy efficiency	Environmental	Social	Economic	Health
1	Urban	●			●	○	○	○	
2	Urban		●	●		○	○		○
3	Urban		●	●		○		○	○
4	Urban	●	●		●	○	○	○	
5	Urban		●			○	○		
6	Urban		●	●		○	○	○	○
7	Urban	●				○			
8	Urban		●			○		○	
9	Urban	●		●		○		○	
10	Urban	●				○			
11	Neighbourhood		●	●		○	○		
12	Neighbourhood	●	●	●	●	○	○	○	
13	Neighbourhood	●				○	○	○	○
14	Neighbourhood	●		●	●	○	○		○
15	Neighbourhood	●			●	○		○	
16	Neighbourhood		●	●		○	○		○
17	Neighbourhood	●		●	●	○	○		
18	Neighbourhood		●			○		○	
19	Neighbourhood	●				○		○	
20	Neighbourhood	●			●	○	○	○	○
21	Building				●	○	○	○	
22	Building	●			●	○	○	○	
23	Building				●	○			
24	Building				●	○	○	○	○
25	Building				●	○		○	
26	Building		●	●		○	○		○
27	Building				●	○			
28	Building				●	○	○		
29	Building				●	○		○	
30	Building				●	○	○		

Table 2.3 The review on addressing emission reduction in different neighbourhood levels

The analysis for addressing emission reduction in different neighbourhood levels

The cases reviewed in this work were categorised by GHG emissions, energy efficiency, mobility, and spatial quality. Air quality was included into spatial quality while Economy was excluded in this analysis. The location of the case projects was selected randomly but considered not to be concentrated in one area as much as possible.

As shown in Table 2.3, the cases have the strategic differences in different neighbourhood levels. The cases in urban level (1-10) have a tendency to mainly consider mobility (especially public transportation), spatial quality, and electricity grid. Most cases of building level (21-30) are focused on the action to improve building energy efficiency. The categories of actions in neighbourhood level as meso-level (11-20) interestingly is spread out over the whole action categories.

The strategic differences to deal with neighbourhood challenges are mainly attributed to the scale of project and user demand. Electricity grid and public transportation are infrastructures as the fundamental facilities and system. Thus, the challenges regarding the large-scaled development such as electricity grid and public transportation are carried out in neighbourhood or urban scale. Besides, such infrastructure involves the capital-intensive development. It is difficult to be dealt with in building level. In addition, the user demand makes the strategic differences for emission reductions. In case of Sustainable energy action plan in Seoul (1), the effort for reducing electric energy was implemented by the demand of citizen. By participating the citizen to the sustainable energy action plan, the energy strategy was expanded to the whole urban boundary. Energy office solar project (27) was carried out by the demand of the occupants in the public office. The demand of building energy saving led to installing rooftop photovoltaic panel as a pilot project for private sector. Consequently, according to the project scale and user demand, the strategy for the emission reduction is addressed in different neighbourhood level.

The strategy to deal with the climate problem in each case incorporates its own properties in demographic conditions. For example, Hanoi has the challenge to have to provide stable electricity as well as to reduce climate-gas emissions. Meanwhile, Hanoi treats a great deal of wastes as the population exponentially increases. In this current condition, the city implemented the strategy of the landfill gas plant construction (13). Based on a plenty of waste resources, it is expected that the landfill gas plant provides stable electricity and reduces GHG emission, about 128,304 tCO2e/year at the same time. Barcelona is a representative city as a tourist attraction in Spain. It had the problems regarding the increase of traffic congestion and the back of life quality for residents and tourists. However, Barcelona improved the flows of transportation and increased public green zone by running a strategy called as ‘Superblock’ (11) where the city rearranged modular district units in existing grid-shaped urban zone. Accordingly, we can know that demographic information such as population and waste resources in Hanoi and tourism in Barcelona is a significant clue to handle the environmental problems.

2.3.3 New Assessment Criteria and KPIs for Dashboard

Based on the analysis for neighbourhood performance measurement systems (Chapter 2.3.1) and for addressing emission reduction in different neighbourhood levels (Chapter 2.3.2), this study defined new assessment criteria and key performance indicators (KPIs) for Dashboard.

Level	Category	New KPI and Assessment Criteria for Dashboard	ZEN KPI and Assessment Criteria	Unit	Note
Building-oriented	GHG emissions	**Total GHG emissions**	Total GHG emissions	kgCO2eq/m2 heated floor area (BRA)	
	Energy	**Total Energy need**	Total Energy need	kWh/m2 heated floor area (BRA)/yr	
	Energy	**Self-consumption**	Self-consumption	%	
		Self-generation	Self-generation	%	
		Peak load		kW	Building level
	Power/Load		Peak load	kW	Neighbourhood level
Urban-oriented	Mobility	**Access to public transport**	Access to public transport	meters	
		Mode of transport	Mode of transport	% share	
	Spatial Quality		Demographic analysis	qualitative	
		Delivery of amenities	Delivery of amenities	No. of amenities, Meters (distance from buildings)	
		Proximity to amenities	Proximity to amenities	No. of amenities, Meters (distance from buildings)	
		Localisation of amenities	Localisation of amenities	No. of amenities, Meters (distance from buildings)	
		Public Space	Public Space		
	Demographics	**Demographic analysis**		qualitative	Independent category

Table 2.4 The Comparison between the assessment criteria and KPIs between Dashboard and ZEN

According to the two neighbourhood systems (Chapter 2.1), Dashboard has two assessment scopes in building-oriented and urban-oriented level. Each neighbourhood level focuses on different assessment categories (Chapter 2.3.2), and the categories have their own assessment criteria and KPIs for GHG emission reduction (Chapter 2.3.1). Besides the assessment criteria derived from the categories of building level are carried out by quantitative methodology while the assessment criteria derived from the categories of urban level are implemented by qualitative methodology. (Chapter 2.3.1)

The new assessment criteria and KPIs for Dashboard is shown in Table 2.4. The basic structure of new assessment criteria is accordance with the ZEN criteria (Chapter 2.2). However, in the case of new assessment category, peak load is included in Energy category, and it is calculated in building level since peak load is an important indicator to show the performance of building envelop in the perspective of architectural design (Oldewurtel, 2010). Besides, new assessment category defines Demographics as an independent category since demographics is an important factor which should be considered in the Energy (Simon, 2008) and Mobility as well as Spatial quality in order to reduce GHG emission, as shown in the example of Chapter 2.3.2.

The new assessment criteria and KPIs for GHG emission reduction will be additionally analytic background when conducting methodology for neighbourhood assessment (Chapter 3) and designing user interface of Dashboard (Chapter 5).

3 Methodology for Neighbourhood Design Assessment

This Chapter provides the methodologies that can calculate the emission as a quantitative assessment tool and the methodologies that can evaluate them as a qualitative assessment tool, based on KPIs categorised by the neighbourhood hierarchy in Chapter 2.

3.1 Quantitative Assessment

In this work, the quantitative assessment deals with integrated evaluation for material and energy use in the small-neighbourhood scale (buildings), and it calculates the compensation of climate-gas emission between material and energy use by including the self-energy assessment of PV panel.

For a proper quantitative assessment, right understanding of the relationship between neighbourhood planning and GHG emissions is required. Regarding the relationship, architectural design, energy use, and LCA are considered in different relationships between them. Neighbourhood planning in the perspective of architectural design means architectural works considered in the relationships around building site. The architectural design affects total energy consumption generated by the material production and the operational use of building. Meanwhile, through LCA of the material production and the operational use, GHG emissions can be quantified with the total energy consumption. (Figure 3.1)

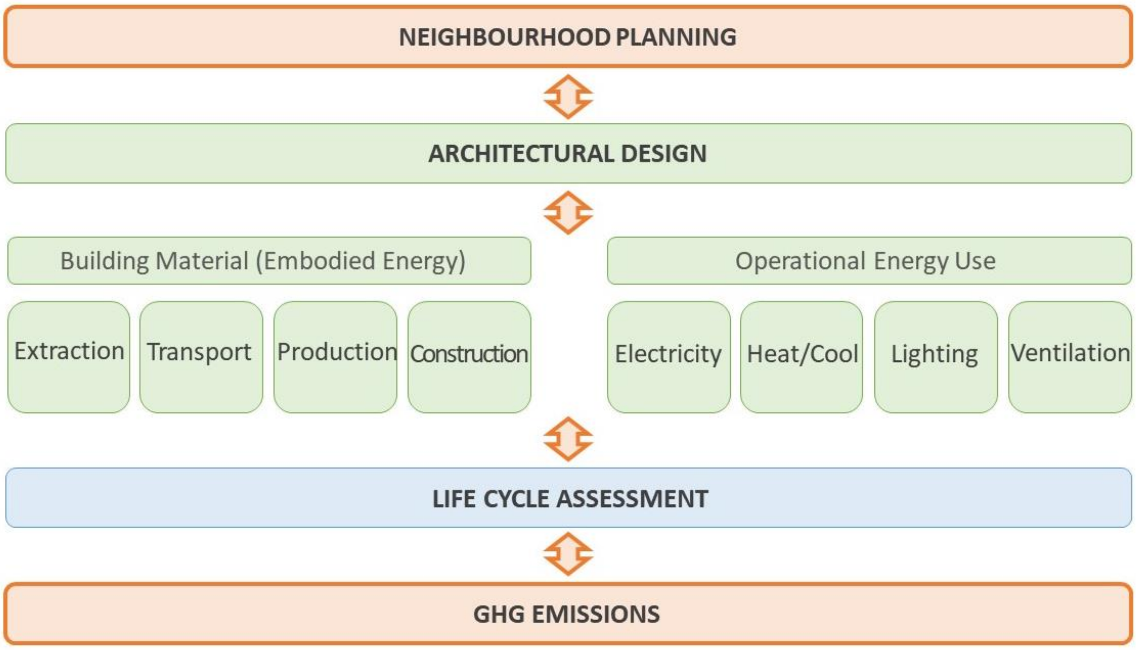


Figure 3.1 Relationship between Neighbourhood planning and GHG emissions

3.1.1 The relationship between Neighbourhood planning and Architectural design

In the neighbourhood planning, architects can consider the relationship between inside and outside of a project site. This relationship affects the orientation, size, volume, and shape of new buildings. The outside condition of neighbourhood allocates the limitation or possibility of inner site plan (Kasprisin, 2011). For example, if there is a park in the northern part of the site while residential area in the other directions, the shape of building in the northern part of the site can be considered interactively with the park while the building can be designed as the closed shape from neighbourhood in other direction parts in order to protect the privacy in the site. Moreover, in order to get enough daylight, the southern part of building can have wide windows but, considering the privacy at the same time. (Figure 3.2)

A cluster of buildings can be regarded as 'small neighbourhood' in a project site which includes multi-purpose buildings such as multi-family housing, school, and hospital. For example, the site for an elementary school project can have various buildings, – classrooms for lower grades, classrooms for higher grades, a canteen, a building for teachers, an administration building, and a gym – and several outside spaces – playground, path, outdoor shelter, parking lots and open space. Two different classrooms for lower grades and higher grades are closely located together for functional relationship while they should have their own individual shelter due to different behavioural characteristics. Gym should be linked to playground to have synergy between two programmes. Building for employees is located where teachers can easily manage their pupils, and the building are closely located with parking lots.

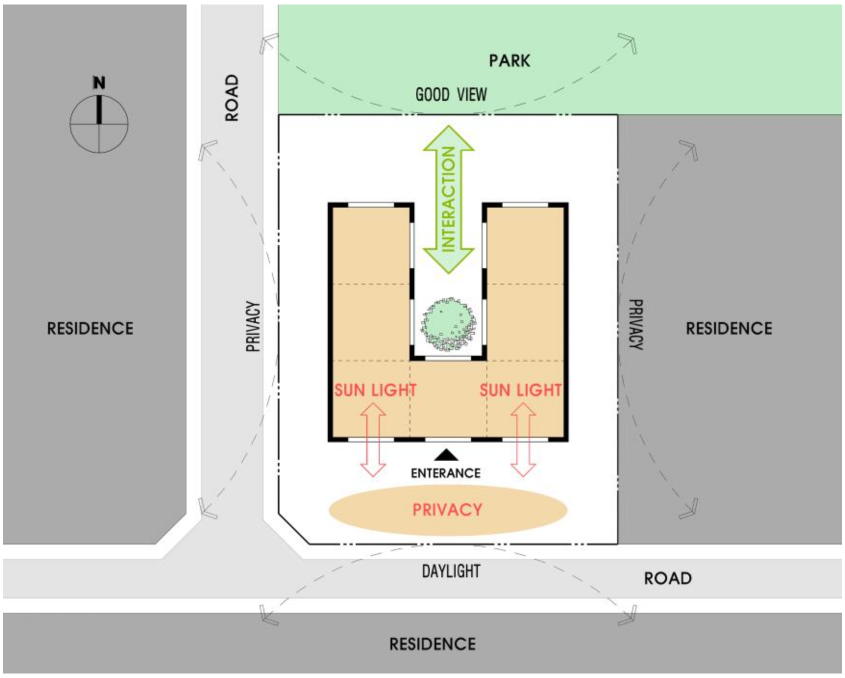


Figure 3.2 The relationship between inside and outside of a site

Figure 3.3 The change of wall area depending on alternatives

The relationships between inside and outside of a site or among buildings which have different functions encourage architects to make various alternatives for the most optimal architectural design. Early design phase includes building orientation, size, volume, building mass, window orientation as well as building material planning. The various alternatives of massing design create different conditions for building walls and windows. Although the alternatives have the same floor area, according to the shape of building, the total area of wall in an alternative is different from the other alternatives, and the area and orientation of windows are differentiated from the others (Figure 3.3).

3.1.2 The relationship between Architectural Design and Energy

Buildings utilise energy during the construction process where building materials are delivered to the site, and construction equipment is used for the structure. Embodied energy is the energy utilised during material product stage (A1-A3) and construction process stage (A4-A5) of building life cycle modules as shown in Table 3.1. Embodied energy is split into initial embodied energy and recurring embodied energy. (Ramesh et al., 2010)

The initial embodied energy is the entire energy generated for initial construction of buildings. The energy is expressed as the following equation. (Ramesh et al., 2010)

$$EEi = \sum miMi + Ec$$

Where, EEi : initial embodied energy of the building
mi : quantity of building material (i)
Mi : energy content of material (i) per unit quantity
Ec : energy use at site for erection /construction of the building

The recurring embodied emission is the entire energy generated for material replacement and building repair, which is shown as the following equation. (Ramesh et al., 2010)

$$EEr = \sum miMi[\left(\frac{Lb}{Lmi}\right) - 1]$$

Where, EEr : recurring embodied energy of the building
Lb : life span of the building
Lmi : life span of the material (i)

Here, we can know that embodied energy is affected by the life cycle of materials and building, and energy source used in the production of materials and the construction.

Buildings consume energy to maintain the quality of their space in operational energy use phase – heating, cooling, lighting, ventilation, and electricity for applications. Focusing on heating and cooling, a space consumes energy to maintain indoor temperature. While heating energy is provided into the room, some of the energy is lost through the exterior wall so that the room temperature becomes steady-state with outdoor temperature. To keep scheduled temperature inside of exterior wall, heating energy should be continuously provided into the wall (Olofsson & Andersson, 2002).

Building envelope is a medium that delivers energy between inside and outside of a space. Walls and windows as the main envelope of building have energy performance to exchange heat. Since easy heat exchange through walls and windows means high heat loss to outside, building envelope should have low heat transfer coefficient to reduce heat loss, heat transfer coefficient describes how well a building element conducts heat through a unit medium divided by the difference in temperature between inside and outside of the space, and the overall heat transfer coefficient is defined as U-value (ISO 6946, 2007).

Regarding total wall area of a building, larger the area of wall is, higher the rate of heat loss is. U-value determined by ISO6943 can be shown by the following equation (Fokaides & Kalogirou, 2011).

$$Q' = UA\,(T_{IN} - T_{OUT})$$

Where, Q' : heat flux as heat transfer rate (W)
U : overall heat transfer coefficient (U-Value) ($W/m^2\,K$)
A : surface area (m2)
T_{IN} : indoor temperature (°C)
T_{OUT} : outdoor temperature (°C)

Here, we can know larger wall area contributes to higher overall heat transfer rate, thus larger heat loss from building envelope.

Meanwhile, windows area rate and window orientation are also related with the energy consumption to maintain indoor temperature. In a study regarding window-to-wall ratio (WWR), there was the most efficient energy performance of the case study in the WWR between 0.3 and 0.45 except for extreme climate conditions. The gap between the energy use in the worst case and the best case accounted for 5-25% (Goia, 2016). Another research on the energy efficient of WWR according to window orientation in an extreme cold region shows that the biggest impact of WWR on energy consumption is reported in the orientation of west or east, followed by south and north (Feng et al., 2017).

Consequently, building design factors such as building material, building orientation in a site, areas based on building shape, window orientation, and energy performance of wall, window, and door affect total energy consumption generated by building material process and building operational use. Moreover, these components of building are important factors that should be considered for neighbourhood design.

3.1.3 The relationship between Energy and LCA for GHG emission

Total GHG emission from the energy use of building can be analysed through Life Cycle Assessment. Life cycle assessment (LCA) is used as a tool to quantify the environmental impact of material or product from the cradle to the gate on the basis of a functional unit (Nuss & Eckelman, 2014). In this thesis, global warming impact – CO2 equivalent emissions generated by energy process for building operation from energy production to energy consumption – is quantified according to the indicators that is focused in ZEN.

In the starting point of LCA, it is important to define a functional unit and system boundary because the functional unit indicates the goal of the assessment while system boundary identifies what scope the assessment will be covered in (Smith & Nephew, 2013).

Total GHG emissions is calculated with a unit, kg of CO2 equivalence as the concentration of radiative forcing over period time compared with that of CO2 (Change, 2007). However, the energy in building or neighourhood scale is used in the various forms such as electricity or thermal energy with different units. Fortunately, the energy can be quantified with a unit – kWh or Wh as the definition of a composite unit of energy equivalent to one kilowatt of power sustained for one hour.

Futthermore, the amount of GHG emission per a unit of building materials can be calculated through the EPD (Environmental Product Declaration) and Ecoinvent database. This study defines the functional unit as “kg” for building materials and “kWh” for operational energy use to calculate total GHG emissions for aggregated energy use, which means that LCA will be conducted for the life cycle of buildings or neighbourhood based on LCA data for kg_{CO2eq}/kg and kg_{CO2eq}/kWh for embodied energy and operational energy use, respectively.

The system boundary for the life cycle phases is defined in accordance with the life cycle modularity principle in NS-EN 15978 and prNS 3720 (Table 3.1) where embodied energy for building materials is involved in Product stage (A1-A3), and energy use for maintaining indoor temperature is addressed in Operational energy use (B6) of Use stage (B1-B7). In LCA, total GHG emissions include indirect emissions as well as direct emissions. “Direct GHG emissions are those taking place directly from a source as consequence of an activity resulting in the GHG emissions while indirect emissions are those occurring through indirect pathways.” (Marianne et al., 2018) In the perspective of life cycle stage, the stage for the analysis of direct emissions can be addressed in Product stage (A1-A3) and Operational energy use (B6) while the stage for indirect emissions can be addressed over most life cycle stages of the system boundary - Product stage (A1-A3), Construction stage (A4-A5), Use stage (B1-B7), and End of life stage (C1-C4).

Life cycle assessment is a technique to assess environmental impacts for a product over its holistic life from extraction of raw material to disposal or recycling (Nuss & Eckelman, 2014). LCA is carried out to improve product process and provide decision-making regarding environmental impacts.
The ZEN system boundary for the life cycle phases is defined in accordance with the life cycle modularity principle in NS-EN 15978 and prNS 3720. In the ZEN research centre, the whole life cycle is reported from extraction of raw materials, production, transport, installation, use, maintenance, repair, replacement, energy during operation, water during operation, transport during operation, deconstruction, waste treatment, reuse, recovery and end use of waste in a circular economy according to NS-EN 15987.

Module	A1-A3			A4-A5		B1-B7							C1-C4				D
Life cycle stages	Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction - installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/ demolition	Transport	Waste processing	Disposal	Reuse, recovery, and recycling potential
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Table 3.1 Life cycle modules (NS-EN 15978)

Considering life cycle stages, Life Cycle Inventories (LCIs) are determined and addressed in the energy production flow to analyse the impact over the supply chain. LCI data is mainly available from existing information such as EPD and Ecoinvent data. If LCI data do not exist, data can be acquired by direct research or by integrating existing information (Nuss & Eckelman, 2014).

The energy sources of building operating to maintain indoor environment comfort mainly come from electricity, district energy, or both. In Norway, most electricity production is generated from hydropower. In 2017, roughly 149 TWh was produced in total electricity, of which 143 TWh is preoccupied in hydropower, 2.1 and 0.2 TWh are produced by wind power and biofuels, respectively.

Fossil thermal energy was used to product 3.2 TWh (NVE, 2018). When it comes to Nidarvoll Skole in Trondheim as a case study (Chapter 6), district hot water generated by residual waste source is used as main heating source. The residue waste as a main load was used to generate about 490,000 MWh (76.9%) in total 640,000 MWh. The other resources that generate hot water were fossil gas, electricity, bioenergy, ambient heat, and fossil oil, which accounted for 9.7%, 9.0%, 3.3%, 0.5%, and 0.4%, respectively in 2017 (Statkraft, 2018).

Based on local properties of the case study (Chapter 6), the LCA for this study, in order to make simple calculation for total GHG emission, assumes that all energy consumption for heating comes from district hot water while cooling, lighting, appliance and ventilation except for heating are operated by electricity.

The conceptual LCI flow analysis for the energy supply system considering the functional unit and system boundary is shown in the Figure 3.5.

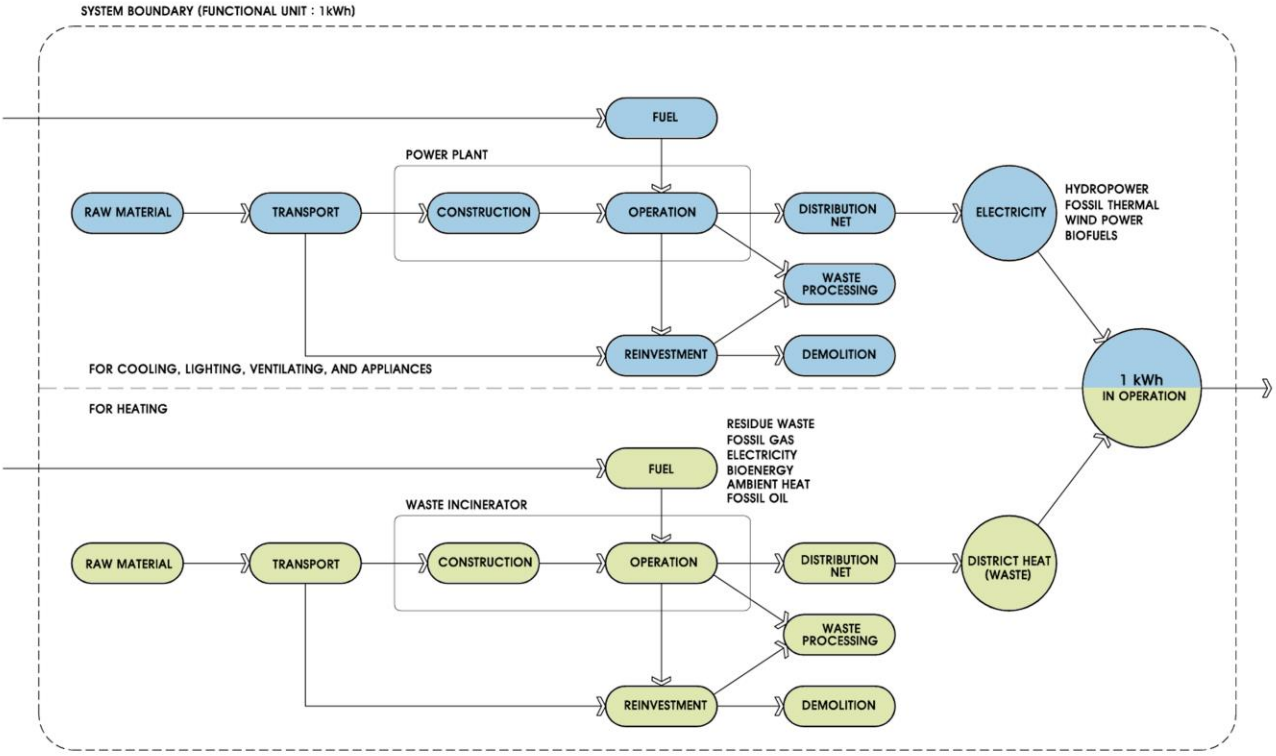


Figure 3.4 The conceptual LCA of the energy supply system

Through the LCA methodology, GHG emissions from energy use in Operational stage will be calculated as CO2 equivalent emissions for a functional unit, 1 kWh, and consequently, total GHG emissions will be outputted as 'tCO2eq/m2 outdoor space (BAU)/yr' over a neighbourhood's reference study period of 100 years or 'kgCO2eq/m2 heated floor area (BRA)/yr' over a building's reference study period of 60 years according to the ZEN KPIs for the GHG emission category.

3.2 Qualitative Assessment

Based on the analysis of assessment criteria (Chapter 2.3), the assessment categories carried out in neighbourhood level are mainly mobility and spatial quality. As a qualitative methodology, this chapter explain how these categories can be evaluated regarding GHG emission reduction, and how they are related with neighbourhood design.

3.2.1 Mobility

In the perspective of architectural works, the assessment of mobility should be defined as the relationship between neighbourhood design and mobility.

In an effective strategy to reduce GHG emissions, the reduction of vehicle travel miles is a crucial issue since vehicle travel leads to the fuel use which generates greenhouse gases. Public transport promotes the reduction of the travel miles. In the case of the U.S., it is reported that households with two private cars can reduce 30% of household GHG emissions by eliminating a car and using public transportation. (APTA, 2008)

The use of public transportation reduces traffic congestion. The congested travel can lead to fuel consumption without traveling, thus public transportation encourages automobiles traveling to achieve better fuel efficiency in the same road.

In the relationship with neighbourhood design, accessibility between buildings and public transportation can be a key to promote the use of public transportation since the accessibility improves the usability of public transportation. The ZEN research centre defines ‘access to public transport’ as an assessment criterion and KPI to assess neighbourhood performance regarding GHG emissions. The aim of the criterion in the ZEN is to ‘ensure the availability of frequent and convenient public transport as a low-carbon choice’. (Marianne et al., 2018) The assessment methodology is based on BREEAM Communities technical manual. The technical manual as a qualitative assessment tool evaluates the accessibility with BREEM credit marked according to the distance between building entrance and transport node. The credit has compliances that define the distance measuring and transport node. It is shown as Table 3.2. (BREEAM, 2012)

Credits	Distances (urban)	Distances (rural)
1	≤650m	≤1300m
2	≤550m	≤1100m
3	≤450m	≤900m
4	≤350m	≤700m

Table 3.2 BREEAM credit for access to public transport (BREEAM, 2012)

Well-organised parking area distribution also helps to improve the fuel efficiency of automobiles. Along with traffic congestion, the absence of parking area leads to the fuel consumption without moving due to the waiting on the road. Furthermore, it aggravates the congestion led by stop on the road. In neighbourhood design, parking lot planning which can be interconnected with other parking area is a criterion to assess the neighbourhood mobility performance.

Moreover, the promotion of eco-friendly mobile is important criterion for the reduction of greenhouse gases. The neighbourhood design that considers bicycle route, bicycle parking lot, and electric vehicles (EV) parking lot can reduce the use of automobiles operated by fossil fuel, thus reducing GHG emissions.

In the perspective of neighbourhood design by architects, the access to public transport, parking area distribution, and the promotion of eco-friendly mobile are important assessment criteria for GHG emission reduction. Moreover, they can be evaluated by quantitative assessment tool such as the BREEAM credit.

3.2.2 Spatial Quality

The main aim of the spatial quality assessment is to ensure eco-friendly lifestyle and environments in line with the user demand. In neighbourhoods, residents travel elsewhere according to their needs. If a neighbourhood environment cannot satisfy the residents, they would travel to other environments in order to seek their needs. The travel miles and frequency affect the energy consumption such as transport uses. By improving the value of spatial quality in neighbourhoods, the travel of residents can be reduced, thus the high spatial quality can reduce neighbourhood energy and GHG emissions.

Based on the ZEN assessment criteria and KPIs and their definitions (Marianne et al., 2018), we can find how the assessment criteria can be evaluated in the perspective of neighbourhood design. The ZEN research centre defines the core elements in the selection of the assessment criteria: user demand, amenities, and public space. (Marianne et al., 2018)

User demand can be analysed by a demographic analysis since user trends and backgrounds reflect the needs, ideas, and knowledge. The demographic profiles include information regarding age, gender, cultural background, household information, population, employment, income, educational attainment, and health. In the perspective of neighbourhood design, the demographic information can be analysed with visual graph such as bar, table, pie graph.

In a neighbourhood, Amenities are a key factor to assess the liveability for neighbourhood occupants and the life quality. The ZEN assessment criteria regarding amenities are divided into 'delivery of amenities', 'proximity to amenities', and 'localisation of amenities'. These criteria can be evaluated as the accessibility between buildings and amenities and the number of amenities. Accordingly, these criteria can be shown as the metric or BREEAM credit (Chapter 3.2.1) and the distribution for the assessment methods.

Public space is one of the key dimensions to assess spatial quality in neighbourhood. Public space plays an important role in the social interaction since it encourages people to communicate together, to make activities, and to enjoy leisure. In neighbourhood design, public space can be analysed and assessed with the distribution.

In the perspective of neighbourhood design, demographic, amenities, and public space can be analysed and evaluated by using visual information such as graph and distribution in a map.

4 Current Dashboard Review

This chapter researches current dashboards that are used to calculate GHG emissions and energy efficiency in building scale as the small-neighbourhood, and web-based platforms that provide with information regarding mobility and spatial quality - defined in Chapter 3.2.1 and 3.2.2 – in neighbourhood scale as the large-neighbourhood.

Based on EU climate change goal, integrated planning tools have been developed for emission reduction in urban planning and building design process. The urban and building planning around neighbourhood are implemented with the collaboration and cooperation of various experts in different industrial sectors. However, it is not easy to integrate their technical knowledge and to organise their criteria toward a united goal since they use different technical methodologies. The state-of-the art tools have made efforts to integrate different technologies for emission reduction and energy performance improvement in order to overcome communication challenges between different experts. The dashboard review exemplifies the characteristics of the tools.

The main purpose of this chapter is to find what strategies the existing tools have for dealing with the challenge of the communication among stakeholders and to find how the tools in the different scales are differentiated in the perspective of visualisation and evaluation contents to acquire inspirations for improved dashboard design.

This Chapter analyses the background data flow between the current tools and their supporting tools and identifies the characteristics of the tools based on strengths, weaknesses, opportunities, and threats (SWOT) analysis. Based on the review of the current tools, this chapter also shows the development strategy of ZEN Dashboard for neighbourhood design.

4.1 Dashboard in Building Scale

Architectural works use visual software for architectural design. Current visual tools integrate energy simulation with the design function. Sketch-up and Autodesk Revit as representative tools for architectural design have been extended by connecting them with Sefaira and Insight360, respectively to measure energy performance of building designs.

Meanwhile, the tools for greenhouse gas assessment have been mainly developed at research institutions that enable more specialized and detailed analysis. A typical example is Integrated Excel tool of the ZEN research centre.

4.1.1 Sefaira

Sefaira is a web-based commercial tool to provide simulations regarding energy performance and sunlight condition in the operational use phase of a building or a cluster of buildings.

Sefaira is plugged in Sketch-up which is a design tool that can promptly make 3D models of buildings. It is proper to design the building mass in early analysis of building size, building orientation on site, and building façade. Sefaira uses EnergyPlus to calculate energy performance of the building designed as a basic engine for building energy simulation. EnergyPlus performs the simulation of building energy use in detail considering defined HVAC system and electric power.

Sefaira accepts building envelope information of Sketch-up modelling and delivers the data to EnergyPlus with defined energy demands for building operation in the dashboard of Sefaira. The performance from EnergyPlus is displayed in the web-platform of the tool as a user-friendly interface.

Energy analysis is quickly performed with simple massing design from Sketch-up with its powerful compatibility. As well as Sketch-up, the tool can be plugged in Revit tool which is suitable for detailed design of architectural works, which means that it can use both Sketch-up and Revit as 3D model information which means that energy analysis can be performed from rough massing design to building model that has detailed material information.

Moreover, understandable visualisation and UI design for architects with simple icons and graphic information is another competitiveness of this tool

It provides extra guidelines for effective energy-saving design, linked to other website related with the energy-saving design, which has possibility to expand information that this tool needs so that Sefaira can play a role on a platform where various information is shared.

As a commercial tool, it has a challenge to be used for extensive projects as non-commercial studies such as educational purpose or research.

Dashboard will use Sefaira as a basic tool for energy efficiency analysis since it has a strong point to be able to calculate energy performance promptly and have high compatibility with Sketch-up that can generate architectural modelling simply and rapidly for the application of various mock-up tests.

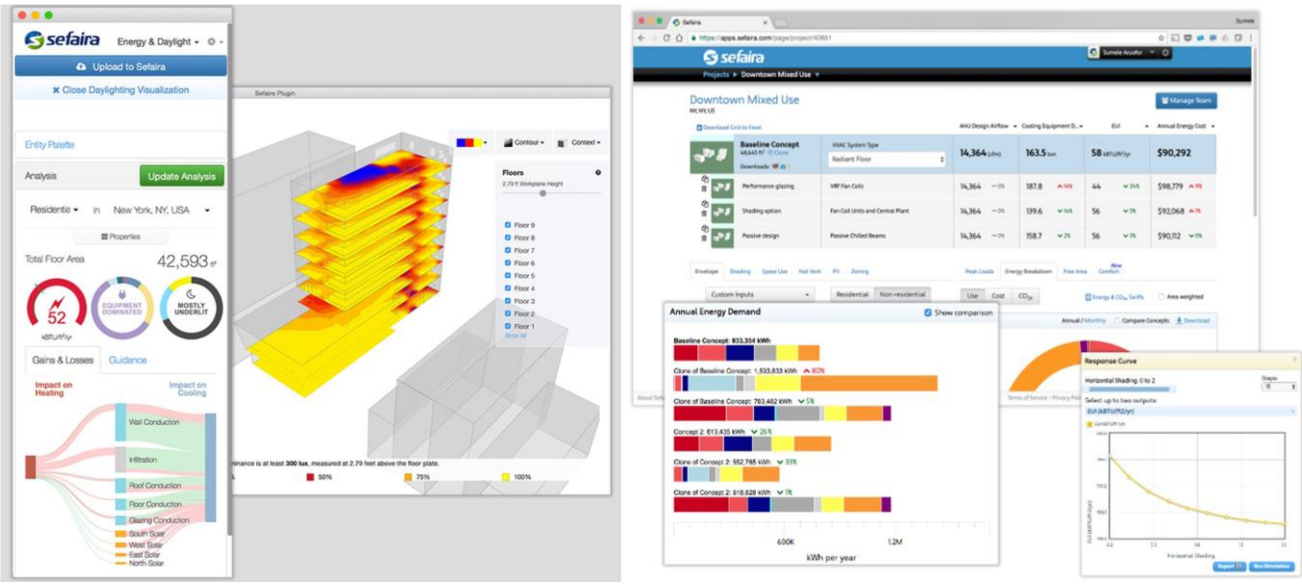


Figure 4.1 Screenshot of Sefaira dashboard

4.1.2 Insight360

This tool is web-based tool to provide simulation information for energy performance and daylight analysis in operational use phase of building.

Main data flow is run via Autodesk Revit, and EnergyPlus. Insight360 uses 3D model information from Revit software which is one of the representative BIM (Building Information Modelling) tool. It employs EnergyPlus as a major energy analysis engine. Insight360 delivers information related with the calculation of energy performance from Revit to EnergyPlus and then shows the result from EnergyPlus as optional parameters with visualisation that architects can understand.

Since Revit can be used from early design to detail design phase of architectural works, the users can acquire energy performance information in various phases of architectural works. Most data required in the calculation of energy performance is included in Revit data so that it requires less input data by using information defined in Revit.
Moreover, it shows easy-understanding visualisation and UI to provide simplified parameters associated with energy performance, such as building orientation, envelope performance, and HVAC system.

There are limited options that users can choose in HVAC system and material information related with thermal transmission coefficient.

Insight360 provides free version tool for educational purpose so that it can be utilised in various project for academic studies.

The compatibility with Revit software can exaggerate the competitiveness against other tools due to the poor processing speed of Revit tool.

Insight360 has well-organised parameters related with energy performance. Since users can understand what factors in building design have relevance with energy efficiency, Dashboard in the thesis will mainly adopt the parameters in Input window of the Dashboard (Chapter 5.2.1).

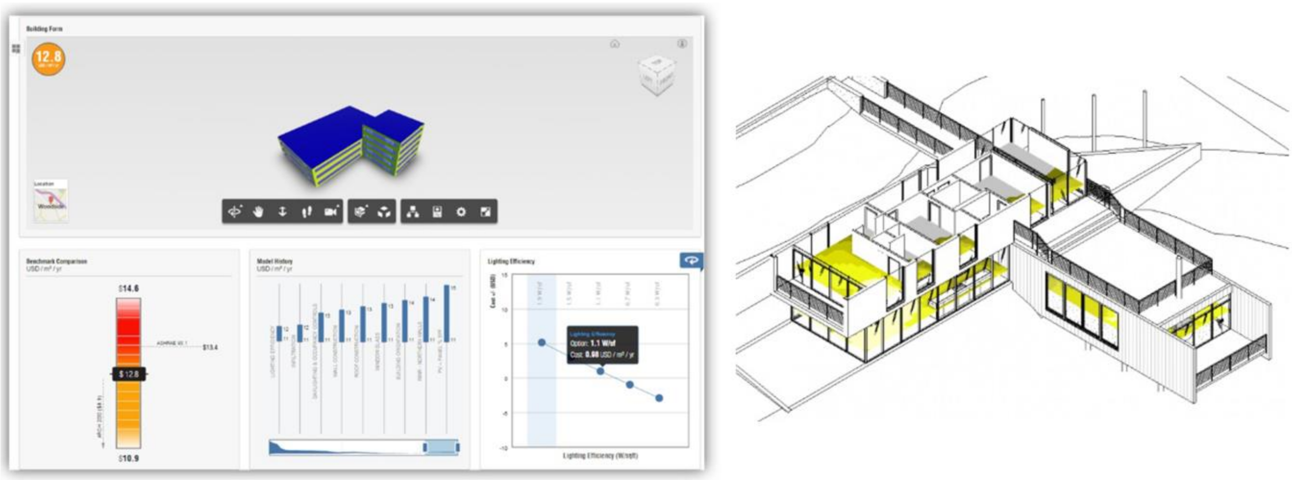


Figure 4.2 Screenshot of Insight360 dashboard

4.1.3 ZEB Excel Tool

ZEB Excel Tool had been developed in ZEB research as a tool to calculate GHG emission from embodied energy of building materials in their own product life cycle from raw material to disposal.

ZEB Excel Tool utilises spreadsheets of Microsoft Excel to arrange database and calculate emission data. Based on LCA methodology, building lifetime and functional unit are defined, and Environmental Product Declarations (EPD) data and Ecoinvent database of building materials are collected into the tool

EPD data as a verified document includes emission intensity for functional unit in accordance with system boundary defined in NS-EN 15978:2011. Ecoinvent as LCI database provides process data for industrial products or materials with their environmental impacts. This tool has various categories defined by building elements to gather EPD and Ecoinvent database and to arrange the database. The collected data is estimated by quantifying the amount of material from early building design in ZEB Excel Tool.

It has a classification system according to building elements, which help architects as the users to collect and manage their material data. It also has the other classification system according to material life cycle. Thus, users can calculate the embodied emission of materials in each life cycle stage.

It is not easy for beginner to use this tool. ZEB Excel tool has two different classification systems. One is based on architectural knowledge while the other is based on life cycle assessment. It is only proper for those who have knowledge regarding both fields.

It is easy to have compatibility with other tools. This tool is oriented in Excel tool which has high compatibility with other applications. Thus, it has high possibility to interconnect with other design tools, calculation tools, and management tools.

EPD and Ecoinvent data in this tool were inputted in manual without real-time interaction with EPD or Ecoinvent system. The data is required to update regularly.

Along with emissions from energy use in building, the portion of embodied emission from materials of building is significant in total GHG emissions. Thus, the ZEN Dashboard will incorporate ZEB Excel Tool to calculate embodied emissions from building materials or elements.

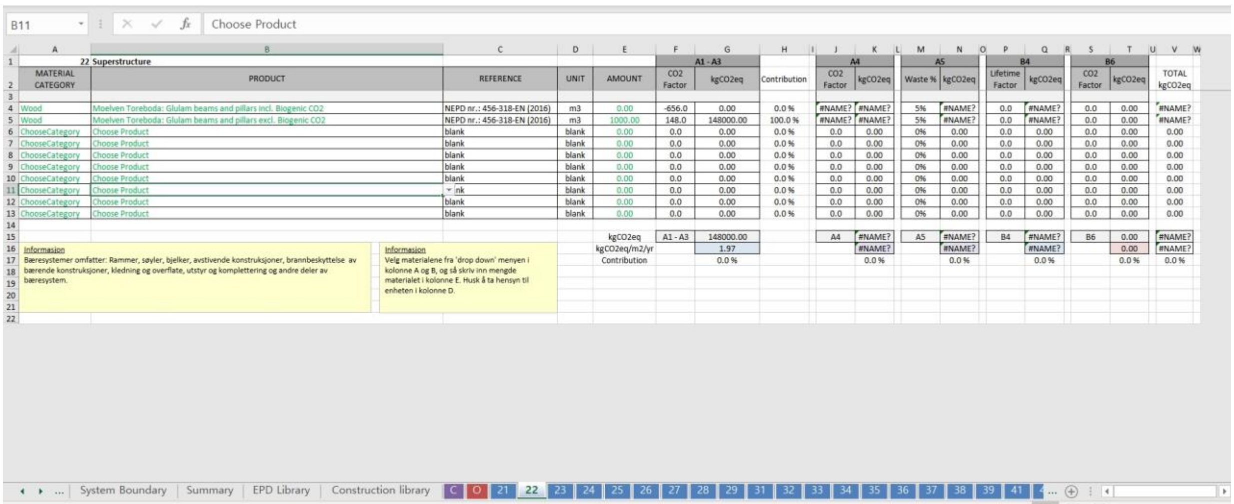


Figure 4.3 Screenshot of ZEB Excel tool

4.2 Dashboard in Neighbourhood scale

Currently, Web-based platform for various stakeholders has been developed as a tool for urban planning. Urban planning for energy and climate-gas reduction requires the participation of stakeholders in various sectors such as government, urban planner, architect, energy supplier, and even citizen. It also needs a great deal of database all over neighbourhood or urban information related with the environmental impact. Unfortunately, it is not easy to gather the data and to digitalise the information. In line with the challenge, the tools for urban planning are not perfect yet. They will be improved and be dealt with as long-term projects.

4.2.1 CityBES

CityBES is a kind of web-based platform to show building energy performance and operational GHG emission intensity of each building in urban scale. The main purpose of the platform is to analyse the potential retrofit of city buildings with provisions of benchmarking analysis, urban energy planning, and building operations by supporting 3D building models. (Chen et al.,2017)

It uses CityGML to generate 3D building information. CityGML is a data format to provide virtual 3D city and landscape model. CityBES is based on CBES (the Commercial Building Energy Saver Toolkit) which provides energy analysis for independent commercial buildings such as offices and retails. CBES uses EnergyPlus for energy simulation of existing buildings. Building energy data calculated by EnergyPlus is delivered to CBES. Information of Commercial building performance in CBES is represented on CityBES with CityGML, where the urban energy performance is visualised with colour code and graphs.

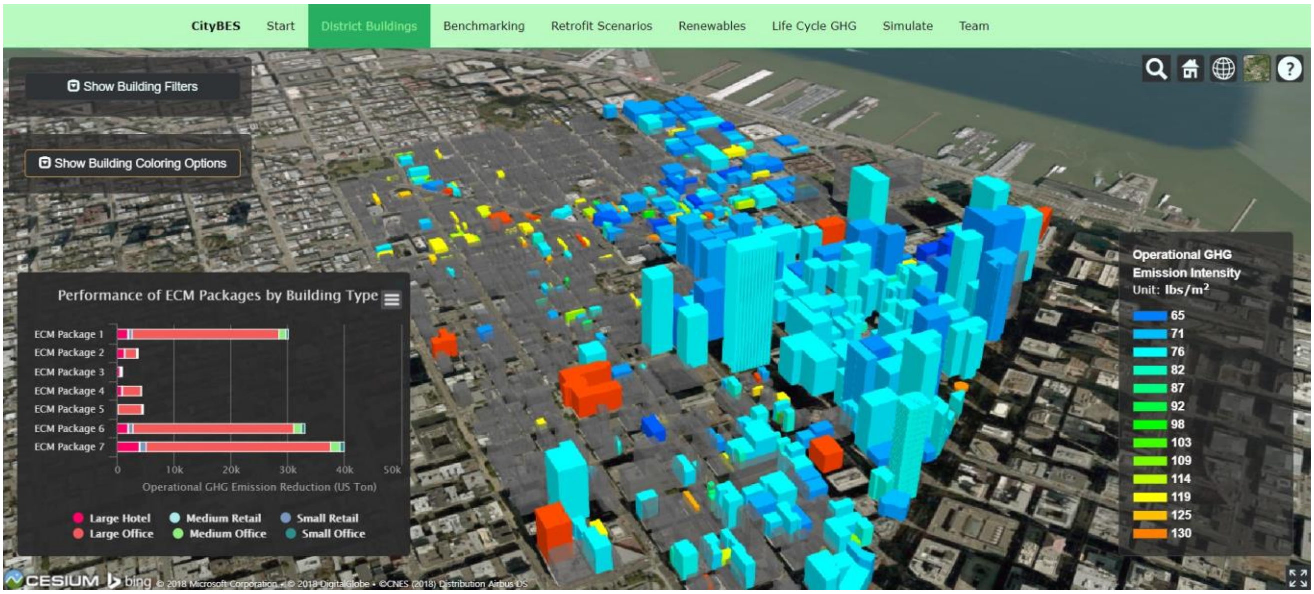


Figure 4.4 Screenshot of CityBES Platform

By using virtual 3D modelled and colour-coded information, users can easily understand the hierarchical relationship among urban buildings. The platform provides ECM (Energy Conversation Measure) package which can define retrofit conditions to enable to make comparable urban strategies.

There is a limitation to choose the option of building type since it is focused on commercial buildings.

CityBES is playing role on a frontier to analyse integrated energy performance in urban scale. This tool can be easily extended to include urban information by sharing studies and open data strategy in the platform, which means it has powerful competitiveness.

The calculation of integrated energy performance in urban scale, as an opportunity, can be conversely a threat to have heavy burden in the computer processing capability. (Chen et al.,2017)

CityBES has well-organised categories according to its purpose – retrofit simulation, benchmarking, urban energy planning, and building energy performance. The sub-categories in building energy performance - divided into 2 parts, building types and evaluation indicators - will be referred to the building efficiency part of Dashboard. Due to the practical problem from computing capability for city-scaled energy integration, Dashboard will consider efficient evaluation methodology in another way rather than the energy integration.

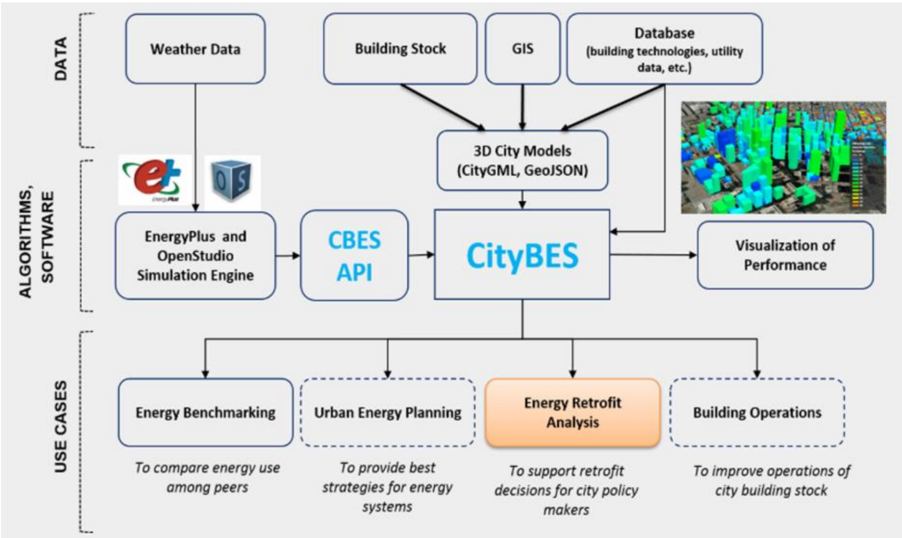


Figure 4.5 Data flow of CityBES (Chen et al.,2017)

4.2.2 OEIRAS E-CITY

It is web-based platform to provide 2D visual information focusing on the spatial quality of Oeiras municipality in Portugal. The main purpose of this platform is to improve integrated use of spatial information for sustainable development. (Amado et al., 2018)

The platform is based on WebGIS (Geographic Information System) which consists of three parts : database server, application server, and file server (Amado et al., 2018). Data of file server delivers to application server where geographic data is interoperated with mapping software, and then the integrated information is managed in database server. The platform visualises the responses from user requests on the web browsers.

Each colour-coded module as a spatial domain encourages users to easily understand the spatial properties for energy performance.

It only concentrates on energy grid information such as electricity and natural gas. It is not enough to analyse spatial quality in practical works.

The web platform shows the possibility to overcome the limitation of building information by visualising the relationship among neighbour domains rather than that of buildings.

Without user-based controller, it tends to show given information. In the real making-decision process, it is less likely to motivate the participation of stakeholders.

By showing the relationship between energy demand and supply in each city block, the platform proves that entire energy balance of a city is one of the most important purposes which a ZEN tool can have. It is a significant motivation to be able to apply to Dashboard in regard to how each building performance can be used in energy strategies of neighbourhood.

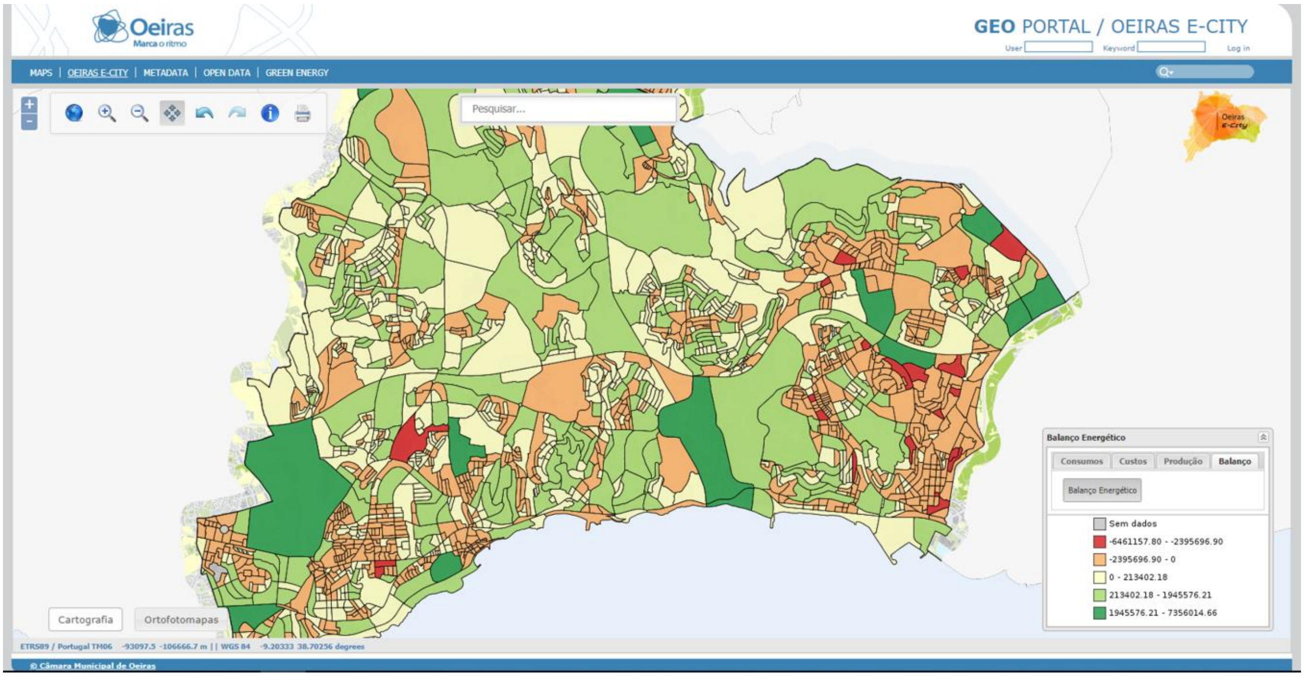


Figure 4.6 Screenshot of Oeiras Platform

4.2.3 Sustainability Dashboard

In 2008, Surrey city in England approved the Sustainability Charter 1.0 to improve urban sustainability with three core themes: economic, environmental, and socio-culture. Sustainability Dashboard as an outcome of Charter 2.0 is developed on Charter 1.0, where the updated Charter has main eight community themes based on core three themes: inclusion, built environment and neighbourhoods, public safety, economic prosperity and livelihoods, ecosystems, education and culture, health and wellness, and infrastructure.

Sustainability Dashboard manages and presents the outcomes of each theme to achieve the sustainability as a long-term goal.

Interestingly, main workflow is performed by surveys and interviews according to the goal of each theme. Internally, city council staff, city management team and administrators are directly engaged in the data source updates including consulting and interview. Externally, community of each theme establishes the relationship and interconnection of the themes through stakeholder workshops. Citizens are also engaged in the update of the dashboard through speech and social media. The direct information and survey are organised to documentation and presentation on the platform.

In the perspective of approach to the city issues, this platform considers comprehensive relationships among various theme to achieve the goal.

It is a well-organised system toward main issues: each theme has its own organisation with explicit guidelines and continuously updated documents.

When it comes to the visualisation, excessive textual expressions can make it difficult for non-experts to use the dashboard.

It is expected that the capability to gather well-organized information over a long period of time ensures strong competitiveness of this dashboard.

Main themes and sub-categories are specialised and focused on the issues of the city. It is challengeable to apply to other cities or expand to wider boundary from the city.

The platform includes how demographic information is related with spatial and environmental quality. Dashboard of the paper will refer to the platform in regard to the relationship between demographic indicators and spatial quality of ZEN definition.

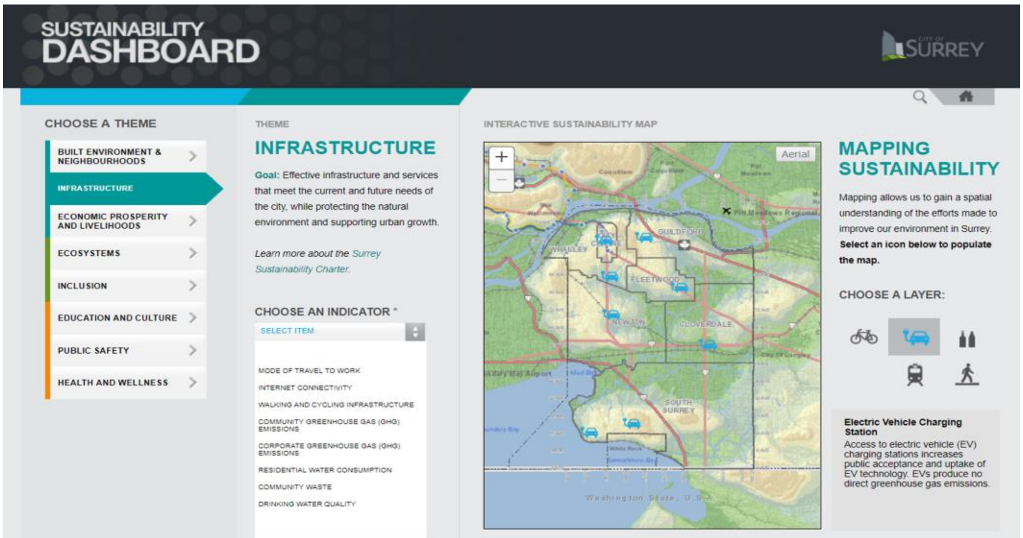


Figure 4.7 Screenshot of Sustainability Platform

4.2.4 City in Flux

This platform visualises the relationship between mobility network and demographic information in Cape town of South Africa. The tool was developed at a design course of University of Applied Sciences Potsdam.

City in Flux is mainly based on two data sources : mobility data given by 'WhereIsMyTransport' which is a web service to provide the analysis of city transport patterns, and given by 'Statistics South Africa'. The background of the mobility data is divided into main two transport modes, taxi and bus, linearized to each route of the public transportations. Demographic data such as education, income, diversity, and housing, is analysed on the line of transportation routes.

It has user-centred visualisation and information process: It consists of three parts of the dashboard. Overview as a part of the dashboard provides all routes of transportation mapping it over the city map, which can help users understand what type of transportation modes the city has and how the transportation is spread over the city. The detail view part shows the user demographic information around the stations on the route of each transportation. Users can figure out the difference situations and gap of the level of demographic in each station through the relative graphic visualisation. Stories as the last part of this tool supports to establish new strategies or retrofit planning by providing current information - pictures, articles, and video scripts - around the selected station and route.

The demographic information consists of main four categories: Education, Income, Diversity, and Housing. However, the information is not enough to make effective strategies for the development of Cape town. For example, when making a plan to build a new facility, it is important to figure out the age distribution and cultural context around a selected station in order to understand what the occupants want, but the platform does not have the information. Moreover, providing only relative evaluation of each category can make stakeholders struggle to establish new plan in detail.

The platform shows the relationship between transportation route and demographic statements in an urban area, which provides a motivation to know how demographic information can be applied to the approach to deal with social issue, and to visualise it.

The platform provides the analysis for given information without interaction with users or information created by user. It can be less potential for the platform to have a scalability for database and the improvement of the dashboard.

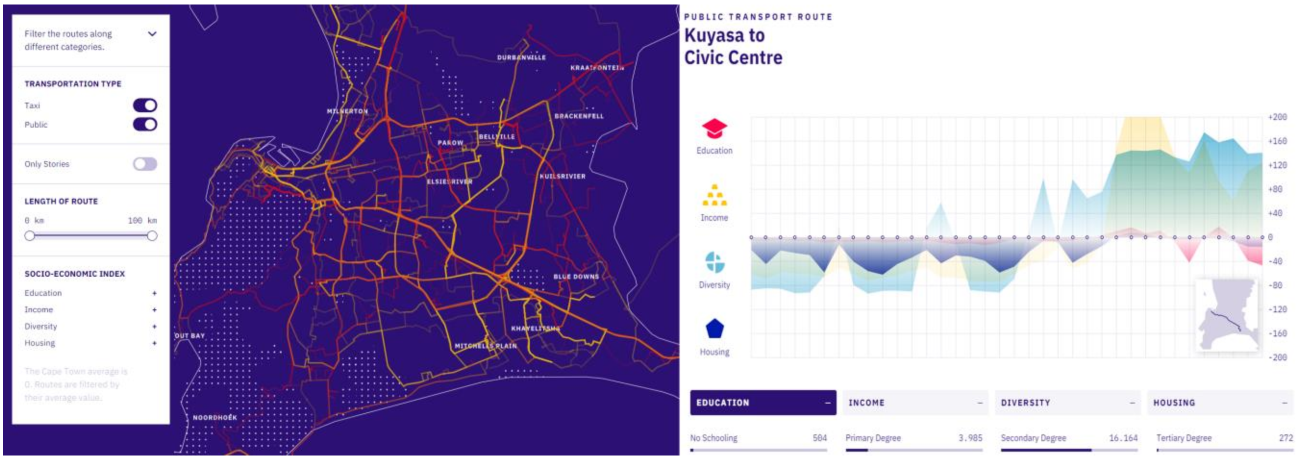


Figure 4.8 Screenshot of City in Flux Platform

This platform represents the relationship between demographic information and public transportation routes with its clear concept of the toolbox. The concept-based visualisation can be applied to other indicators for zero emission neighbourhood beyond the public transportation route. ZEN Dashboard has a layered display concept in the large-neighbourhood platform, where demographic information can be over-rapped on the information of mobility and spatial quality related with ZEN KPIs. It is to analyse the relationship between demographic and ZEN KPIs even though the indicator of demographic information independently exists in the platform.

4.3 Analysis of Current Dashboard

a. What strategies do the tools have for dealing with the challenge of the communication among stakeholders?

Toolbox for the building level mainly requires the information related with engineering as well as life cycle inventory. In order to use Sefaira and Insight360, it is required to define mechanical and electric engineering information to calculate energy use and energy efficiency. However, it is not easy for architects to understand such technical information for engineering. These tools basically include the technology to convert architectural design factors to the variables that affect energy performance. Through Energyplus engine, energy performance is output from architectural information. However, the output is not also understandable for architects so that the tools provide visual information for the results, which users can understand, by using graph or architectural language. Moreover, these tools support users to define engineering conditions for building energy use by providing available scope of the equipment options. EnergyPlus and UI of the tools are core strategies that can communicate with other stakeholders. In case of ZEB Excel tool, information for life cycle assessment is required in architectural elements. This tool help architects understand what information is required for GHG emission calculation by categorising information of life cycle inventory to architectural elements. The building-scaled tools consider communicating with mechanical, electric engineers, and environmental analysists and have the strategy that architects as a user enable to make easy understanding.

The tools for the neighbourhood scale provide a platform to have communications among stakeholders. CityBES and E-CITY give stakeholders such as urban planner, policy maker, energy distributor, and architecture team ‘discussion place’ for urban energy strategies by showing the distribution of building energy efficiency, energy balance. Sustainability Dashboard provides the the evaluation of spatial quality, practical needs, demographic statement through the research targeting city manager and citizen. In case of City in Flux, the relationship between the route of transportation and demographic information is visualised for urban planner and stakeholder associated with transportation. The neighbourhood-scaled tools have the strategy where various stakeholders can share information and deal with common issues in a map-based platform.

b. How are the tools in the different scales differentiated in the perspective of visualisation and evaluation contents?

The tools in building scale are based on their software. Sefaira supports Sketch-up software while Insight360 has Autodesk Revit as its host software. ZEB Excel tool is based on Microsoft Excel. The tools for energy evaluation and emission calculation plays a role as a supporter to help main design tool or emission analysis tool.

On the other hand, the tools in neighbourhood scale are based on a platform role to gather various perspective information with effective visual methods. CityBES collects 3D building modelling with energy use level of different building hierarchy. E-CITY provides 2D domain boundary to illustrate the distribution of energy balance. Sustainability Dashboard and City in Flux shows infographic and linear graphic, respectively to provide stakeholders with effective information. The tools visualise their data in common language for various stakeholders.

c. Inspiration in the macro perspective

The evaluation of GHG emission and energy performance requires various process of the calculation and analysis, and it also needs the collaboration with stakeholders that have different perspectives. In order to include various evaluation processes, an improved dashboard is required to have the flexible platform to accept various tools for total calculation and evaluation. Sefaira plugged in Sketch-up is suitable for the conceptual design while Insight360 plugged in Revit is proper to the early design and detailed design phase. If ZEN Dashboard accepts the compatibility with both Sketch-up and Revit, it could implement the evaluation of operational energy use in more extensive design phases.

The tools in different scales have different methodologies and strategies for the issue of energy and greenhouse-gas emission. ZEN Dashboard as a total platform dealing with both different scales needs to be separated into main two dashboards in order to the effective neighbourhood assessment.

5 ZEN Dashboard

Since the project work regarding dashboard for operational energy use of ZEN boundary in fall semester in 2018, the concept and design for Dashboard - it named as ZEN Dashboard - have been developed and expanded in the scope of the neighbourhood assessment based on ZEN KPIs in this thesis.

In the building scale, the evaluation of embodied emissions generated by building material is added with the impact of building energy operation. In the building operational phase, the energy balance is additionally evaluated with the calculation of self-electricity generated by photovoltaic panel. Besides the evaluation of building and a cluster of building in neighbourhood, the evaluation scope of ZEN Dashboard was developed toward wider scope of neighbourhood and urban scale.

This chapter describes the concept of ZEN Dashboard design and illustrates the design of ZEN Dashboard as a conceptual design to be able to evaluate ZEN KPIs that defined in the study based on architectural works and decisions. Furthermore, it shows the background software that can deliver information and calculate data for the successful decision-making among stakeholders to achieve the zero emission neighbourhoods.

ZEN Dashboard as a conceptual UI (User Interface) design does not consider actual interconnection between the software in this paper. Dashboard as a platform suggests the possibility for the integration among software, computing tools, or web-based database.

5.1 Design concept

According to two different methodologies to deal with GHG emissions in neighbourhoods (Chapter 3) and the strategies of current state-of- art tools (Chapter 4), the design concept of ZEN Dashboard is also divided into two main strategies in the perspective of small- and large-neighbourhood scale. Additionally, the integrative strategy between the different perspectives is described as the design concept.

5.1.1 Collaboration-workflow Strategy (in small-neighbourhood scale)

The early design phase is worked by a collaborative team that includes architects, mechanical engineers, and environment analysists. Architects create spaces for human activities setting up the design concept according to analysis for neighbourhood relationships around project site, and they design building shape, window orientation, wall condition, and room layout as well as building material planning. Space information such as room area, room volume, and building envelope is delivered to mechanical engineers. They analyse room conditions from information of architectural design, evaluate HVAC system, and calculate energy load in order to establish optimized indoor environments. Meanwhile, Environment analysts conduct LCA with building energy performance and HVAC system designed by engineers to evaluate environmental impact (Sterner, 2017). They also analyse embodied emission from building material information delivered by architects.

However, these team works have a tendency to be performed in one-way. When a part of information or design is changed in the workflow, the issue can lead to spend long time for modification and to consume a lot of energy to revise the current work in the other sector (Shi & Yang, 2013).

In order to deal with the problem of one-way workflow, ZEN Dashboard suggests 'collaborative sharing flow'. The dashboard enables expert team to share their ongoing works at the same time.

Unlike the one-way flow that delivers outcomes completed in a design stage, the dashboard as a platform which can encourage architectural design to incorporate the feedback suggested by engineers or analysts during design works by sharing information among architects, engineers, and analysists in one platform table. **(1)** in Figure 5.1

A dashboard shares basic information of each sector to make easy understanding for each other. By doing that, architects can make a design considering mechanical design concept while mechanical engineers can make equipment schedules considering the main approach of environment analysists. Environment analysist can also establish comparative LCA understanding the change of architectural or mechanical design. The basic information in this process should be expressed in easy technical language, especially a kind of language that architects can understand easily. **(2)** in Figure 5.1

This dashboard based on Revit software can make virtuous circle of information through feedback from operational phase. Revit is a representative BIM tool. Building information modelling (BIM) is a process that goes beyond the planning and design phase of the project, expanding throughout the building life cycle (Eadie et al., 2013). The outcomes performed by this dashboard in the early design phase can be maintained as a type of BIM information. The BIM information would be still used in the operational phase of ZEN work stages defined by ZEN assessment criteria and Key Performance Indicators (Marianne et al., 2018) Accordingly, the outcomes estimated from the dashboard in the early design phase can be assessed in the comparison with real outcomes generated in the operational phase. **(3)** in Figure 5.1

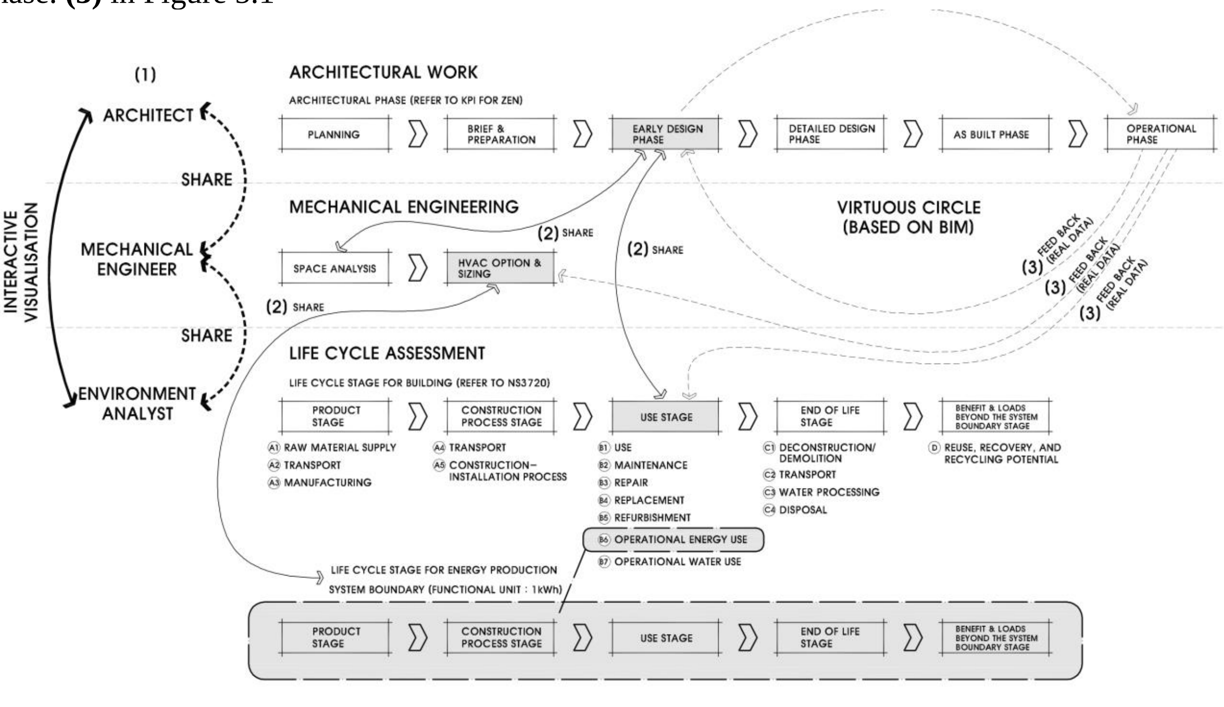


Table 5.1 Collaborative workflow and feedback concept (need to revise)

Collaboration in ‘BUILDING’ platform

The core idea of ‘BUILDING’ platform is the effective collaboration among different experts such as architects, engineers, and environment analysists sharing their own knowledges and information in order to achieve zero-emission neighbourhood. ‘BUILDING’ platform provides Input Table which can define the necessary information to calculate the energy performance and to analyse GHG emissions. In the Input Table, Architecture table defines the type, the area, and volume of the building, and U-value of the building envelope. Based on the information of Architecture table, in the

System table, the system and schedule of HVAC, lighting, and appliance efficiency are defined by mechanical and electric engineers. Based on the input data defined by architects and engineers, the amount of building energy demand is calculated. The energy demand is required in the calculation of GHG emission for building energy use with the carbon intensity of each energy source and the energy production flows analysed by environment experts.

In this process, the essential input information is shared among the stakeholders through the open data in Input Table. The shared information can help stakeholders in each sector understand the works and technical information of the other sectors. The design team which is consisted of various experts will be able to understand the work scope, process, and requirement of different fields in a common goal. Such collaboration in the early design stage with 'BUILDING' platform will reduce time, workload, and mistakes for the successful completion of the project.

5.1.2 Conversation-platform Strategy (in large-neighbourhood scale)

Based on the analysis of dashboard review (Chapter 4), the strategy of ZEN Dashboard in large-neighbourhood scale is to serve a platform for various stakeholders in order to discuss policy or planning in the same purpose.

It has well-organised categories, assessment criteria, and indicators based on KPIs developed in Chapter 2 in order to integrate different technologies among the stakeholders. The stakeholders for the categories of 'GHG EMISSIONS' and 'ENERGY EFFICIENCY' involve urban planners, municipal authorities, power suppliers, and architects. 'MOBILITY' is engaged by urban planners, municipal authorities, transportation planner, and architects. In addition, 'SPATIAL QUALITY' and 'DEMOGRAPHICS' categories are engaged by urban planners, municipal authorities, architects, and citizens. Thus, 'NEIGHBOURHOOD' platform will be a 'discussion' or 'policy making' place.

The ZEN Dashboard provides layered information in a map-based display. A map-based display can layer various information related with each indicator on a map. It helps analysing the comprehensive information. As a platform, it has the strategy that accepts to link various web-based information.

As a method to gather information related with a criterion or an indicator, the output from ZEN dashboard in small-neighbourhood scale can be used for a part of information in large neighbourhood-scaled dashboard. Again, the large neighbourhood-scaled dashboard can give small-neighbourhood key information in order to carry out master plan or site analysis in small-neighbourhood dashboard.

5.1.3 Integration Strategy (between the different scales)

Both Dashboards between macro and micro neighbourhood scale make the synergy for architectural works by sharing information of each platform.

Urban information around project site is the important condition for building planning and design. In large neighbourhood-scaled Dashboard, urban conditions such as infrastructure, accessibility to the site or from the site, and demographic surrounding are significant cues to develop building design for emission reduction. On the other hand, the quantitative assessment of building design for emission and energy performance in small neighbourhood-scaled dashboard is used as the information of urban emission and energy performance. An energy performance assessment for all buildings in the Dashboard of small-neighbourhood scale will be an important evidence to evaluate the urban energy performance distribution in Dashboard of the large-neighbourhood scale.

5.2 ZEN Dashboard design

ZEN Dashboard is mainly divided into two main platforms: 'BUILDING' as a small-neighbourhood scale and 'NEIGHBOURHOOD' as a large-neighbourhood scale. Additionally, it has 'PROJECT' platform where users can design modelling plugged in the tools such as Autodesk Revit and Sketch-up, as a role of the bridge to connect Dashboard with design tools.

Platform	NEIGHBOURHOOD	PROJECT	BUILDING
Scale	Large-Neighbourhood	-	Small-Neighbourhood
Contents of Dashboard	GHG EMISSIONS ENERGY EFFICIENCY MOBILITY SPATIAL QUALITY DEMOGRAPHICS	Sketch-up Autodesk Revit	MATERIALS OPERATIONAL ENERGY USE

Table 5.2 Main contents of Dashboard

The BUILDING platform performs quantitative assessments to calculate the amount of energy used in small neighbourhood (building or a cluster of buildings) and GHG emissions generated by the energy use. On the other hand, the NEIGHBOURHOOD platform plays a role on an information supporter for decision-making of stakeholders by providing qualitative assessments.

Design works in the project platform are analysed in the building platform while they can be developed through the neighbourhood platform considering information of the platform. The relationship between the platforms is simply shown in the cover of ZEN Dashboard.

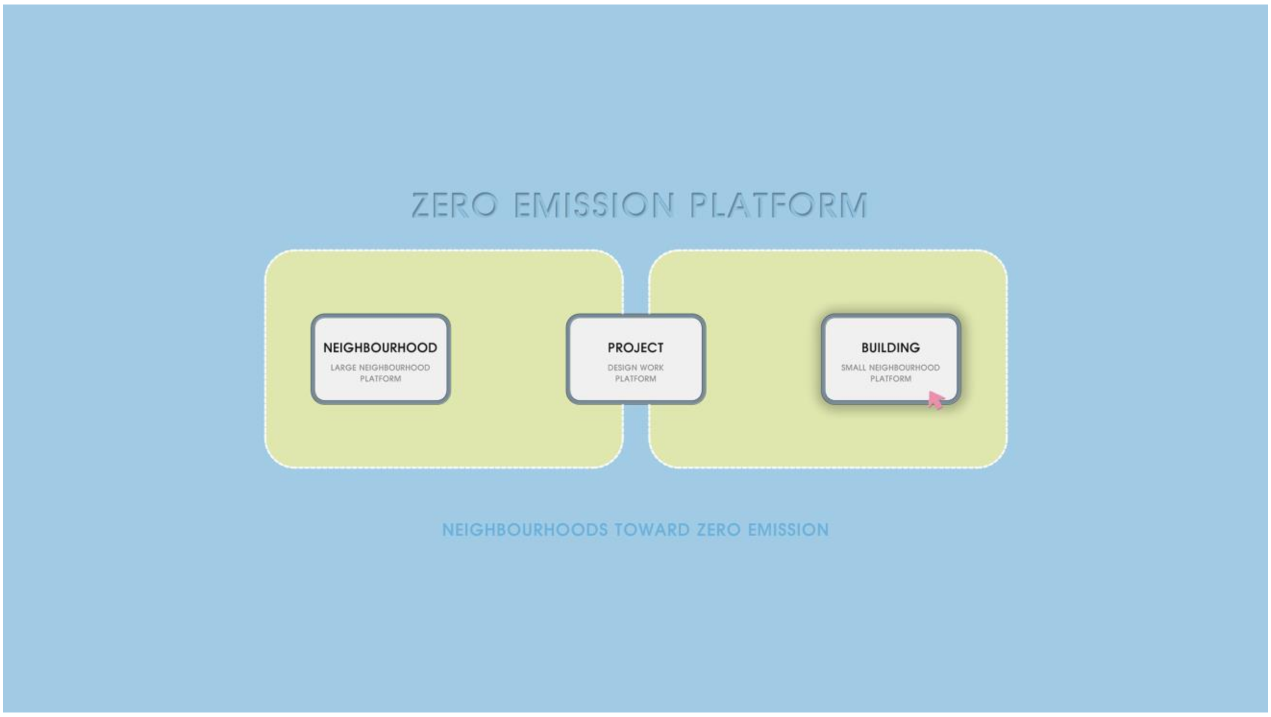


Figure 5.1 Main cover of ZEN Dashboard

5.2.1 Small Neighbourhood Platform

In ‘BUILDING’ as the small-neighbourhood platform, the main structure of the platform consists of Interaction, Input, and Output parts. The Interaction Window as the main controller exchanges information with Input Tables. The changes of information in the Interaction Window affect the outcomes in the Output Table while the Output Table supports design decision in the Interaction Window. Input Tables share information each other and provide data to the Output Table to calculate quantitative results.

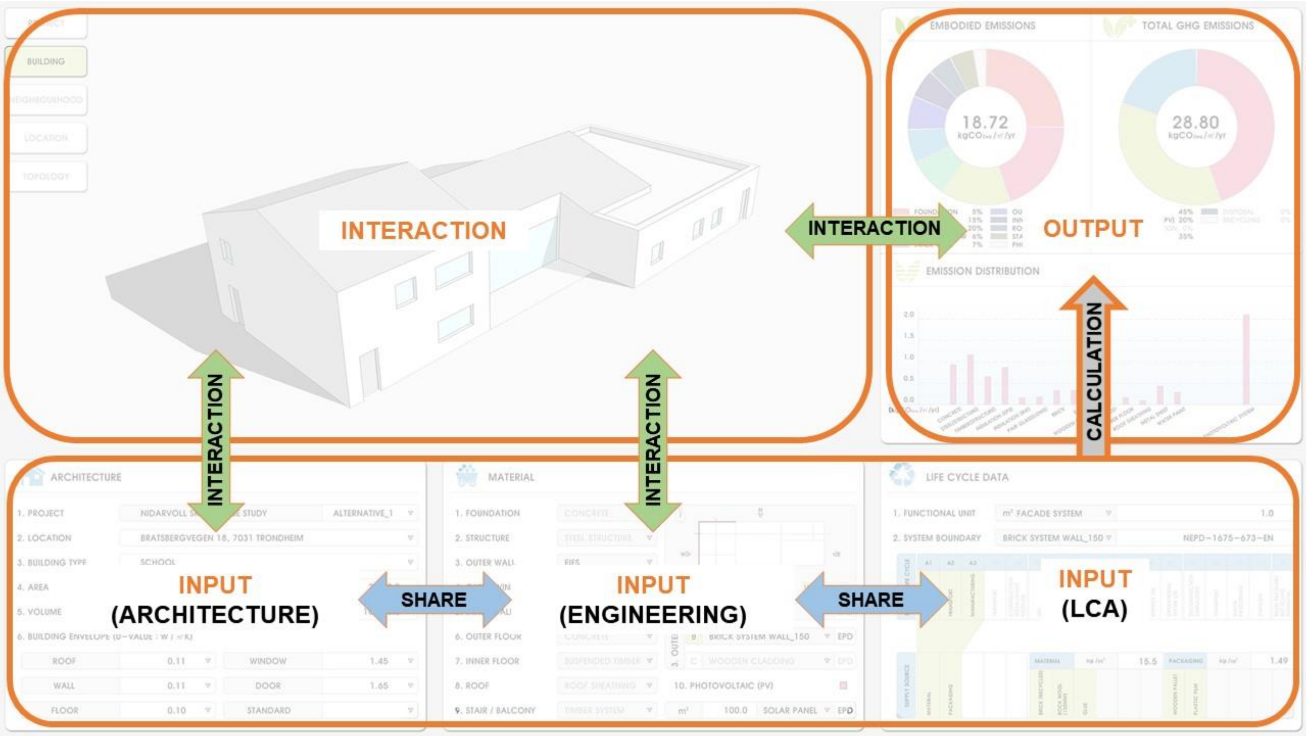


Figure 5.2 Main structure of Small-Neighbourhood Platform

‘BUILDING’ platform consists of two dashboards: Dashboards for building material and for operational energy use.

a. Dashboard for building material

The main purpose of Dashboard for building material is to show the embodied emission from building materials. The material information from building modelling is delivered to ‘ARCHITECTURE’ and ‘MATERIAL’ of the Input Tables. Through the life cycle information defined in ‘LIFE CYCLE DATA’ of the Input Table, the embodied emissions are calculated and presented in the Output Table. The output of embodied emissions can give the building material planning feedback to decide material choice for GHG emission reduction.

Interaction Window

Architectural modelling in Sketch-up or Autodesk Revit is plugged into the Interaction Window with model information such as material data defined in each component of the model. The data is delivered to the Material of Input Table to share it with environment analysists.

Moreover, in the Interaction Window, 3D model information enables stakeholders such as mechanical engineers and environment analysists as well as architects, to have easy understanding for architectural spaces.

Input Table

Input Table is mainly divided into three tables: ARCHITECTURE, MATERIAL, and LIFE CYCLE DATA.

ARCHITECTURE

It consists of Project, Location, Building Type, Area, Volume, and Building envelop as a basic model information. Project name, Location, Building Type can be directly defined in 'PROJECT', 'LOCATION', and 'BUILDING TYPE' of Input Table or delivered from Revit tool. In case of 'PROJECT', it is categorized as alternatives or schematic designs for a project.

The information of 'AREA' and 'VOLUME' are received from Revit model information where the measured values are changed according to model design. The values cannot be directly defined in Input Table. The basic information of ARCHITECTURE table is shared with environment analysists to establish the goal and boundary of environmental analysis.

U-value of building envelope can be defined in 'BUILDING ENVELOPE', or it can be given Revit information. U-value is not often considered in the initial design phase. In this case, we can allow a value of local regulations or design guides produced by 'STANDARD' controller of 'BUILDING ENVELOPE' in order to design mechanical system with optimized energy use for the building. The information is used in ZEN Dashboard for operational energy use (Chapter 5.2.1 b).

The data of location, type, area, volume, and U-value of building designed by architects are core information that should be shared with engineers for the calculation of energy performance.

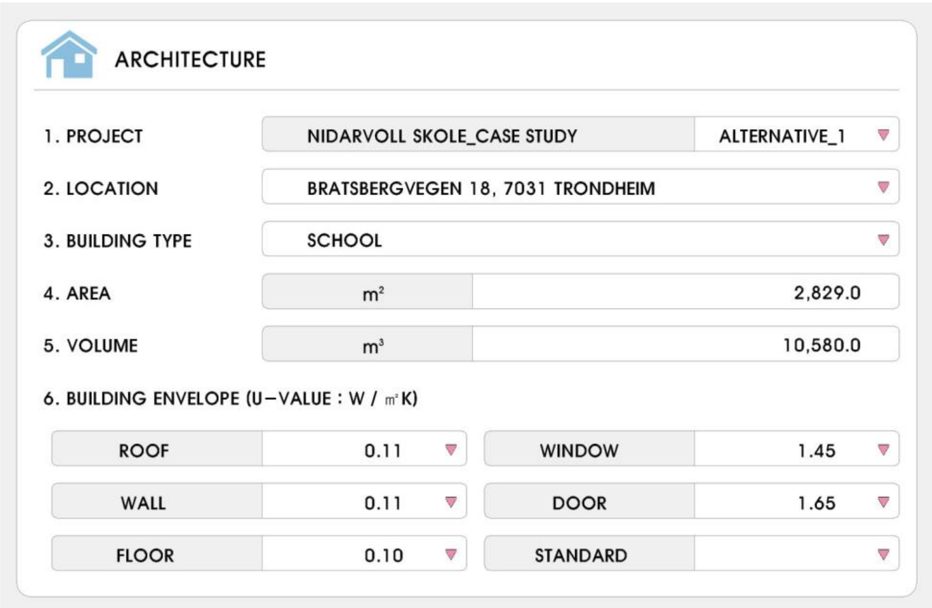


Figure 5.3 ARCHITECTURE in Input Table

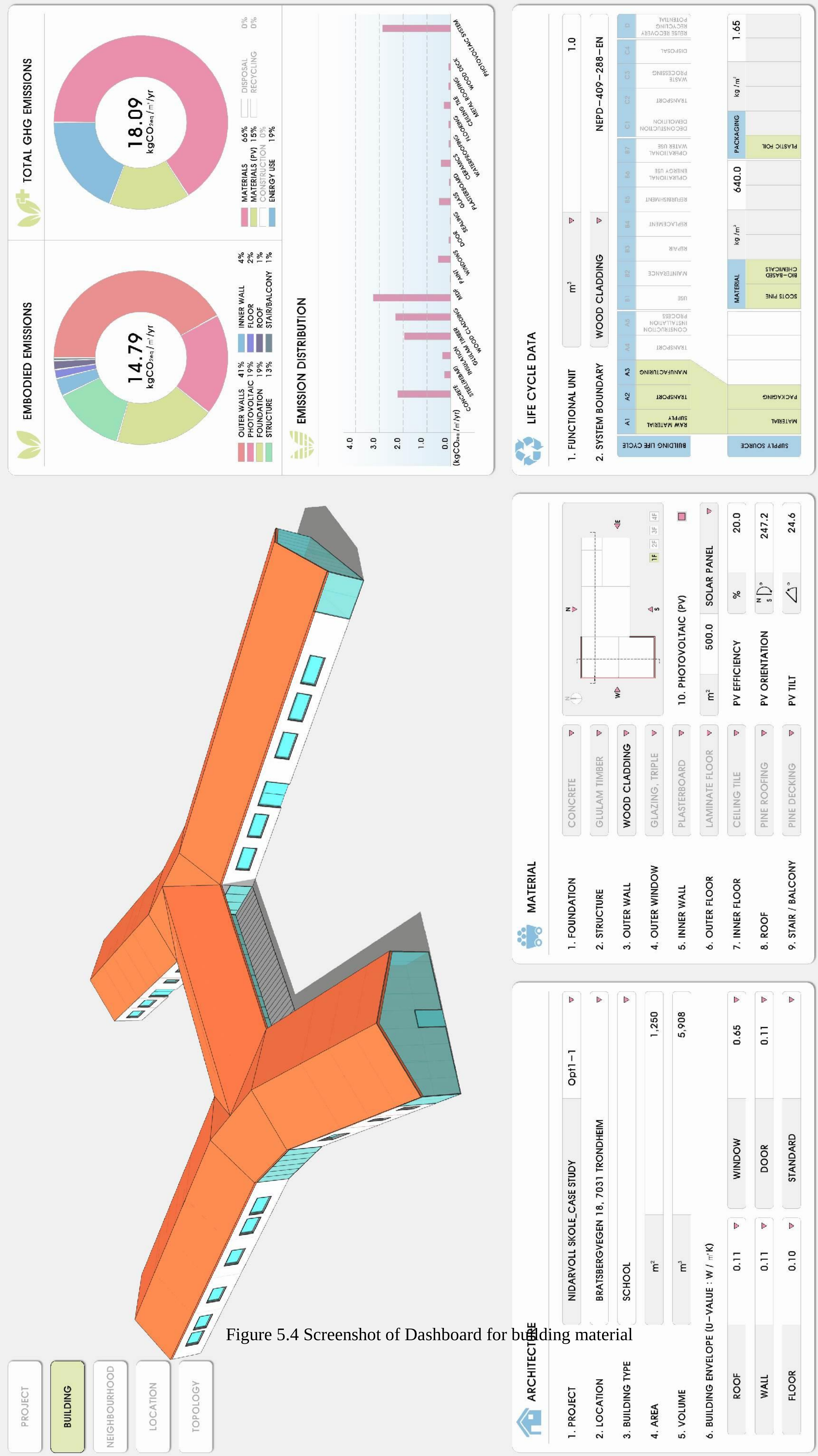


Figure 5.4 Screenshot of Dashboard for building material

MATERIAL

The material information of a building model is defined in the MATERIAL input table. When using Revit as a modelling tool, material information is interconnected with that in Revit. The material information based on EPD data is used for the calculation of embodied emission according to the system boundary and carbon intensity defined in LIFE CYCLE DATA table.

The category of material information follows the building elements in accordance with NS 3451:2009 since the classification of material mainly depends on the function of building elements, and it is also for easy understanding of architects as a main user.

The display in right upper part of the table provides simple floor plans, section drawings, and elevation features to define specific scope of materials. Additionally, MATERIAL table includes the material information for photovoltaic panel (the right down part).

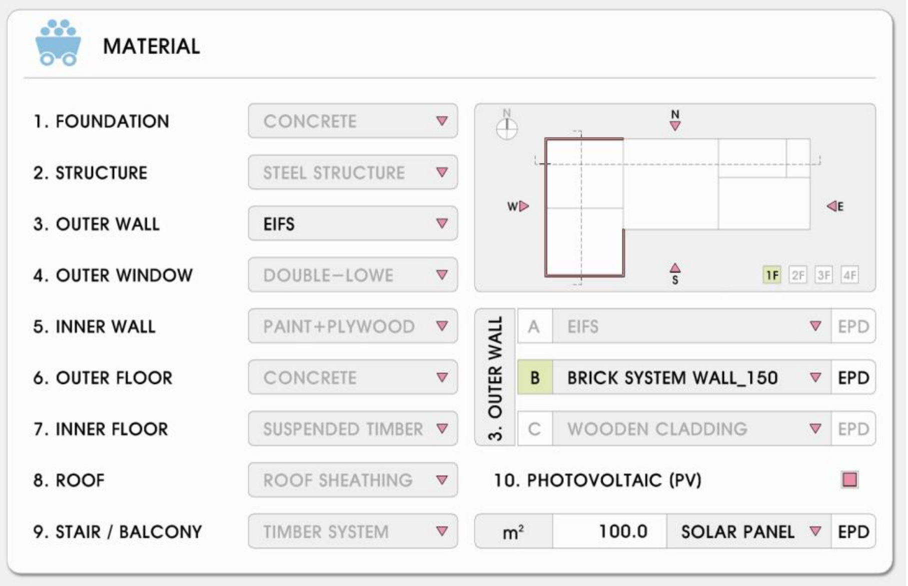


Figure 5.5 MATERIAL in Input Table

LIFE CYCLE DATA

It is divided by two main parts: Functional Unit and System Boundary. In the perspective of architect, those are a core part that architects can understand comprehensively regarding LCA workflow because a functional unit indicates what LCA conducts while system boundary limits the work scope.

The toolbar of Functional Unit can set up a unit and define the amount of the unit regarding each material defined in MATERIAL table. The information is interconnected with software for LCA, such as Excel, Stan, and Arda. System Boundary provides information of life cycle stage defined in a project. An upper list box of Building Life Cycle in System Boundary is accordance with the life cycle of building defined ZEN research and NS-EN 15978:2011. The selection of life cycle stage in the Building Life Cycle template means the system boundary for LCA of the material defined. Supply source template shows life cycle inventory and its up-stream flows. For example, as shown in Figure 5.8, the production process of 'Brick System Wall_150' as an EPD material consists of material and packaging in the system boundary from raw material supply to manufacturing (A1-A3). The process of material is divided into brick, rockwool, and glue while that of packaging is divided into wooden pallet and plastic film. The carbon intensity of material and packaging is 15.5 and 1.49 kg/m², respectively. The EPD information provides the value of carbon intensity, but if the value does not exist, the carbon intensity can be calculated by Ecoinvent data or related research information.

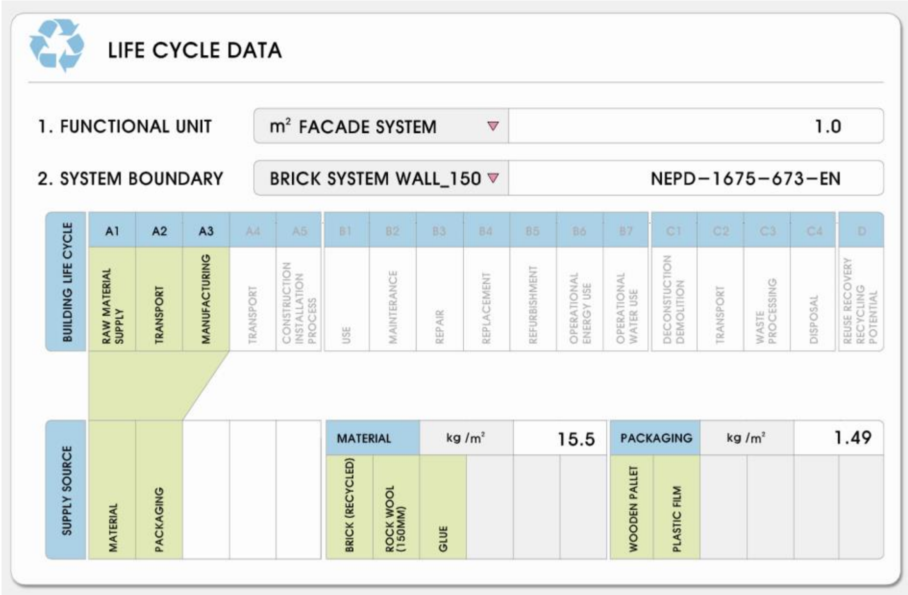


Figure 5.6 LIFE CYCLE DATA in Input Table

Life Cycle Data shows where GHG emissions come from and which process chain the emissions are concentrated on. It is valuable for architects and engineers to make easy understanding for LCA and easy analysis considering the result from Output Table.

Output Table

Output Table consists of EMBODIED EMISSIONS, TOTAL GHG EMISSINOS, and EMISSION DISTRIBUTION.

EMBODIED EMISSIONS

The sector provides the distribution of embodied emissions for materials based on building elements defined in MATERIAL input table. With the distribution, user can figure out the concentration of embodied emissions and consider the improvement of material choice.

TOTAL GHG EMISSIONS

It shows the numerical value and the distribution of total GHG emission generated in the building life cycle. The outcomes for numeral value and distribution are calculated by multiplying carbon intensity collected by Life Cycle Data of Input Table by the values from Sefaira or Insight360 via EnergyPlus, interconnected with System of Input Table. The information can be used for comprehensive building planning based on the strategy for GHG emission reduction. Furthermore, The numerical value of each building is used as a datum of ‘GHG EMISSIONS’ category in ‘NEIGHBOURHOOD’ platform (Chapter 5.2.2).

The table of TOTAL GHG EMISSIONS is shared with Dashboard for operational energy use.

EMISSION DISTRIBUTION

It visualizes the distribution of embodied emissions based on material use. Unlike the information of EMBODIED EMISSIONS, the graph is the distribution of emissions by material used in a building, which allows the material planning in a whole building rather than the choice of materials for the building elements.

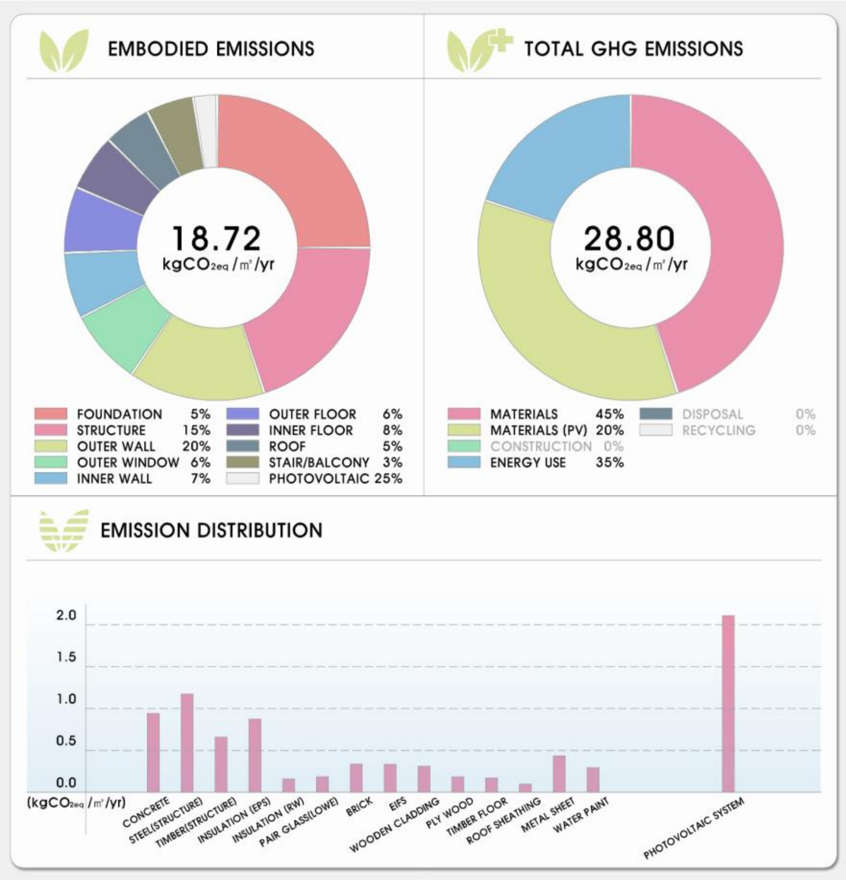


Figure 5.7 Display of Output Table in the Material Dashboard

b. Dashboard for operational energy use

The main purpose of ZEN Dashboard for operational energy use is to provide the information related with the design strategy for the improvement of building energy performance. The information from building modelling and 'ARCHITECTURE' Table is delivered to 'SYSTEM' Table where energy performance is calculated. Through the life cycle information defined in 'LIFE CYCLE DATA' Table, the emissions from the simulation of building energy use are calculated and visualized in the Output Table. The output can give feedback to the improvement of building energy planning.

Interaction Window

The Interaction Window serves the same function as that of the dashboard for materials.

Input Table

ARCHITECTURE

The input table serves the same function as the ARCHITECTURE table in the dashboard for materials.

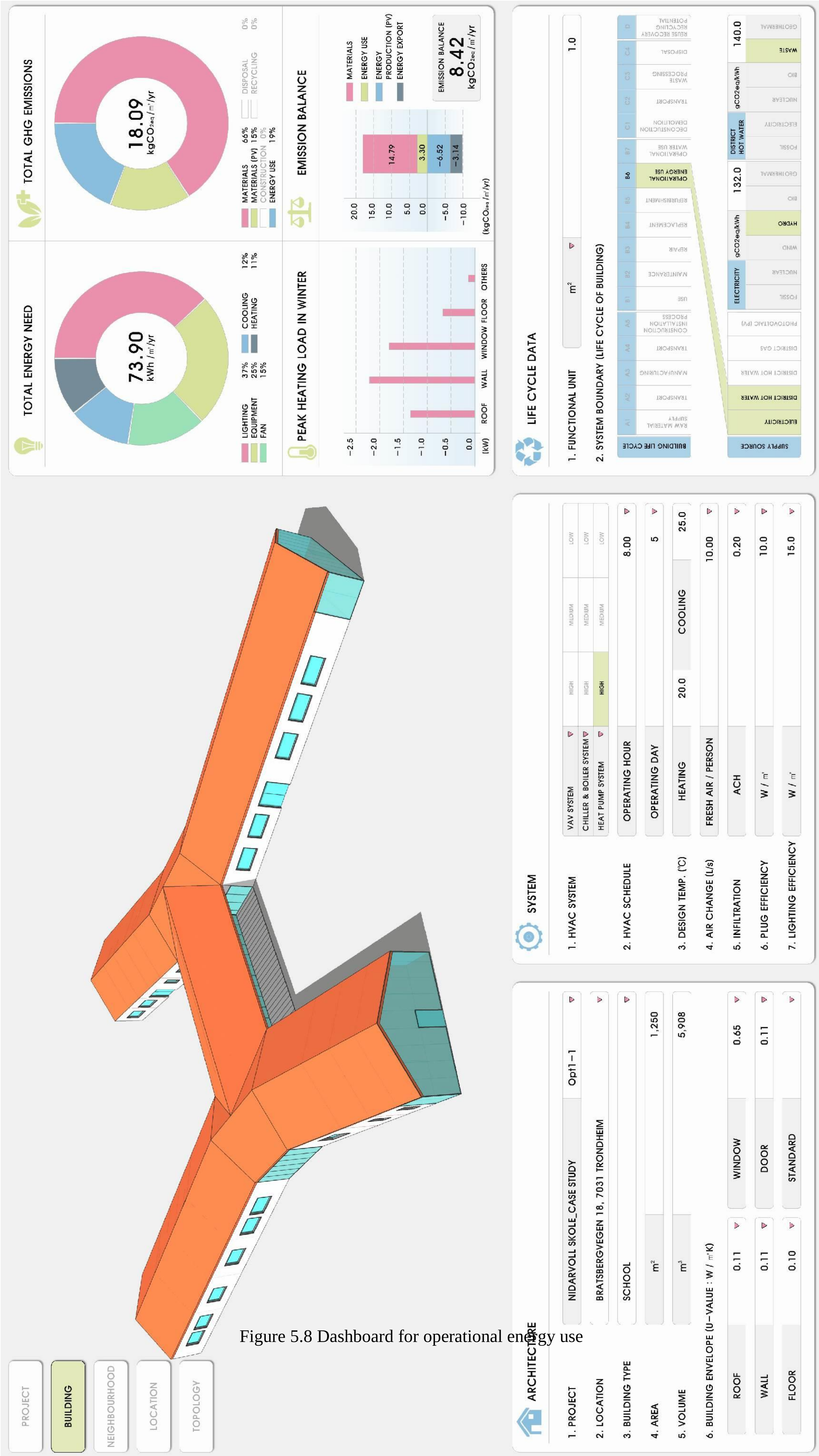


Figure 5.8 Dashboard for operational energy use

SYSTEM

‘SYSTEM’ includes HVAC system type, HVAC Schedule, Design Temperature, Air change, Infiltration, Plug Efficiency, and Lighting Efficiency as basic energy users. ‘HVAC SYETEM’, ‘HVAC SCHEDULE’, and ‘DESIGN TEMP.’ are information for HVAC performance, operation time, and operation temperature, respectively. When building type is defined in ‘ARCHITECTURE’, HVAC system is automatically categorised as general types of HVAC system according to building type. There are many types of HVAC systems, and different types of HVAC systems are used depending on the type of building. For example, variable-air-volume (VAV) system, chiller and boiler system, and heat pump system are generally used in case of commercial building (Tobias, 2018). Architects can choose a HVAC system and its performance categorised in HVAC template. Because architects do not generally have in-depth knowledge about HVAC system, easy classification of HVAC is required in Input Table.

‘AIR CHANGE’ and ‘INFILTRATION’ are information regarding indoor air quality. Furthermore, ‘PLUG AND LIGHTING EFFICIENCY’ are information for electricity use.

The information in the SYSTEM table is interconnected with Revit information as the least conditions required to calculate energy consumption in Sefaira or Insight360.

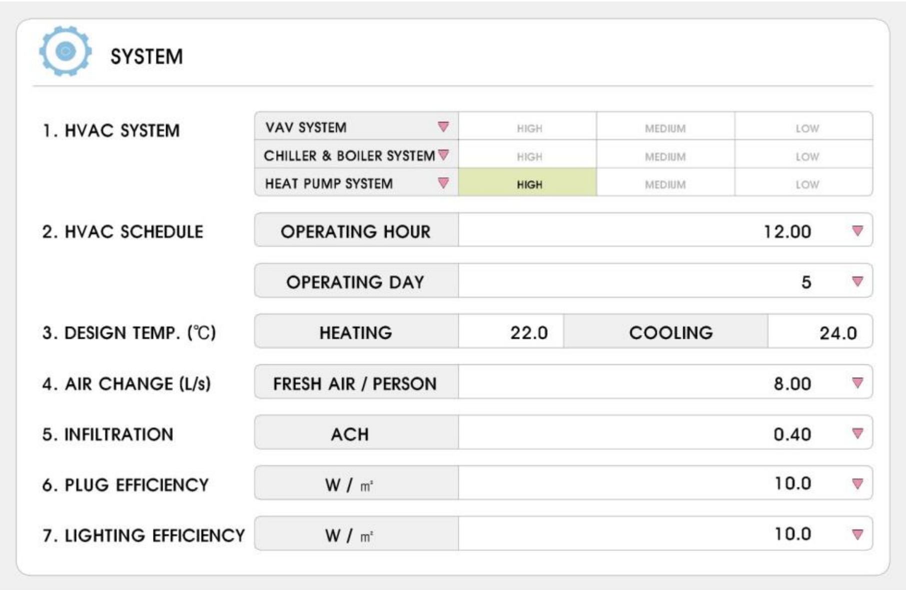


Figure 5.9 System part in Input Table

LIFE CYCLE DATA

Main structure of the table is same with that of LIFE CYCLE DATA in Dashboard for building material.

When user defines life cycle stages in the list box, main upstream process of another list box (Supply Source) for the selected stage appears below the list box of Building Life Cycle. Again, when user selects resources that supplies to life cycle stages selected in the Building Life Cycle template, the upper-stream chains from selected resources appears beside the list box of Supply Source. Last, the bottom-up processes are selected in the list boxes, and carbon intensity (gCO2eq/functional unit) calculated for all defined process chains is outputted. For example, in case of Nidarvoll Skole project (Chapter 6), when Operational Energy Use of Building Life Cycle is selected in the System Boundary after 1 kWh is defined as the functional unit, the stage is activated as green colour, and a list box of Supply Source appears below Building Life Cycle. The project can select electricity and district hot water in the list box of Supply Source because the buildings of the project use both as main energy sources. After that, in two check boxes of Electricity and District Hot Water which is activated by selections of Electricity and District Hot Water, users can select Hydro in Electricity and Waste in district Hot Water, respectively, and then, carbon intensities of electricity and district hot water are outputted from LCA data - 132.0 gCO2eq/kWh, 37.3 gCO2eq/kWh. It is shown as Figure 5.12.

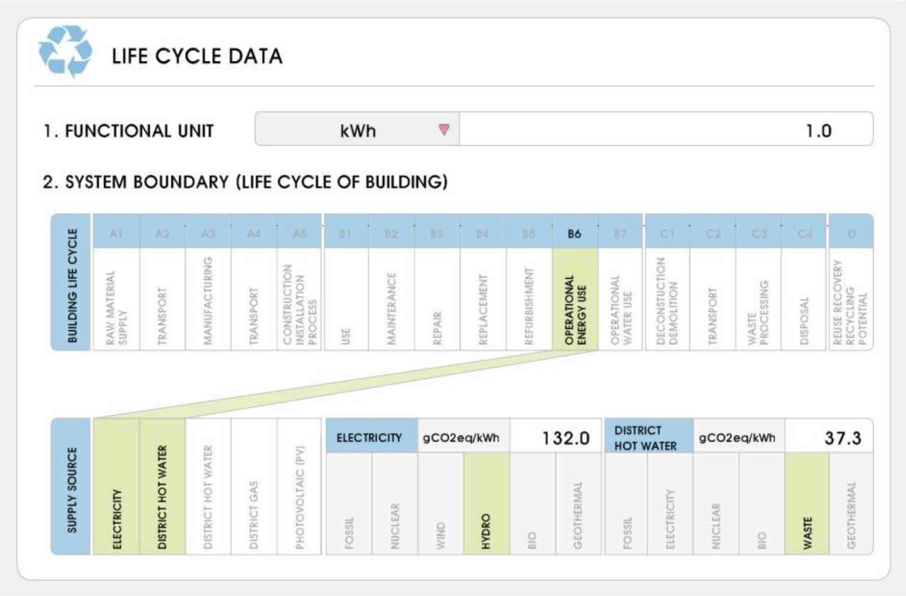


Figure 5.10 LIFE CYCLE DATA in Input Table

Output Table

It mainly consists of four results: ‘TOTAL ENERGY NEED, ‘TOTAL GHG EMISSIONS’, ‘PEAK HEATING LOAD IN WINTER’, and ‘EMISSION BALANCE’.

TOTAL ENERGY NEED

It shows the numeral value of total energy need defined by ZEN KPI. The main energy users are classified as the same with the GHG emission drivers. The distribution also uses pie chart for easy comparison among different energy users. The outcomes for numeral value and distribution are calculated by Insight360 and EnergyPlus which are interconnected with data from System of Input Table.

TOTAL GHG EMISSIONS

It is shared with Dashboard for building material as a same output.

PEAK HEATING LOAD IN WINTER

It shows the numeral values of building envelope components such as roof, wall, window, and door for their peak heating load with bar graph. Through the illustration for each components of building envelope in Output Table, architects can consider which component of 3D modelling should be improved in Interaction Window. The outcome is calculated by integrated data among 3D model in Interaction Window, and architecture and system information in Input Table.

EMISSION BALANCE

It represents the emission balance defined by ZEB.

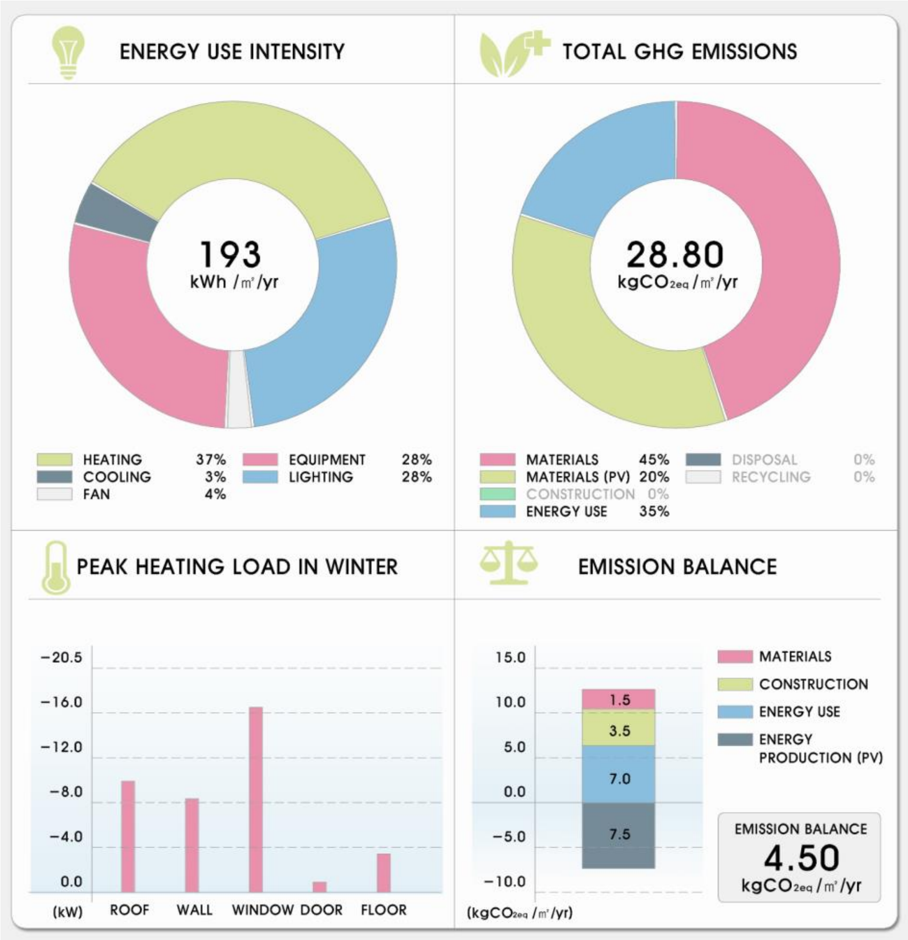


Figure 5.11 Display of Output Table in the Operational energy use Dashboard

c. Comparison Interface

The Comparison Interface in 'Building' platform provides the outputs for total GHG emissions, total energy need, and emission balance where the users can analyse several alternatives at the same time.

Each design alternative in both Dashboard of building material and operational energy use can be shown in a Comparison Interface to identify comparative outcomes. Simply, Interaction Window and Output Table is shown in each display window for design alternatives. Input Table can appear overlapping on the Output Table when the label is activated in the upper part of each Output Table (blue house). Furthermore, the box of Total GHG Emissions, in case of Dashboard for operational energy use as an example, can be changed to that of Energy Use Intensity when the label is activated in the bottom part of each Output Table (green leaves). Each component of Peak Heating Load in Winter can be directly compared with that of the other alternatives because the bar graph has absolute values unlike Total GHG Emissions and Energy Use Intensity.

The interface is shown in the case study for Nidarvoll Skole, Figure 6.8, Chapter 6.2.3

5.2.2 Large Neighbourhood Platform

Urban planning is a holistic process to deal with urban issues related with social, political, economic, and environmental developments (Susan.S, 2019). The main purpose of ‘NEIGHBOURHOOD’ platform is to improve the decision-making for the urban planning.

‘NEIGHBOURHOOD’ as the large-neighbourhood platform has a main structure consisted of Assessment Criteria, Display Window, Display Indicators, and Assessment Diagram.

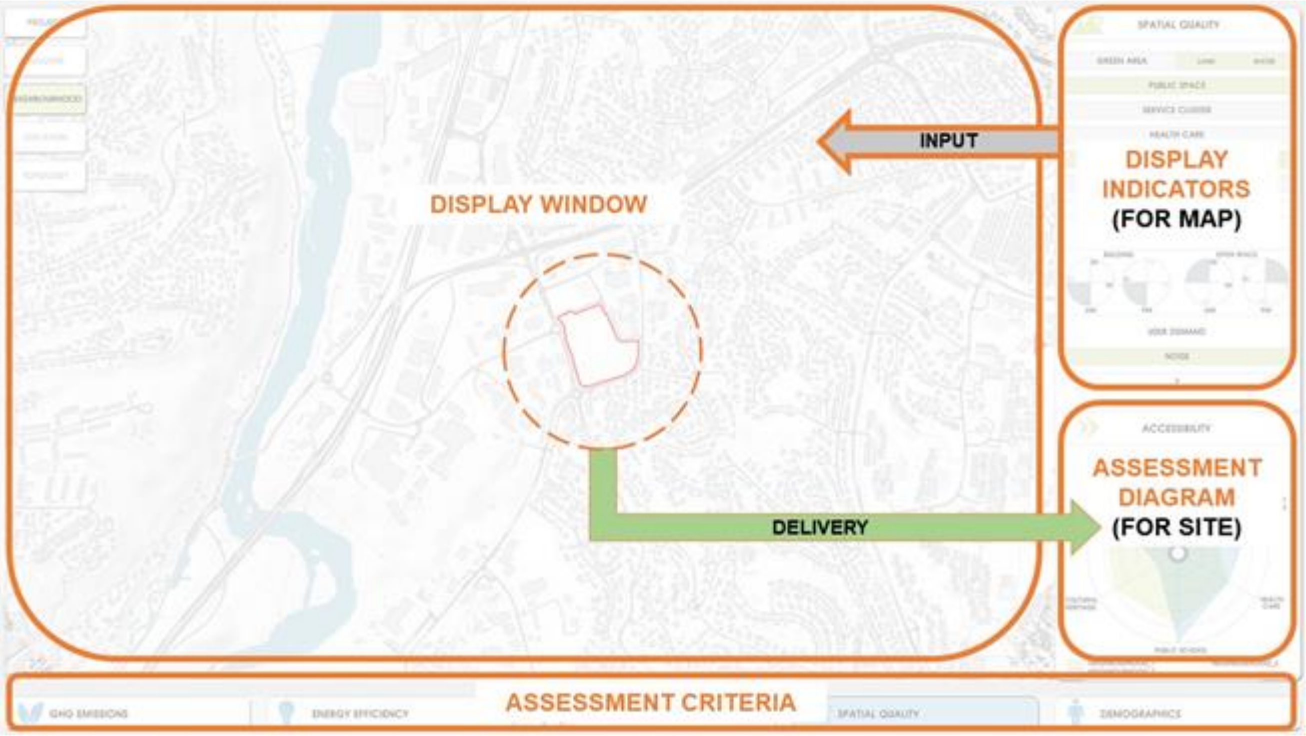


Figure 5.12 Main structure of ‘NEIGHBOURHOOD’ platform

Display Window shows 2D visual map information based on a project site, interconnected with the location information of ‘PROJECT’ or ‘BUILDING’ platform. As well as the project site, when users ‘click’ the cursor(pointer) around the screen map, the other territorial boundary is activated, and the information related with the interconnected database of the territory is delivered to the Assessment Diagram. The visual information of Display Indicators can be overlapped in the Display window showing the relationship between the activated boundary and the indicators. Assessment Criteria based on the definition of ZEN KPIs consists of ‘GHG EMISSIONS’, ‘ENERGY EFFICIENCY’, ‘MOBILITY’, ‘SPATIAL QUALITY’, and ‘DEMOGRAPHICS’. The toolbars have their own indicators shown in the Display Indicators.

a. GHG EMISSIONS

When the ‘GHG EMISSIONS’ toolbar is activated, Display Indicators and Assessment Diagram associated with the criteria is shown as Figure 5.15. The Display Indicators of GHG emissions consists of ‘RESIDENTIAL’, ‘PRODUCTION & WAREHOUSE’, ‘OFFICE & COMMERCIAL’, ‘TRANSPORT & TELECOMMUNICATION’, ‘ACCOMMODATION & SERVICE’, ‘SCHOOL, SPORTS & CULTURE’, ‘HEALTH’, AND ‘SOCIAL SECURITY’ as building type according to NS 3457-3: 2013. The Indicators show GHG emission distribution generated by each type of buildings in the Display Window. The visualized distribution helps users figure out the current situation of emission generation around the project site and benchmark the building performance based on equal type of buildings with the project. In order to be available to use the emission distribution in neighbourhood scale, the emission data of each building as an entity of urban database is required. Currently, many studies for building stock assessments is conducted in municipal scale. This platform assumes that the database from the studies for building emission is well established in the urban boundary of the project. In line with the studies for building emission, the emission data from ‘BUILDING’ platform plays a significant role as a building emission entity in the GHG emission criteria of ‘NEIGHBOURHOOD’ platform.

Assessment Diagram provides an evaluation for the climate emission of the project site or activated boundary in each phase of building life cycle based on NS-EN 15978:2011. By selecting the benchmarking site as well as the project site in the Display Window, the project can make comparative analysis with the benchmarks.

Figure 5.13 Dashboard for GHG emissions

b. ENERGY EFFICIENCY

The category of ‘ENERGY EFFICIENCY’ has the Display Indicators for ‘ENERGY USE INTENSITY’, ‘PEAK HEATING LOAD’, ‘SELF-GENERATION (of energy)’, ‘ENERGY BALANCE’, and ‘SUNLIGHT POTENTIAL’ as the indicators for energy efficiency as well as ‘ELECTRICITY GRID’ and ‘DISTRICT HEATING’ as the indicators for infrastructure in displayed neighbourhood scale. The information of indicators for ‘ENERGY EFFICIENCY’ except for ‘SUNLIGHT POTENTIAL’ are delivered from city database or ‘BUILDING’ platform as the same way of building emission data in the ‘GHG EMISSIONS’ category, and it is indicated in the Display Window. ‘SUNLIGHT POTENTIAL’ presents the possibility regarding how much electricity can be generated through PV panels on the roof of existing buildings. In order to use the ‘SUNLIGHT POTENTIAL’ information in the Dashboard, it is required to investigate the information at the neighbourhood level.

The distribution of ‘ENERGY USE INTENSITY’ and ‘PEAK HEATING LOAD’ shows where the energy use is concentrated so that users can refer the information to their own project in order to benchmark them for energy efficiency. Furthermore, urban energy planners and energy distributors can make effective strategy to improve urban energy performance with the data, considering existing infrastructure information from ‘ELECTRICITY GRID’ AND ‘DISTRICT HEATING’.

‘SELF-GENERATION’, ‘ENERGY BALANCE’, and ‘SUNLIGHT POTENTIAL’ show the distribution for energy surplus area and low energy area, or the area that have potential energy. Through the distribution map in the Display Window, stakeholders can make strategy and planning for energy efficient neighbourhood and energy balance neighbourhood.

The Assessment Diagram in ‘ENERGY EFFICIENCY’ presents the energy performance of independent boundary chosen in the Display Window. Users can compare the energy performance of new buildings, calculated in the ‘BUILDING’ platform, with that of other building in the displayed map. They can also establish a benchmark for energy efficiency of the early design in the comparative analysis.

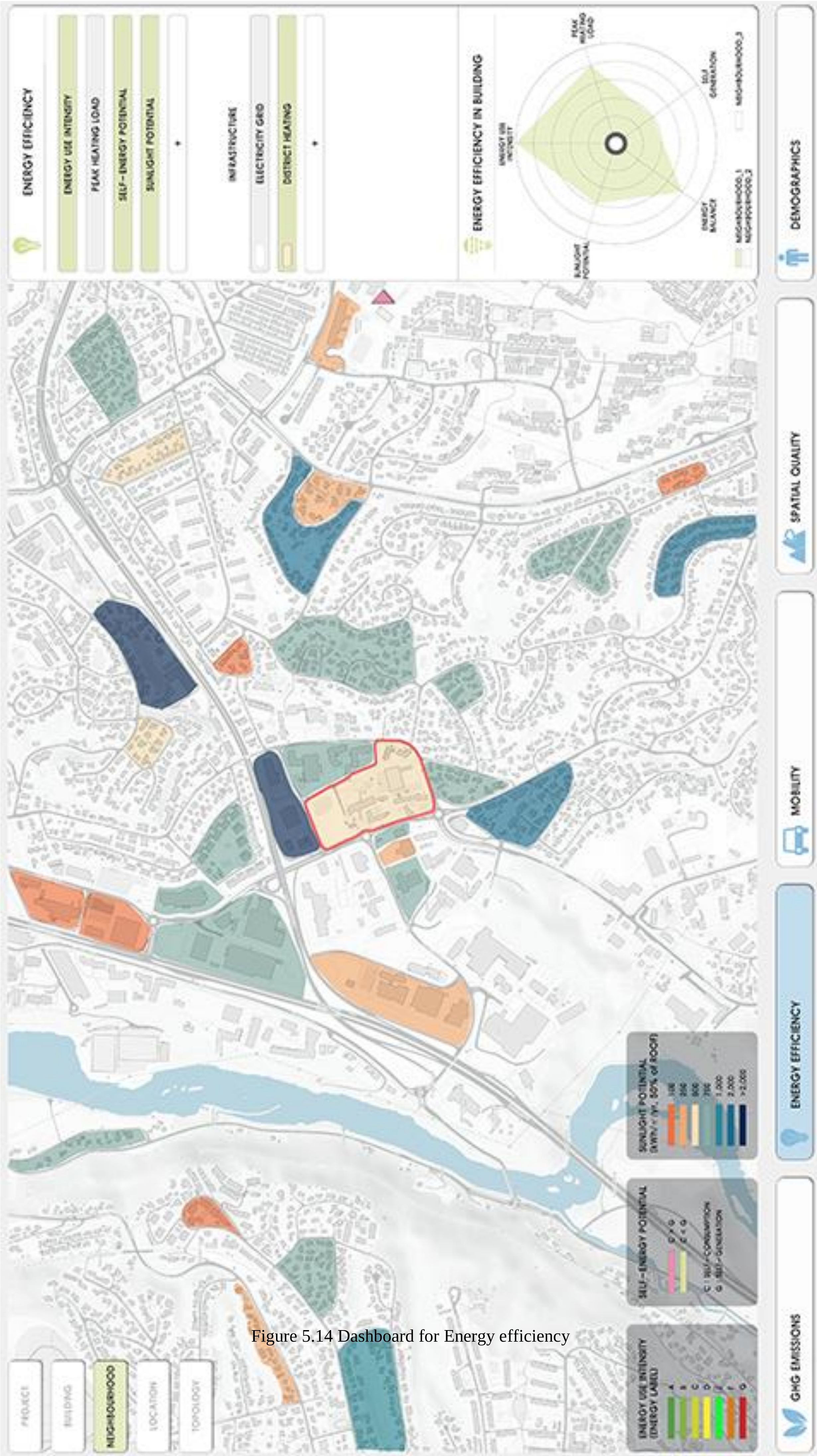


Figure 5.14 Dashboard for Energy efficiency

c. MOBILITY

The Display Indicators of ‘MOBILITY’ criteria represents the distance to city centre, the location of charging station for electric vehicles, and the information of transportation mode such as bus, tram, train, bicycle, and private vehicle. The distance to city centre as an indicator to show how often citizen use transportation, is crucial information to establish the energy-saving traffic system and strategy together with transportation mode. (Marianne et al., 2018)

Transport mode is divided into two sectors: public transportation and private vehicle. Public transportation such as bus, tram, or train includes the information of its route and station while private vehicle such as bicycle or automobile provides the information of its route and parking area. The distribution condition of route, station, and parking area affects the accessibility to the destination, and the accessibility impacts on climate-gas emitted in urban area.

‘CHARGING STATION’ displays the location of electric vehicle charging station, which provides transportation experts with a cue to encourage drivers to use electric vehicle.

Assessment diagram in “MOBILITY” indicates the accessibility from the project site to city centre and transport mode. Through the evaluation of accessibility, architects can design space program to improve the accessibility of project site while urban planner and policy maker can take into account the improvements of indicator which has low accessibility around the project site.

Figure 5.15 Dashboard for Mobility

d. SPATIAL QUALITY

The main purpose of spatial quality is to reduce the increase of travel demands to other place according to ZEN KPIs definition (Marianne et al., 2018). ‘SPATIAL QUALITY’ provides the information for location of amenities, available public space, and residents demand as well as environmental condition in line with the welfare of residents. The resident-centred spatial quality requires the diversity of indicators depending on the characteristics and demands of residents so that the Display Indicators has room for adding and changing the indicator depending on the resident demands.

The location distribution of amenities such as ‘SERVICE CLUSTER’, ‘HEALTH CARE’, ‘PUBLIC SCHOOL’, and ‘LEISURE’ shows how easily residents can access to the amenities for life, health, leisure, and education within walking distance.

‘PUBLIC SPACE’ indicates the location of open space, parks, and squires where the public can have free access. ‘MULTIPLE USE POTENTIAL’ provides the locations of buildings or open space that is available to use for visitors and the public according to time unit defined by Dashboard users. The synergy of different amenities is one of significant factors to reduce the space demand for energy saving. Architects can make planning for space program of the project building considering the available public space around the project site in early design phase.

‘GREEN AREA’ including green space and water space is one of key dimensions to have to be considered in the early architectural work. It also provides urban designers with information for environmental preservation and improvement.

Assessment Diagram is used for the analysis of benchmark and the quality of boundary defined in Display Window with regard to accessibility to the amenities for daily life, health, leisure, and education within walking distance in order to achieve the satisfaction of live in neighbourhood.

To achieve the developed neighbourhood plan including spatial quality, local demographic in current and future trends should be analysed. ‘USER DEMAND’ would be considered with the demographic information and statistics.

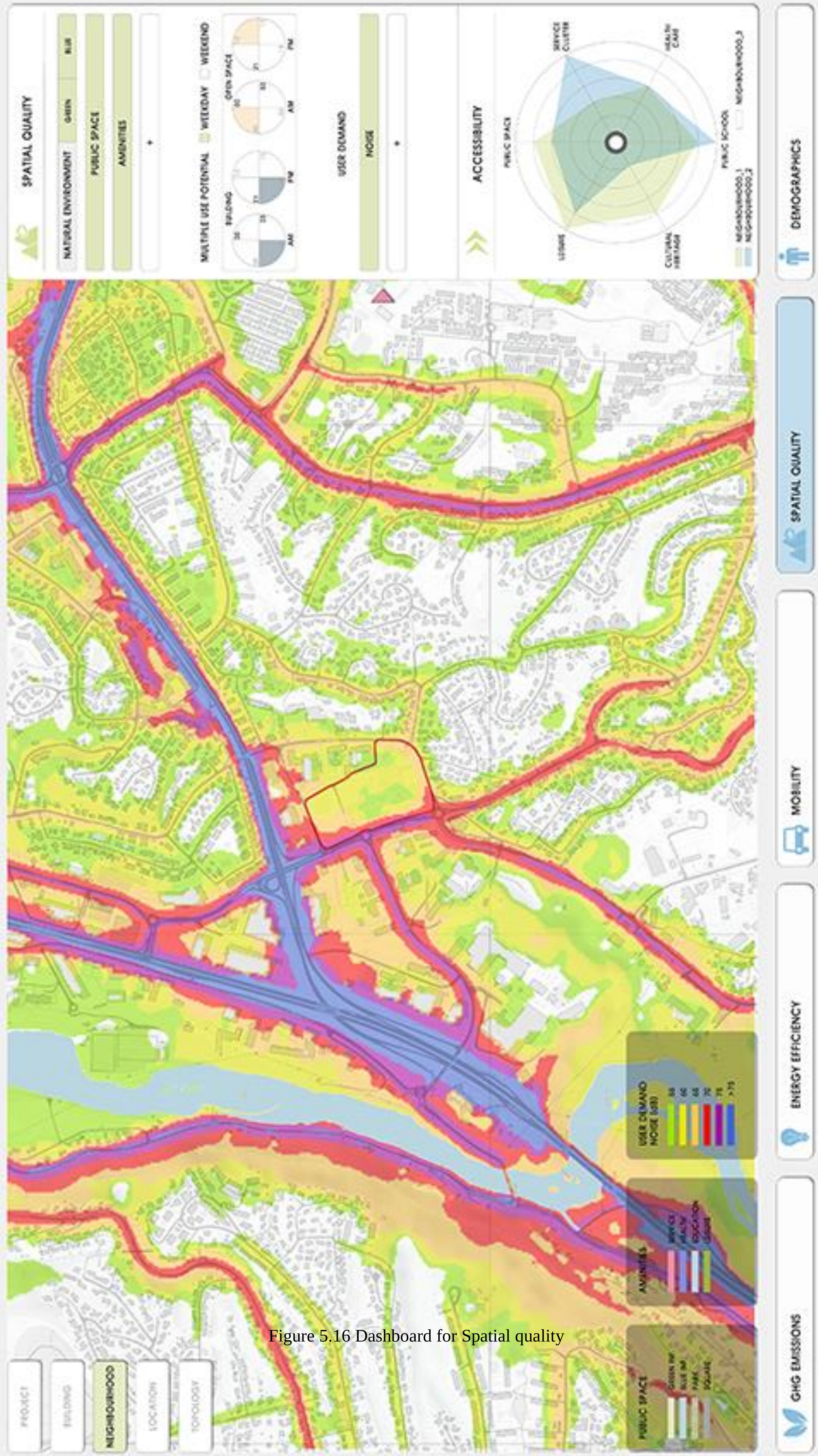


Figure 5.16 Dashboard for Spatial quality

e. DEMOGRAPHICS

The demographic needs are included in the assessment criteria and KPIs of ZEN as a category of spatial quality. Beyond the category of spatial quality, the whole strategies for zero emission neighbourhood are affected by demographic profile as we can figure out in Chapter 2.3.2. Therefore, the demographic information deserves to be categorised as a qualitative assessment in neighbourhood scale. It will play a role as a supporter to suggest the direction for the target of the other categories.

'DEMOGRAPHICS' shows 'PEOPLE' related with the information of age, gender and cultural background, 'EMPLOYMENT' related with the information of sectors, incomes, employment, and unemployment, and 'EDUCATION ATTAINMENT', interconnecting with city statistical database. The information for demographics is not directly visualised in the map of Display Window to protect personal information. Dashboard suggests the data is visualised in limited boundary as its graphs. When users choose a project site in the Display Window, a limited range is set around the project site, and the information about the range is displayed in graphs.

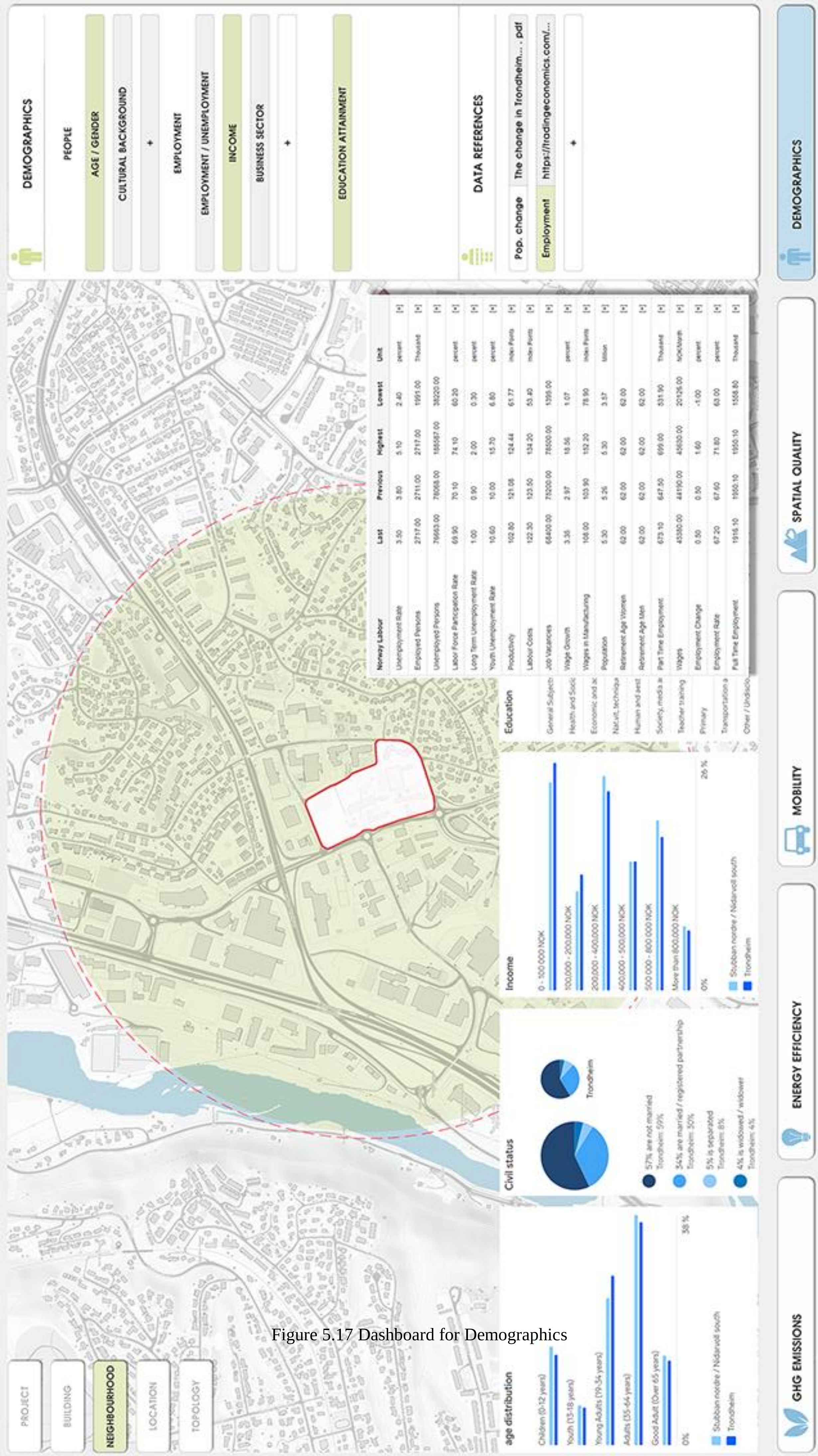


Figure 5.17 Dashboard for Demographics

5.3 Background software flow

5.3.1 Software and Database description

a. Autodesk Revit

Autodesk Revit is building information modelling software for architects, landscape architects, structural engineers, MEP engineers, designers and contractors. The software allows users to design a building and structure and its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model database. In Dashboard, Revit plays a role as a main container to include information regarding the relationship between neighbourhood design and GHG emission.

b. Sketch-up

Google Sketch-up is 3D modelling software for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design.

c. Sefaira

We can refer the description of Sefaira to Chapter 4.1.1

d. Insight360

We can refer the description of Insight360 to Chapter 4.1.2

e. EnergyPlus

EnergyPlus is a building energy simulation programme. The engine is based on the heat balance concept. Total energy use and peak heat or cooling load in the dashboard is calculated from the heat balance by EnergyPlus. The gap between outside heat balance generated by solar energy and air condition and inside heat balance generated by HVAC system makes energy transfer through the building envelope to keep the energy equilibrium, consuming energy to maintain designed indoor condition. Through the energy simulation, we can design an energy-optimized building.

f. Microsoft Excel

Microsoft Excel has the basic features of spreadsheets, using a grid of cells arranged in numbered rows and letter-named columns to organize data manipulations like arithmetic operations. It has a battery of supplied functions to answer statistical, engineering and financial needs. In addition, it can display data as line graphs, histograms and charts, and with a very limited three-dimensional graphical display.

g. EPD

Environmental Product Declaration (EPD) is an independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products.

h. Ecoinvent

The Ecoinvent database provides documented process data for products, helping users make informed choices about their environmental impact.

i. Urban database resources

Urban database linked to 'NEIGHOURHOOD' platform is listed in Appendices.

5.3.2 Information flow

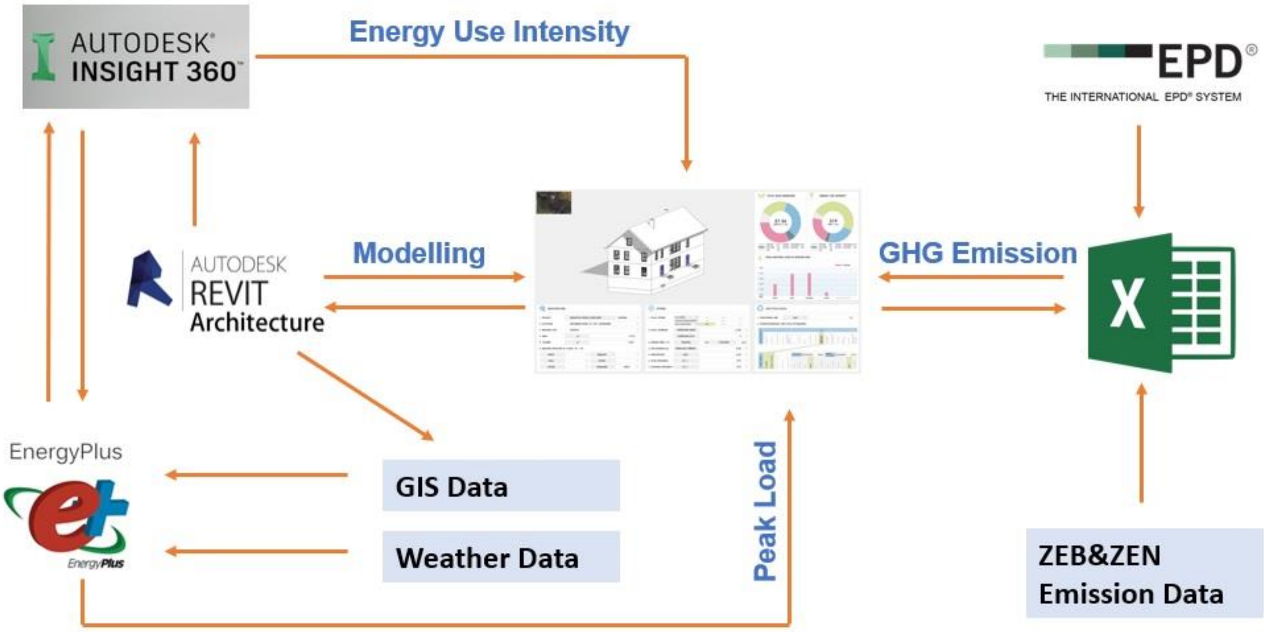


Figure 5.18 Information flow in ‘BUILDING’ platform

6 Case study

The main purpose of this case study is to identify potentials and improvement of the dashboard design by applying an actual ZEN pilot project. For this case study, the retrofit building project of a school site (Nidarvoll Skole) located in Sluppen area in Trondheim has been selected. The retrofit work includes the design of a new kindergarten in the site. ZEN Dashboard developed in Chapter 5 is applied during the design phase considering the energy performance and GHG emissions of retrofit design options.

This chapter explains the overview of the current Nidarvoll Skole, the new kindergarten design, the scope and assumption, the application of ZEN Dashboard, and the result. This case study is implemented according to architectural design process.

6.1 Overview of Case study

6.1.1 Nidarvoll Skole

Nidarvoll skole is an old public school that has a historical value in Trondheim region. The district of today's Nidarvoll was a farm area in the region of Sluppen until 1883. In 1884, the new school was open under the name Volden school with 81 students. The school has been expanded since 1884. The gym which is also used as the gym today was constructed in 1939, and it was expanded in 1956 and refurbished in 1984. Nidarvoll had a new building in 1961, and three single-story blocks in 1966, when pupils from Nardo moved to Nidarvoll. Also, Nidarvoll Skole had been one of the biggest schools in Trondheim until 1969. Today, the school as a public elementary school has more than 400 students, and plays a role of the school community.

Figure 6.1 View of Nidarvoll Skole

Nidarvoll Skole had five main buildings. The building group are western-sided in the site along with a main road while playgrounds and open space are located in the eastern side. The locations of each building are shown as Figure 6.2.

6.1.2 Architectural Design

The main architectural works include the master plan of the school site, new kindergarten design, the refurbishment of the existing buildings. (Figure 6.2)

The master plan is conducted in the whole site area (①, blue area) for the school design focusing on future-oriented sustainability, where the location of buildings and open space are defined in the site, considering the current and future environmental conditions around the site. The kindergarten (②) is designed as a part of the master plan with the main concept of the interaction between new building and old existing buildings. An existing building (③) deserves to be preserved as a historical building so that it is refurbished to improve building performance without the change of layout in each floor while the other building (④) is partially removed and remodelled with the new design. The main description of the architectural building works is shown in Table 6.1.

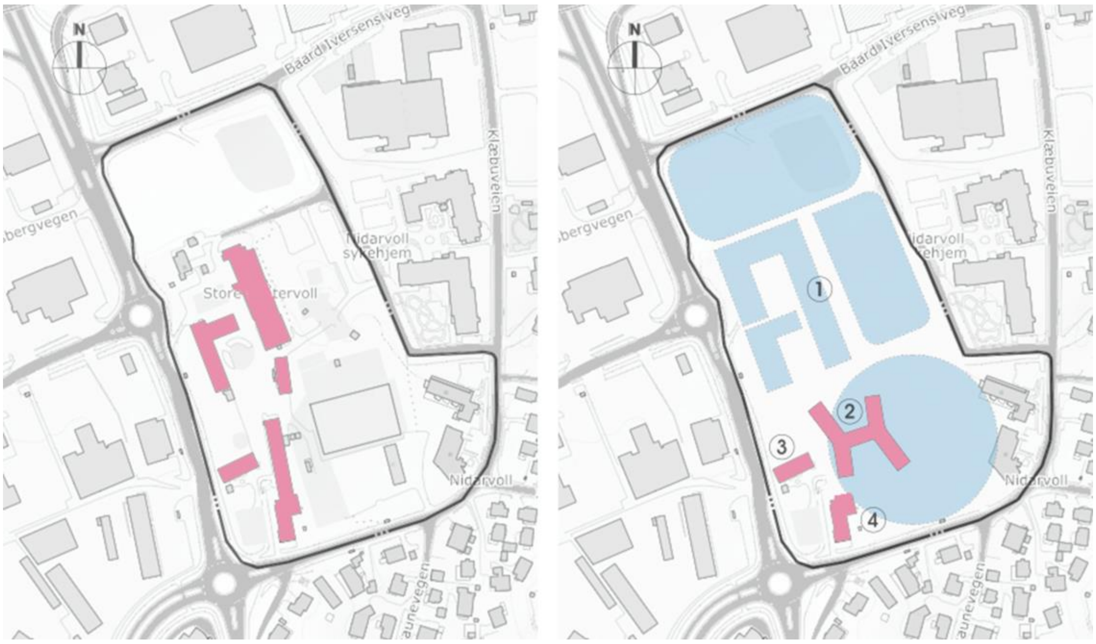


Figure 6.2 The existing site plan of Nidarvoll Skole(left) and the new architectural work of Nidarvoll Skole(right)

Project Name	Nidarvoll Kindergarten
Location	Bratsbergvegen 18, 7031 Trondheim, Norway
Total site Area	35,491.9 ㎡
Purpose	Educational facility
Capability	148 persons (including staff)

Project Work	Building	Building Level	Heated floor area (BRA) (㎡)	Volume (㎥)
Kindergarten (②)	New	1st Floor	1,250	5,875
Total		1 Storey	1,250	5,875
Canteen (③)	Refurbishment	1st Floor	205	422
		2nd Floor	214	766
Total		2 Stories	419	1,188
Administration (④)	Remodeling	1st floor	304	1,064
		2nd floor	211	844
Total		2 Srories	515	1,908

Table 6.1 The description of the case study

6.1.3 The scope and assumption

This case study focuses on the new design of kindergarten. The kindergarten design is developed by applying the 'NEIGHBOURHOOD' and 'BUILDING' platform.

'NEIGHBOURHOOD' platform provides necessary information regarding the current and future conditions required in the site analysis (Chapter 6.2.1). 'BUILDING' platform analyses the building energy performance and GHG emissions for the architectural design alternatives at the stage of massing study (Chapter 6.2.2) and basic design (Chapter 6.2.3).

In the case of canteen and administration building, the energy performance for the operational use phase of the buildings is applied through the 'BUILDING' platform. The energy performance data of the buildings is used to evaluate total energy need in the 'ENERGY EFFIENCY' criteria of 'NEIGHBOURHOOD' platform, which is to show how the information calculated in 'BUILDING' platform can be used in 'NEIGHBOURHOOD' platform.

ZEN Dashboard used the common input values in Architecture, System, and Life Cycle Input Table of the 'BUILDING' platform in order to focus on how the energy performance and the emissions analysed in the dashboard are interacted with the change of architectural design. In the case of the condition in Architecture Input Table, the U-value and PV panel was defined as shown in Table 6.2 and Table 6.3, respectively. The U-value for the building envelope was defined according to the value of previous ZEB case study, the Living Laboratory in NTNU (Goia et al., 2015). It is assumed that the PV panel is installed on the roof of the building. Since each design alternatives have the same roof area and slope while the orientation of the roof can be changed relying on the building orientation, the panel was set in the same conditions except for the orientation of the panel.

Reference	Roof	Wall	Floor	Window	Door	Unit
Goia at al., 2015	0.11	0.11	0.10	0.65	0.11	W/㎡ K

Table 6.2 U-value applied in the Case study

Photovoltaic panel area	500 ㎡
Efficiency	20 %
Tilt (the Tilt of Roof)	24.6 °

Table 6.3 The specification of photovoltaic panel

In the System Input Table, the mechanical and electric system condition was commonly applied as shown in Table 6.4. HVAC system was defined as a high-efficient system which is widely utilised in the office or school building. The time and temperature schedule of HVAC system, air change, infiltration, and electricity use were accordance with the schedule defined in Sefaira (Chapter 4.1.1).

HVAC system	Split Packaged Heat Pump
HVAC schedule	8 hours per day / 5days per week
Design Temperature	Heating: 20℃ / Cooling: 25℃
Air change	10.00 L/s
Infiltration	0.20 ACH
Plug efficiency	10.0 W/㎡
Light efficiency	15.0 W/㎡

Table 6.4 Description of system condition in System Input Table

In the Life Cycle Data Input Table of ZEN Dashboard for operational energy use, it was assumed that as the main energy source of building, electricity is generated from hydropower and district heating comes from the residue waste. It was also assumed that all heating sources come from the district heating while all electricity is used for cooling, ventilation, lighting, and appliances except for heating in order to simplify the calculation of total GHG emissions. In the final energy use, we defined the carbon intensity for electricity and district heating according to the previous data of ZEB research and Statkraft (Statkraft, 2018), respectively. (Table 6.5)

Energy Source	Carbon Intensity	Reference
Electricity	**132.0** gCO2eq/kWh	(I. Graabak, 2011)
District heating(waste)	**140.0** gCO2eq/kWh	(Statkraft, 2017)

Table 6.5 Carbon intensity for energy use

The establishment of application scope and technical conditions can distinctively make the comparative analysis of energy performance and GHG emissions in the design alternatives of the new building.

6.2 The application of ZEN Dashboard

ZEN Dashboard mainly assesses a neighbourhood in the different perspectives of 'small-scaled neighbourhood' and 'large-scaled neighbourhood'. In the small-scale, ZEN Dashboard focuses on the building design in the early design phase of building life cycle. The early design phase can be divided into site analysis, massing study, and basic design phases according to the architectural design process. The case study in the small-neighbourhood scale will follow the early design phase. In the large-scale, ZEN Dashboard focuses on the urban planning. Chapter 6.2 shows how the information and assessments in different neighbourhood scales can give feedback to each other by illustrating the application in each design phase of the Nidarvoll Skole project.

ZEN Dashboard is not actually interconnected with calculation tools and city data. ZEN Dashboard is a conceptual platform to show the possibility to develop a tool which can integrate various types of information to reduce GHG emissions and energy use in our neighbourhoods. Thus, the information and the calculation required for the actual case study application were derived by using the related web information, energy calculation software, and GHG emission-calculation tool.

6.2.1 Site analysis phase

Site analysis as a contextual analysis is to figure out the parameters for the reasonable design by considering the conditions around a project site prior to the design. The existing conditions involves the current situation such as site location, site boundary, topographical feature, natural environmental condition and the relationship with neighbourhood contexts as well as the potential of the future changes around the site.

The indicators of 'NEIGHBOURHOOD' platform as an assessment tool in large-scaled neighbourhood are not perfectly matched to the parameters of site analysis since the 'NEIGHBOURHOOD' platform focuses on urban planning while the site analysis focuses on architectural design. However, the indicators of the platform can provide the site analysis contexts for energy use and CO2 reductions ultimately. The context of the site analysis implemented for architectural design and the Dashboard indicators applied to the site analysis are shown in Table 6.7.

Site Analysis	Dashboard (‘NEIGHBOURHOOD’ platform)		
Context	Category	Indicator	Note
Location	General	-	Upper categories in Dashboard
Site boundary	General	-	
Topology	General	-	
Adjacent building hierarchy			Not applied
Soil properties			Not applied
Natural Environment	Spatial Quality	Natural Environment	
Noise	Spatial Quality	Noise	Use Demand
Public space	Spatial Quality	Public Space	
Amenities	Spatial Quality	Amenities	
Occupancy time	Spatial Quality	Multiple Use Potential	
Bicycle path	Mobility	Bicycle	
Accessibility (to amenity and to the site)	Mobility	Distance to City Centre	
	Spatial Quality	Accessibility	Site assessment

Table 6.6 The Dashboard indicators applied to the site analysis of case study

The site analysis was carried out as the context shown in Table 6.6. The indicators of ‘NEIGHBOURHOOD’ platform can be applied to the contexts of site analysis except for adjacent building hierarchy and soil properties on site. Location, site boundary, and topology information are not included in the large-scaled neighbourhood platform. The information is defined from the setting value for building model in the ‘PROJECT’ platform plugged in the modelling tools such as Sketch-up or Revit. In the case of topology, when it is not defined in the modelling tool, the information can be delivered from the web-based data of ‘Kartverket’ (Kartverket, 2019) as a Norwegian Mapping Authority. The other contexts were implemented by the indicators of Spatial Quality and Mobility categories in ‘NEIGHBOURHOOD’ platform. The information of Natural Environment, Public Space, and Amenities around the site is shown in Spatial Quality criteria (Figure 6.3) in order to consider the connectivity between natural environments and the site, the usability of the adjacent public space to the site, and the possibility of the on-site programmes interconnected with the amenities around the site. Especially, the assessment of accessibility to various amenities can be analysed through the Assessment Diagram of ‘Accessibility’ in the Spatial Quality (Figure 6.3). In the case of Noise analysis, the information is not directly included in the indicators of Spatial Quality. However, it is important factor to assess the satisfaction of residents in a neighbourhood. Thus, Noise was analysed in the indicator of User Demand of Spatial Quality category (Figure 6.4). The information of Public Transportation, Bicycle, and Charging Station for electric vehicles as a mobile network which encourages people to use eco-friendly transportation is shown in Mobility category, where architects can consider the interconnectivity between the site programmes and the mobile network. (Figure 6.5) The distance to the city centre as a degree to figure out how often the occupants of the project site use the transportation, is indicated in Mobility criteria. (Figure 6.5)

The site analysis helps defining indoor and outdoor space programmes of buildings designed in the site and provides the significant cues for the main direction, shape, and size of buildings carried out in Massing study phase.

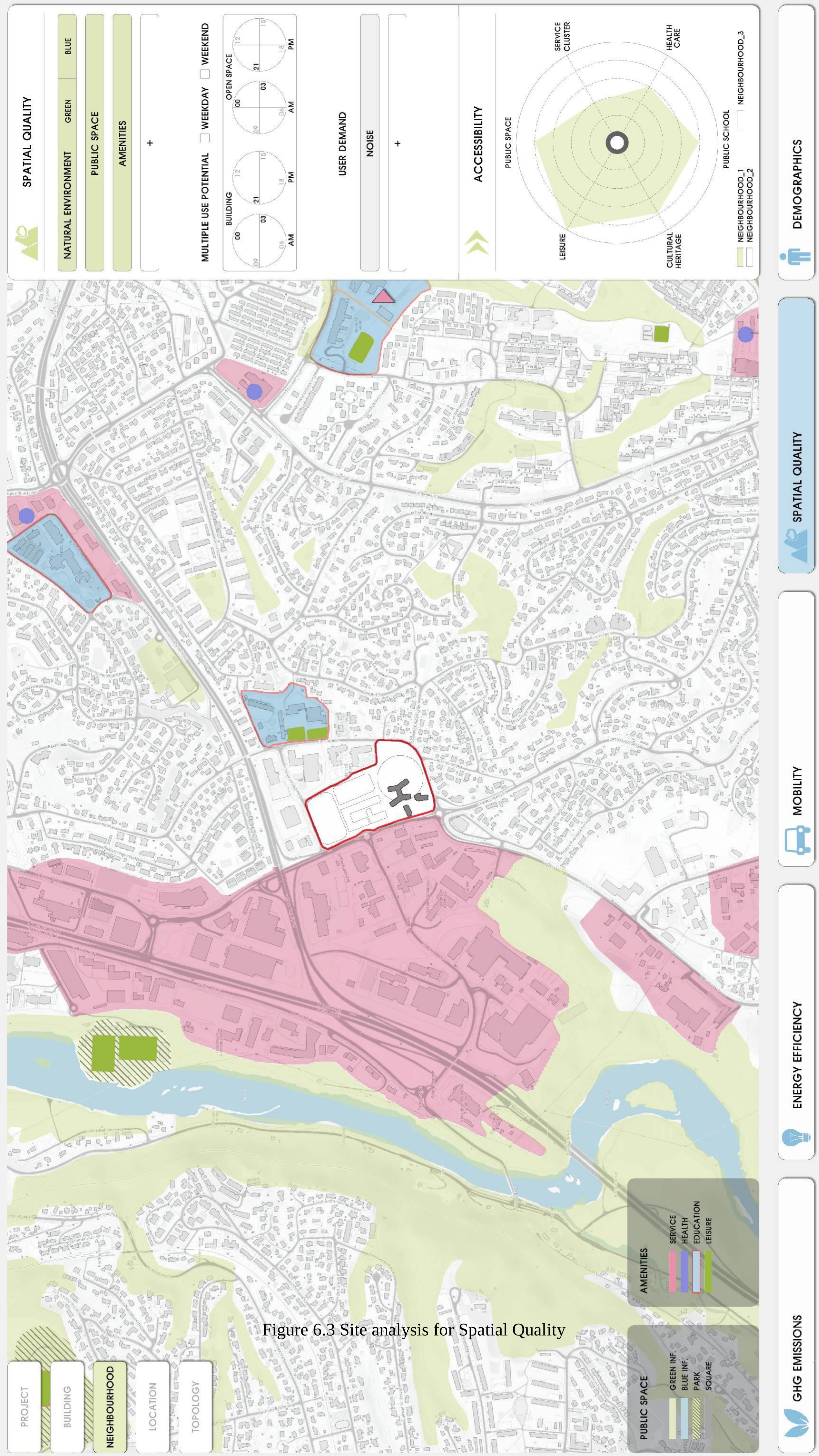


Figure 6.3 Site analysis for Spatial Quality

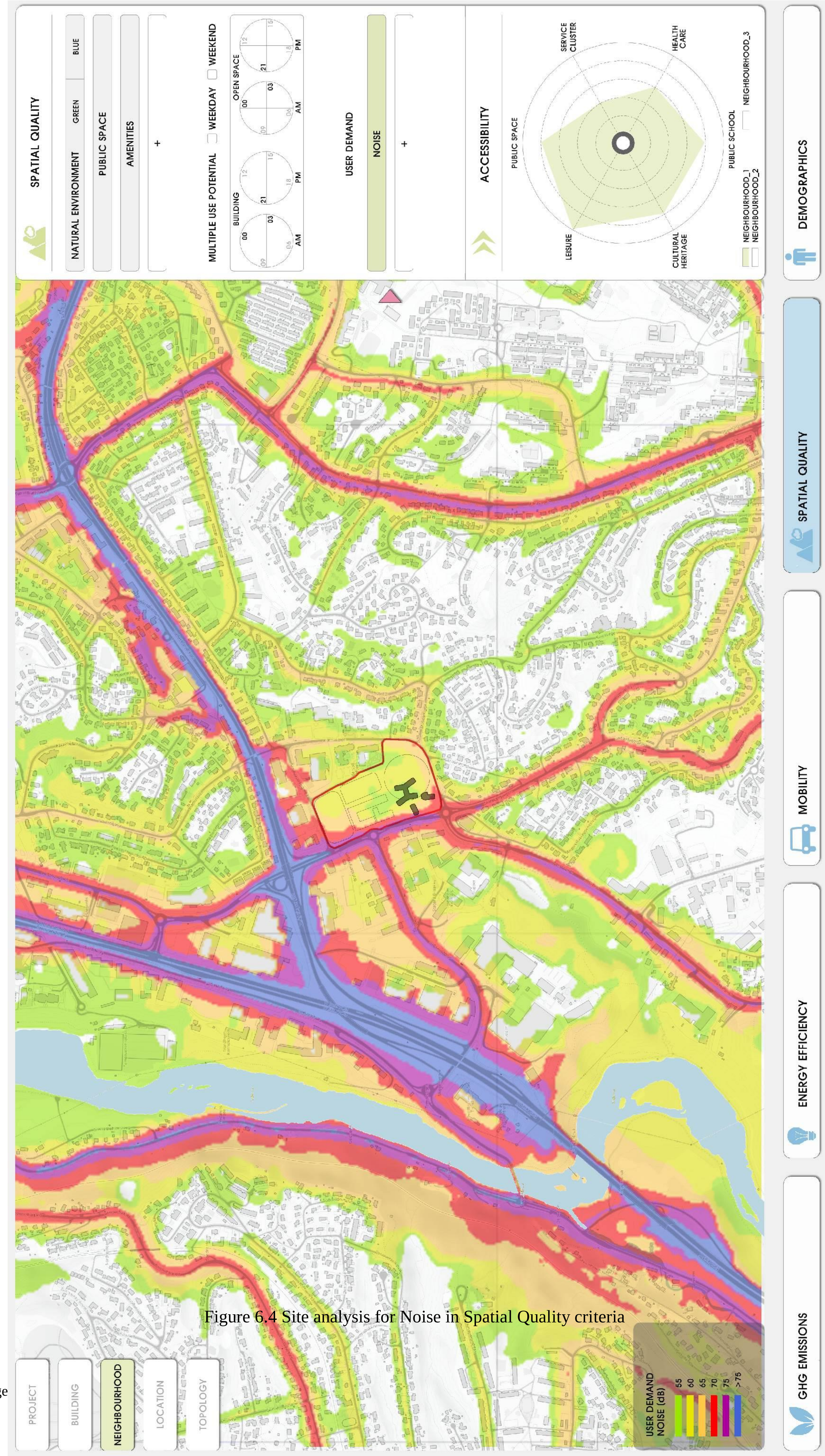


Figure 6.4 Site analysis for Noise in Spatial Quality criteria

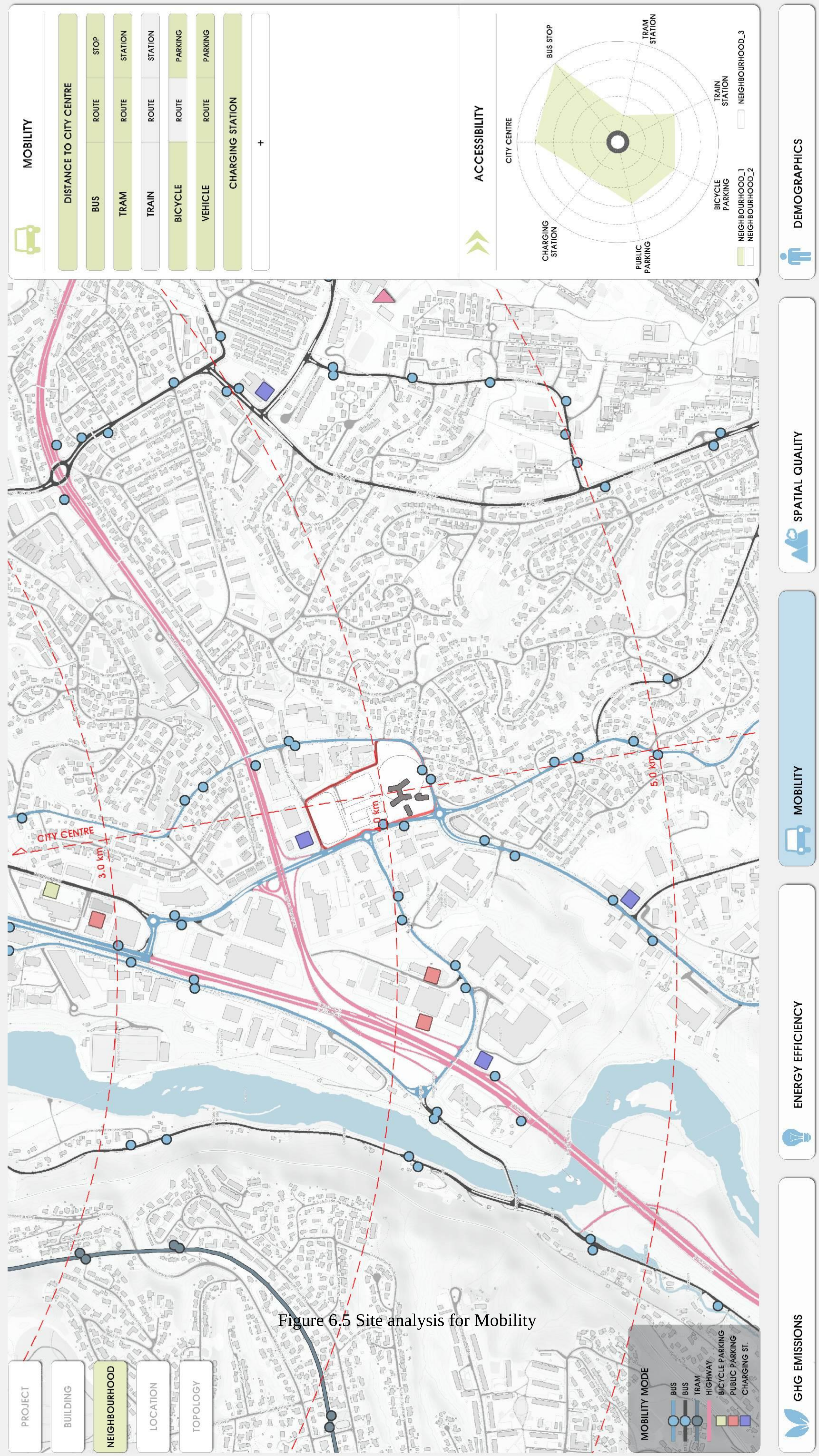


Figure 6.5 Site analysis for Mobility

6.2.2 Massing study phase

Massing study is a design to decide the general shape, form, and size of buildings based on the design concept and the conditions from site analysis. As a three-dimensional block, the study affects the area of building envelope which is significantly related with the acceptance of natural energy such as sunlight and outdoor air as well as the use of operational energy such as electricity and district heating.

This case study focuses on mass model to be able to reduce the operational energy use for the new building (kindergarten). Through the ‘BUILDING’ platform of ZEN Dashboard, the energy analysis was performed for two alternatives (Opt1 and Opt2) of the massing study. The alternatives have different building orientation, building shape, and PV panel orientation decided by the roof shape while other design factors are set to be the same for them.

The models of the two alternatives were generated in Sketch-up plugged in the ‘BUILDING’ platform, and energy analysis was implemented by Sefaira, assuming that the platform can be interconnected with the calculation tool. Based on the models for Opt1 and Opt2 in Interactive Display of the platform, the PV panel information was defined in the dashboard for building material. The orientations of PV panel for Opt1 and Opt2, assuming the installation on the building roof, were set at an angle of 247.2 ° and 258.5 °, respectively while the tilts were defined in the same angle of 24.6 ° as an angle of the roof. The other design factors related with energy performance was accordance with the architectural design conditions defined in Chapter 6.1.3.

As a simulation comparison, Total energy need, Total Electricity Demand, PV-generation, Net Electricity Use are shown in the Output Table of the dashboard for building operational use. (Figure 5.x) The differences of the energy simulation for Opt1 and Opt2 is indicated as shown in Table 6.8. In the case of Total energy need, the results were not significantly different since they had same areas, volume, and Wall-Window Ratio (WWR). However, Total Electricity Demand of Opt1 was larger than that of Op2, attributed to different building orientation and window orientation. Interestingly, Opt1 had better results for Net Electricity Use due to more efficient conditions for electricity production from PV panels. Thus, the mass model of Opt1 was selected for further development in this thesis.

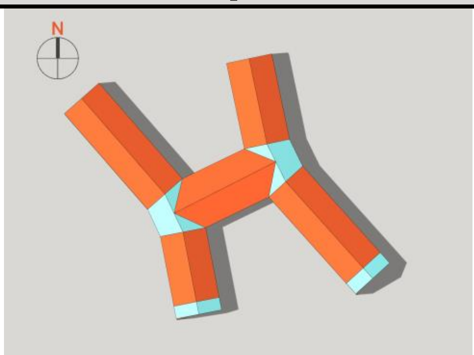
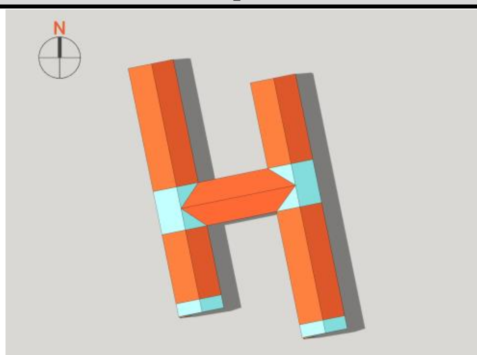
Alternative	Opt1	Opt2
Mass model		
Building Area	1,250 m^2	1,250 m^2
PV panel orientation	247.2 °	258.5 °
Total Energy Need	112,109 $kWh/m^2/yr$	112,879 kWh/yr
Total Electricity Demand	96,428 kWh/yr	95,240 kWh/yr
PV-generation	91,556 kWh/yr	78,459 kWh/yr
Net Electricity Use	4,872 kWh/yr	16,676 kWh/yr

Table 6.7 Energy simulation comparison of Mass alternatives

6.2.3 Basic design phase

Basic design phase defines the major materials of building and the layout of room space, where the area and shape of wall, floor, and roof as well as window size are specified according to the spatial properties of rooms. For an example, window size for the natural light capacity and the openness of indoor space is considered at the stage. ZEN Dashboard focused on the alternatives for materials granted by atriums of the kindergarten. The Dashboard provided the results for the difference of building materials that encompasses the atrium. The GHG emission was calculated as the amount of CO2 generated by the building operational energy and the embodied energy of the building material.

The Opt1selected in the massing study phase was developed in basic design phase. In this stage, Opt1was evolved into two different alternatives: Opt1-1 and Opt1-2. In 'BUILDING' platform, GHG emission analysis was performed on Opt1-1 with atriums that consist of glass walls and steel sheet roofs and on Opt1-2 with atrium made of whole glass wall and roof. The two alternatives remained the same in the other design and technical factors related with the emissions.

In 'BUILDING' platform, the amount of CO2 is calculated based on building model and Input Table. Assuming the interconnection with the platform, the actual calculation was carried out by using Safaira, EnergyPlus, and ZEB Excel tool.

In ‘MATERIAL’ of Input Table, the main materials of Opt1-1 and Opt1-2 was defined as Table 6.8. Each alternative was differentiated in the materials for the roofs of four atriums. The roof materials of Opt1-1 was defined as steel plate with waterproofing and insulation while the roof of atriums was set up as triple glazing glass and windows in Opt1-2.

Dashboard Categories	NS 3451 No.	NS 3451 Element	Application parts		Material_1	Material_2	Material_3
1. FOUNDATION	21	Groundwork and Foundations	Same		Concrete	Rebar	Insulation
2. STRUCTURE	22	Superstructure	Same		Glulam timber		
3. OUTER WALL	23	Outer Walls	Same		Wood cladding	Insulation	MDF/Paint
					Door		
					Sealing		
4. OUTER WINDOW					Window	Glass	
5. INNER WALL	24	Inner Walls	Same		Plasterboard	Insulation	Paint
					Sanitary tile	Waterproofing	
					Window	Glass	
6. OUTER FLOOR	25	Floor Structure	Same		Flooring		
7. INNER FLOOR					Ceiling tile		
8. ROOF	26	Outer Roof	Opt1-1		Steel plate	Waterproofing	Insulation
			Opt1-2	Atrium	Window	Glass	
				Others	Steel plate	Waterproofing	Insulation
9. STAIR / BALCONY	28	Stairs and Balconies	Same		Wood decking		

Table 6.8 Main materials for Opt1-1 and Opt1-2

Based on Table 6.8, The Output Table (Figure 6.6) for Opt1-1 visualised the embodied emissions by building elements and materials. The outer wall occupied the biggest in the distribution of embodied emissions by building elements, which accounted for 41%. It was followed by photovoltaic system, foundation, structure, inner wall, floor, roof, and balcony as the rate of 19%, 19%, 13%, 4%, 2%, 1%, and 1%, respectively. In case of the distribution by building materials, MDF, PV system, concrete, glulam timber, and wood cladding were major drivers to generate embodied emissions.

In the case of Opt1-2, the distribution by building elements and materials had a similar tendency with Opt1-1 even though having slight differences in the rate of the distribution for windows and steel of the roof and in the total GHG emissions.

Through the embodied emissions distribution, we can see that the concrete, wood, and PV panel set in this case study have high carbon intensity in their production. We can refer the application of ZEN Dashboard for the material of Opt1-1 to the Screenshot of Dashboard for building material, Figure 5.5, and the application for Opt1-2 in the same way.

Figure 6.6 The screenshot of Output Table for Opt1-1(left) and Opt1-2(right) in Dashboard for materials

ZEN Dashboard for operational energy use in the 'BUILDING' platform was performed to indicate the total energy need and peak heating load, and it showed total GHG emissions and emission balance integrating the embodied emissions for materials. The total energy need and peak heating load are visualised based on the distributions by energy drivers and building elements. Lighting was the largest driver in operation energy, recorded at over 30% of total energy need in both Opt1-1 and Opt1-2. Peak heating load had a similar trend in the two alternatives. Wall had the largest peak heating load in winter, followed by window, roof, floor, and others. The emission balance of Opt1-1 and Opt1-2 showed how much the emissions from material and energy use can be compensated by the energy production and exported energy generated by PV panel. The PV panel installed in the same condition for Opt1-1 and Opt1-2 reduced GHG emissions as much as 9.67 $kgCO2eq/m^2/yr$.

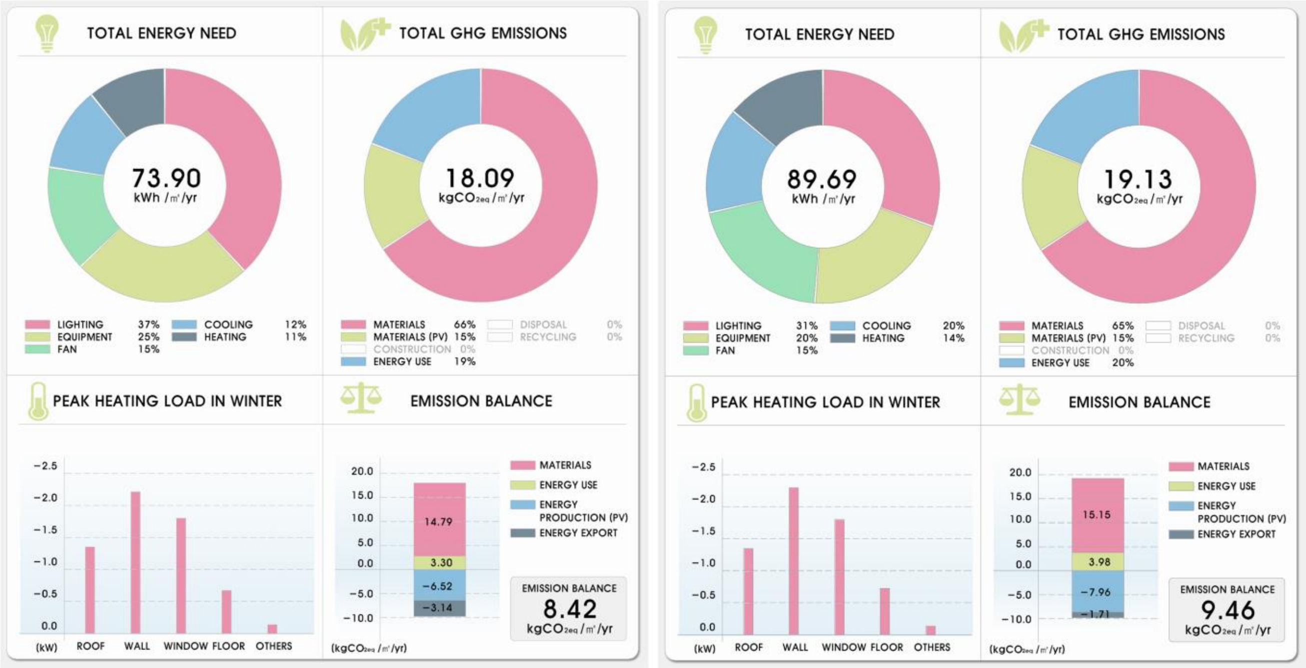


Figure 6.7 The screenshot of Output Table for Opt1-1(left) and Opt1-2(right) in Dashboard for operational energy use

In order to compare Opt1-1 with Opt1-2, we used the Comparison Interface (Figue 6.8). The results from the two alternatives in the dashboard are shown in Figure 6.7. The amount of total GHG emissions of Opt1-1 and Opt1-2 accounted for 18.09 and 19.13 kgCO2eq/㎡/yr, respectively. The difference for total GHG emissions in Opt1-1 and Opt1-2 was attributed to the energy use at the building operational stage and the embodied emissions from materials as shown in the 'EMISSION BALANCE'. Total energy need of Opt1-2 in the amount of 89.69 kWh/㎡/yr was larger than that of Opt1-1 in the amount of 73.90 kWh/㎡/yr. The difference was noticeable in the sector of heating and cooling as shown in the bar graph of 'TOTAL ENERGY NEED'. Furthermore, through the emission distribution in 'EMISSION BALANCE', we can know the difference of the emissions embodied from materials and the emissions generated from building use between Opt1-1 and Opt1-2 although total compensated emission from PV panel – PRODUCTION and EXPORTED. The emission balance between the energy demand and production was marked at 8.42 and 9.46 kgCO2eq/㎡/yr in Opt1-1 and Opt1-2, respectively.

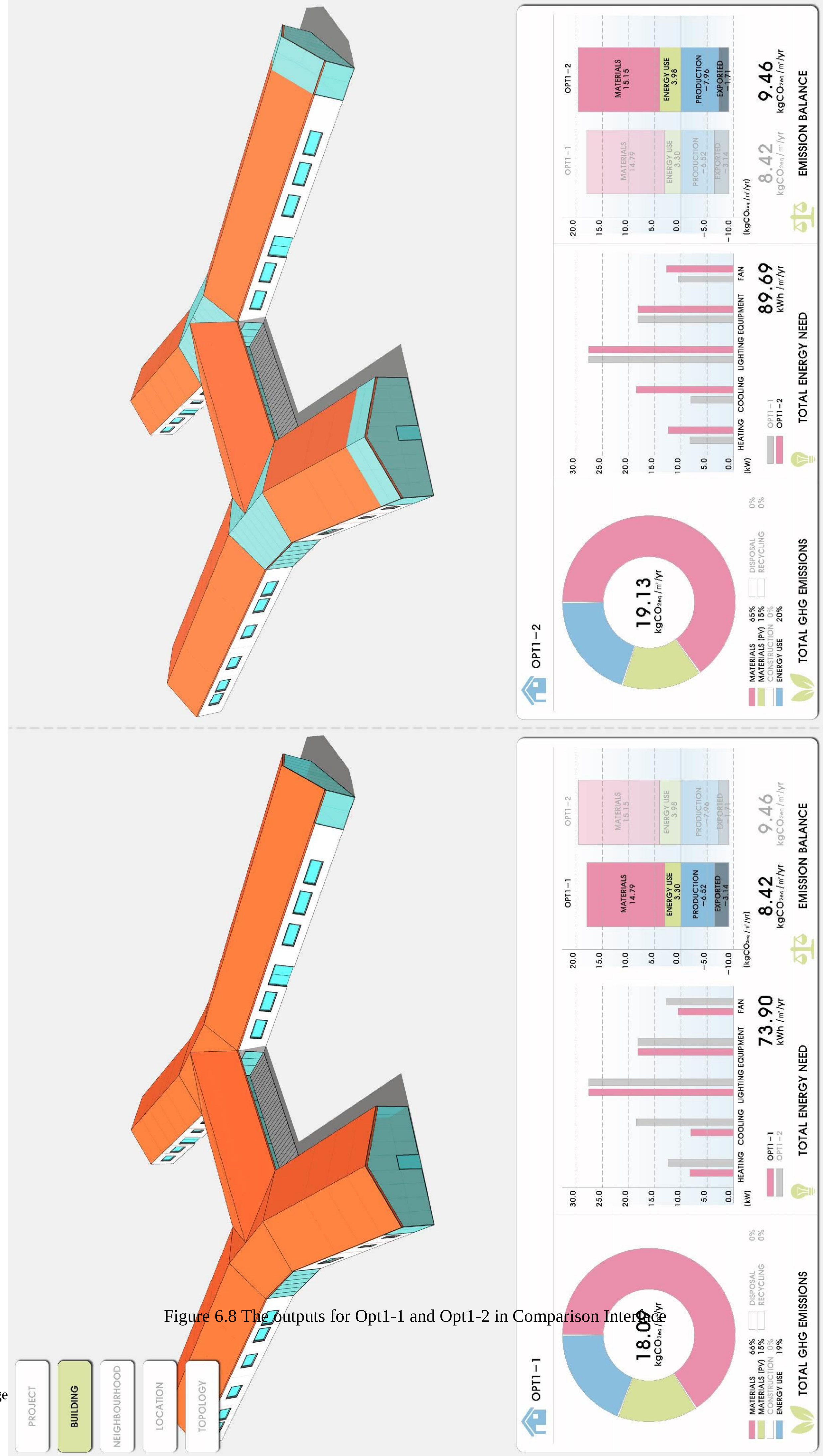


Figure 6.8 The outputs for Opt1-1 and Opt1-2 in Comparison Interface

Throughout the early design phase, Opt1-1 had been decided to be the final design of the kindergarten in Nidarvoll Skole taking into account the performance of GHG emissions and building energy. Compared with the initial alternative (Opt2), the performance of Opt1-1 is shown in Table 6.9. Total energy need is the amount of district heating and electricity energy required in the building. Total GHG emissions are the amount of GHG emissions generated by building operational energy use and the energy use for building material production. Total compensation is the amount of GHG emissions reduced by the electricity from the photovoltaic panel. The electricity includes the amount of the electricity self-consumed on site and the exported energy. Emission balance indicates the gap between total GHG emissions and total compensation. By using the Dashboard, the Opt1-1, which can reduce total energy need from district heating and electricity by 20,508 kWh/yr and total GHG Emissions from operational use and materials by 1,871 kgCO2eq/yr more than Opt2, could be adopted as the final design.

Project	Total Energy Need (kWh/yr)	Total GHG Emissions (operation + materials) (kgCO2eq/yr)	Total Compensation (self-consumption + export) (kgCO2eq/yr)	Emission Balance (kgCO2eq/yr)
Opt1-1	92,371	22,616	-12,085	10,531
Opt2	112,879	24,487	-10,357	14,130
Reduction	-20,508	-1,871	-1,729	-3,600

Table 6.9 The comparison of energy performance between Opt1-1 and Opt2

Due to the ZEN Dashboard, the performance differences between design alternatives were expressed with simple graphic information. Finally, the ZEN Dashboard helped choosing the Opt1-1 intuitionally.

7 Discussion

7.1 Strengths for the Dashboard

Dual platform and synergy

Dashboard has two platforms: ‘BUILDING’ and ‘NEIGHBOURHOOD’ platforms. ‘BUILDING’ platform is a quantitative tool to assess the building energy performance and GHG emissions in small-neighbourhood level while ‘NEIGHBOURHOOD’ platform is a qualitative tool to display the information related with the energy performance and GHG emissions in large-neighbourhood level.

The dual platform system helps architects to be able to make effective designs to reduce GHG emissions in neighbourhood. ‘BUILDING’ platform provides the building performance interacting with the building design while ‘NEIGHBOURHOOD’ platform provides with the environmental information for the site analysis.

Architectural works have different methodologies which can contribute to the reduction of energy use and GHG emissions in different neighbourhood levels. In small-neighbourhood level, building design can be improved toward the GHG emission reduction. In large-neighbourhood level, building design can involve the spatial functions to reduce urban emissions as a part of urban energy planning, and architectural works can provide the urban planning with the possibility of energy saving in building.

According to the characteristics of architectural works, it is essential to have the two different platforms where key architectural information is exchanged between them since ‘BUILDING’ platform assesses the energy performance of the building design which the environmental conditions from ‘NEIGHBOURHOOD’ platform are applied. Besides ‘NEIGHBOURHOOD’ platform integrates the energy efficiency and GHG emissions of buildings calculated from ‘BUILDING’ platform. Thus, the integration of the two platforms enables to monitor the energy and emission performance of neighbourhood at the same time.

Architect-oriented visualisation in ‘BUILDING’ platform

‘BUILDING’ platform as an interface for architects provides intuitive control boxes for architects. The Input Table of the platform uses the terminology and visual information for architect. Although the information in the System and Life Cycle Data of Input Table is for the other stakeholders such as engineers and environment experts, the terminologies of System and Life Cycle Data were refined as the terms which architects can understand. Especially, Life Cycle Data is visualised as the upstream flow of material and energy production which architects can understand, rather than the detailed data required for the environment analysis. The information of Life Cycle Data is visualised as the material flows of the defined products. Through the material flows, architects can understand the schematic life cycle flow of the products.

In Output Table, the outcome of embodied emissions, emission distribution and heating load are visualised as the distribution of building elements, building materials, and components, respectively. In addition, the outcome of total energy need is visually subdivided into heating, cooling, lighting, ventilation, and electric appliances. The visual distributions can help architects easily understand which parts should be considered to improve the outcomes.

Integrated information toward one in ‘NEIGHBOURHOOD’ platform

The main objective of ‘NEIGHBOURHOOD’ platform is to reduce GHG emissions in neighbourhood. By Showing the information about the main contributors of GHG emission in a neighbourhood, this platform can guide stakeholders to establish urban planning with reduced GHG emissions. Through the review of existing dashboards (Chapter 4) and Dashboard design (Chapter 5), this study has figured out that there are a lot of web-based platforms to provide information regarding GHG emissions, energy efficiency, transportation, spatial quality, and demographics in neighbourhood level. However, most web-based platforms only show limited information with different KPIs for the assessment of GHG emissions in neighbourhoood scale. For example, Sustainability Dashboard (Chapter 4.2.3) provides the information related with spatial quality and demographics while CityBES focuses on GHG emissions and energy efficiency of neighbourhoods (Chapter 4.2.1). 'NEIGHBOURHOOD' platform developed in this work integrates most criteria for the assessment of GHG emissions except for economy part in the perspective of ZEN assessment criteria (Chapter 2.2.1). 'NEIGHBOURHOOD' platform also uses various city data provided in the municipality or research organisation. By interconnecting with city data, 'NEIGHBOURHOOD' platform can update the information in real time. The platform can provide the wide range of information for the GHG emission assessment by integrating city data related with the KPIs developed in this study (Chapter 2.3).

Comparison for alternatives

According to the characteristic of architectural works which are completed through the successive decisions among design alternatives, Dashboard has an interface which can compare different design options focused on various assessment criteria. In 'BUILDING' platform, Comparison Interface provides the comparable indicators such as total GHG emissions, total energy need, and emission balance for design alternatives. The interface can help architects make an effective decision for building design to reduce GHG emissions by excluding the worst design alternatives.

In the case of 'NEIGHBOURHOOD' platform, each assessment criteria provides the Assessment Diagram which indicates the comprehensive assessment regarding the indicators of each criteria. Since the diagram provides the assessment information for the selected boundary in the Display Window, several sites in the Display Window can be compared in the assessment regarding the indicators of each category.

7.2 Limitations for the Dashboard

Actual interconnection

As a conceptual assessment tool, Dashboard do not implement the actual interconnection with the computing tools and city data.

The data required for the energy performance and GHG emissions was performed through background software and manually visualised in the Dashboard. In the case study (Chapter 6), the 3D-modelling of Nidarvoll Skole design was generated in Sketch-up. Based on the model, the GHG emissions and energy demand of the school design was calculated by Sefaira, EnergyPlus, and ZEB Excel Tool. The calculated value was analysed and categorised for the visualisation of Dashboard. In the case of city data, the website information related with the assessment criteria was expressed in the Dashboard without the actual interconnection between the Dashboard and city data.

Regarding the whole process for the visualisation of Dashboard, this thesis does not guarantee the problems for the actual interconnection with the computing software and web-information. This study does not consider the technical issues for the compatibility between Dashboard and the software. Furthermore, this study does not consider the copyright for the use of the software and web information. Sefaira, Insight360, and ZEB Excel Tool used in this thesis were allowed only for the educational purpose or for this thesis. Accordingly, the issues such as software compatibility and information copyright should be dealt with for the actual interconnection in Dashboard.

Uncertainty

In case study, the building energy was calculated by Sefaira and Insight360 via EnergyPlus. Sefaira and Insight 360 generated the different result of energy calculation in the same building condition although both use EnergyPlus as their core energy calculation engine. The main reason is because the tools have their own default values which can calculate the energy performance with undefined or rough setting. Therefore, according to the selection of tool for the energy calculation, the energy performance can be different. The case study used Sefaira for the energy calculation of the kindergarten and administration building while Insight360 for the calculation of canteen since the models of kindergarten and administration building were made by using Sketch-up which had the compatibility with Sefaira while the model of canteen was generated by Revit which had the compatibility with Insight360. However, this study did not consider the error between the precise value and the value of tools for energy calculation. Moreover, weather information is necessary to calculation building energy performance. The case study, which was located in Trondheim, used Oslo weather database to the calculation since Trondheim weather information did not exist as the data required for the calculation.

In order to reduce the uncertainty for building energy performance, it is important to conduct the study for the differences between actual buildings energy and the energy simulation, and to build extensive range of database for accurate and consistent building energy calculation.

Verification of ‘NEIGHBOURHOOD’ platform

The main purpose of ‘NEIGHBOURHOOD’ platform is to provide a platform in which stakeholders can establish urban strategy to reduce the energy use and GHG emission of neighbourhoods through the visual information related with the assessment criteria. In order to achieve the purpose of the platform, it is necessary to verify the platform by applying a real case.

However, the assessment criteria such as GHG EMISSIONS and ENERGY EFFIENCY in ‘NEIGHBOURHOOD’ platform does not incorporate the real data for each indicator of the criteria since a great deal of time and works are required for the data analysis for the indicators. Thus, total GHG emissions and energy efficiency of Nidarvoll skole were not applied to the actual neighbourhood assessment in the case study. Moreover, in order to evaluate the usefulness of the ‘NEIGHBOURHOOD’ platform, this thesis does not include the actual participation of various stakeholders, except for architects and environment experts, related with urban planning and urban strategy for energy saving.

Therefore, in order to verify the practicality of ‘NEIGHBOURHOOD’ platform, the research for GHG emissions and energy performance of buildings in neighbourhood scale and more participations of stakeholders are required in case studies for the application of the Dashboard.

7.3 Response to research questions

RQ1. How can a neighbourhood design be related with GHG emissions, and how can the GHG emission of neighbourhood design be quantified and qualified for the emission reduction?

The relationship between neighbourhood design and GHG emission can be explained in two different level of neighbourhood, building-oriented level and urban-oriented level, since neighbourhood defined as a social interrelationship has two directionalities toward urban level and building level.

The GHG emission assessment of neighbourhood design reduction requires objective and well-organised assessment criteria and KPIs. Thus, this study conducted the analysis for various performance measurement systems which have well-organised assessment criteria and KPIs. The analysis shows the assessment criteria for the emission reduction are mainly categorised by GHG emissions, energy, mobility, and spatial quality. The criteria in GHG emissions and energy are calculated based on their indicators while the criteria in mobility and spatial quality are assessed qualitatively.

Moreover, this study reviewed the cases to handle the challenge for GHG emission reduction in different neighbourhood levels. In urban level, the efforts for the emission reduction were focused on energy grid, transportation, and spatial quality categories. On the other hand, the cases focus on the efforts for building energy efficiency in building level.

The GHG emission assessments in the two neighbourhood levels have different assessment criteria and KPIs. The assessment in building level includes total GHG emissions and energy efficiency criteria carried out by qualitative methodology. However, the assessment in urban level focuses on mobility and spatial quality implemented by qualitative methodology.

In building level, GHG emissions are mainly generated by embodied energy of building materials and by operational energy use of building, thus the GHG emissions can be assessed through the relationship between neighbourhood design and building energy. Building materials are selected in the material schedule stage and building façade design stage of the early design phase. The embodied energy from the selected materials and the embodied emission are calculated by life cycle assessment (LCA).

Meanwhile, building operational energy is mainly affected by building orientation, area, wall and window size, and envelope performance which are carried out in the early design phase. The GHG emission is calculated through LCA for the operational energy.

Therefore, energy-saving design for materials and building operation can reduce GHG emissions. Moreover, we can know that the early design phase is crucial for the emission reduction.

In urban level, GHG emission is affected by mobility and spatial quality. The promotion of Public transport use can reduce GHG emission since public transport can reduce travel miles, which lead to the fuel consumption, and improve traffic flow on the road by replacing private automobile.

High spatial quality in neighbourhoods can reduce travel miles since the spatial environment can reduce the user’s needs to leave elsewhere. By reducing travel miles, high spatial quality is attributed to GHG emission reduction.

In order to implement neighbourhood design, the assessment criteria related with mobility and spatial quality can be visualised through the graph, table, distribution, and mapping as a qualitative assessment method.

Therefore, GHG emission assessment should be carried out by different methodologies in each level of neighbourhood in order to perform the effective assessment.

RQ2. What are the drawbacks of existing visual tools for the neighbourhood assessment and how we can develop a new tool for the effective visualisation toward zero-emission neighbourhood?

The concept of current tools is divided into two characteristics in the perspective of different neighbourhood levels. In building scale, the tools such as Sefaira and Insight360 provide energy performance of building design, plugged in main architectural design software. Integrated Excel tool as a tool to calculate GHG emission is based on Excel tool. Energy and emission assessment are quantified by collaborating among expert teams of various sectors. The visualisation and information flow of the tools are optimised for users.

In urban scale, the tools for sustainable neighbourhood have a main concept to share information from various sectors. The platforms provide an easy-to-understand and optimized visual language which enables various stakeholders to establish the environmental strategy effectively.

In the perspective of users, the building-oriented tools have an interface for architects. Sefaira and Insight360 are tools to perform energy simulation for 3D-building models designed. In the visualisation, both generates understandable outputs for architects. However, in the mechanical and electric engineering sectors, the toolboxes which require the input data are not understandable for architects due to technical terminology and complicated set-up. ZEB Excel tool has a classification system which architects can understand. However, it is not easy for architects to understand the classification for operational energy demand. The neighbourhood-oriented tools such as CityBES and E-CITY have map-based visual information which stakeholders can understand.

Although technical information is required in a tool, an integrated tool with other fields should have understandable visualisation for the main user. Map-based display used in the neighbourhood-oriented tools is powerful for various stakeholders to understand the information of the tools.

RQ3. How can a new tool be proposed and visualised for the understanding of the relationship between neighbourhood and GHG emissions and for the optimal architectural design with emission reduction?

Based on the hierarchy of socio-ecological neighbourhood, KPIs analysis, and the review of recent tools, ZEN Dashboard provides main two platforms in small- and large-neighbourhood scale.

Small-neighbourhood platform as a quantitative tool calculates energy performance and GHG emissions for neighbourhood design. Architects, engineers, and environmental experts share the technical information that can give feedback to the other sectors.

Large-neighbourhood platform as a qualitative tool provide city information in order to make effective strategy for GHG emissions reduction through the map-based display where various information can be layered, thus it enables stakeholders to make decisions with comprehensive judgment.

Moreover, key architectural information is exchanged between 'BUILDING' and 'NEIGHBOURHOOD' platforms. 'NEIGHBOURHOOD' platform integrates energy efficiency and GHG emissions calculated from 'BUILDING' platform. With the environmental conditions from 'NEIGHBOURHOOD' platform, 'BUILDING' platform evaluates the energy performance of the building design. Thus, the integration of the two platforms enables to monitor the energy and emission performance of neighbourhood simultaneously

RQ4. How can the proposed visual tool be applied to the case study of Nidarvoll Skole, and how can the tool contribute to the GHG emission reduction of the case study?

According to the early design process – the site analysis, massing study, and basic design, the ZEN Dashboard carried out the evaluation for GHG emissions and energy performance by using the 3D-modelled design of the ZEN pilot project. Through the 'Comparison Interface', GHG emissions of various design options was compared. The amount of total energy need and total GHG emissions in the final design accounted for 92,371 kWh/yr and 22,616 kgCO2eq/yr. Compared with the initial alternative, the amount of 20,508 kWh/yr and 1,871 kgCO2eq/yr was reduced in the total energy need and total GHG emissions, respectively. Dashboard expressed the performance gaps among design alternatives with simple graphic information, thus the ZEN Dashboard helped choosing the Opt1-1 which has the least GHG emissions and building energy use in the alternatives.

8 Conclusion

In neighbourhood design has two orientations, or areas of focus, namely, building or neighbourhood -oriented design. In order to reduce GHG emission at a neighbourhood, the engagement of architects is critical particularly since architectural design involves communication with environmental strategy and planning in the urban level while at the same time involves collaboration with energy engineering in the building scale. This study developed a proof of concept ZEN and user interface that can support architects in their early decision-making process towards achieving zero-emission neighbourhood.

The ZEN Dashboard is a tool to assess neighbourhood performance for primarily GHG emissions and energy efficiency. The assessment of neighbourhood-oriented design requires objective and well-organised assessment criteria and key performance indicators (KPIs). The ZEN Dashboard is in accordance with a set of ZEN criteria and KPIs developed by the FME-ZEN Research Centre. Through the analysis of the ZEN assessment criteria and the investigation of the approach to address GHG emissions in different neighbourhood levels, the new criteria and KPIs for the ZEN Dashboard also incorporates demographics as an independent category. Moreover, the criteria of peak load in building was also included in the energy category for the building envelope assessment.

The framework of new assessment criteria and KPIs was reflected in the design concept and main structure of ZEN Dashboard. The Dashboard is mainly split into two platforms (‘BUILDING’ platform as a quantitative assessment tool and ‘NEIGHBOURHOOD’ platform as a qualitative assessment tool). The ‘BUILDING’ platform is divided into the ‘dashboard for materials’ which interacts with embodied emissions assessment and the ‘dashboard for operational energy use’ which interacts with building energy performance assessment. The ‘NEIGHBOURHOOD’ platform provides stakeholders with map-based information related with the assessment criteria and KPIs. The key information is exchanged between both the ‘BUILDING’ and ‘NEIGHBOURHOOD’ platforms. Thus, the integration of the two platforms enables the architect to monitor the energy and emission performance of neighbourhood simultaneously.

The ZEN Dashboard was applied to an actual ZEN pilot project at Nidarvoll Skole in Trondheim. The case study focused on the sustainable retrofit of kindergarten design incorporating both existing listed buildings and designs for new buildings. It was implemented during the early design phase in order to consider the energy performance and GHG emissions of various design options. Through the use of the ZEN Dashboard, a final design for the ZEN kindergarten was selected. The amount of total energy need and total GHG emissions in the final design accounted for 92,371 kWh/yr and 22,616 kgCO2eq/yr. Compared with the initial alternative, the amount of 20,508 kWh/yr and 1,871 kgCO2eq/yr was reduced in the total energy need and total GHG emissions, respectively. Due to the ZEN Dashboard, the performance differences between design alternatives were expressed with simple graphic information thus, enabling the use of the ZEN Dashboard to help architects in the early design phase to choose the most environmental alternative more intuitively.

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Appendices

Opt1-1

■ Opt1-1 of New Kindergarten

Project Work	Building	Building Level	Heated floor area (BRA) (㎡)	Volume (㎥)	*Total Exterior wall area (㎡)	Note
Opt1-1	NEW	1 Story	1,250	5,875		
Total			1,250	5,875		

* Total Exterior wall area is a value of modelling from Sketch-up.

■ Room descripton

Building	Floor	No.	Room	BRA (㎡)	Volume (㎥)	Note(Height,m)
NEW Kindergarten	1st Floor	*Sefaira	*Sefaira	1,250	5,875	4.7
	Total			1,250	5,875	
				1,250	5,875	

*Room descripton comes from Sefaira.

■ U-value of envelope materials

Project Work	U-value (W/㎡K)					Note
	Wall	Roof	Floor	Door	Window	
Opt1-1	0.11	0.11	0.10	0.11	0.65	Goia et al., 2015

* The U-value refers to previous ZEB case study, the Living Laboratory in NTNU (Goia et al., 2015)

■ Unit Conversion Factors

btu / hour	0.29307107	watts
ft²	0.092903	㎡

■ CO2 emission factor of Norwegian power production

Energy Type	*Emission Factor (g/kWh)
Electricity	132
District heating	140

■ Energy demand and Total GHG emission (without PV)

Project	Total Energy Need (kWh/㎡/yr)	Total Energy Need(kWh/yr)	Total GHG emissions (kgCO2eq/yr)	Total GHG emissions (kgCO2eq/㎡/y
Opt1-1	73.90	92,371	12,280	9.82

■ Total Eergy Demand

	Total Enery Need (kWh/yr)	Rate (%)
Heating	10,879.00	11.78
Cooling	10,918.00	11.82
Interior Lighting	34,234.00	37.06
Interior Equipment	22,822.00	24.71
Fans	13,518.00	14.63
Total	92,371.00	100.00

■ Total GHG Emissions

	Total Enery Need (kWh/yr)	*Total GHG Emissions (kgCO2eq/yr)	*Total GHG Emissions (kgCO2eq/㎡/y	Rate (%)
Heating	10,879.00	1,523.06	1.22	12.40
Cooling	10,918.00	1,441.18	1.15	11.74
Interior Lighting	34,234.00	4,518.89	3.62	36.80
Interior Equipment	22,822.00	3,012.50	2.41	24.53
Fans	13,518.00	1,784.38	1.43	14.53
Total	92,371.00	12,280.00	9.82	100.00

* It is assumed that all heating sources come from Distict heating(waste) while the others come from Electricity.

■ Peak Heating

Components	A block	
	Heating Loads	
	(W)	(kW)
Wall	-2,149.00	-2.15
Window	-1,722.10	-1.72
Door	0.00	0.00
Roof	-1,260.10	-1.26
Floor	-580.50	-0.58
Others	-61.40	-0.06
total	**-5,773.10**	**-5.77**

■ Energy Profile

Opt1-1	Energy Source	Energy Carriers		Delivered (A)		Total Generation (B+C)	
Operational Energy Demand	Heating	Delivered (A)		10,879			
	Elec.	Total Elec. Demand	Delivered (A)		19,712		
			Self-Consumption (C)			61,780	
		Exported (B)					29,776

PV Generation	91,556		Self Generation (%)	66.88%
PV Energy Use	61,780		Self Consumption (%)	67.48%

Opt1-2

■ Opt1-2 of New Kindergarten

Project Work	Building	Building Level	Heated floor area (BRA) (㎡)	Volume (㎥)	*Total Exterior wall area (㎡)	Note
Opt1-2	NEW	1 Story	1,250	5,875		
Total			1,250	5,875		

* Total Exterior wall area is a value of modelling from Sketch-up.

■ Room descripton

Building	Floor	No.	Room	BRA (㎡)	Volume (㎥)	Note(Height,m)
NEW Kindergarten	1st Floor	*Sefaira	*Sefaira	1,250	5,875	4.7
	Total			1,250	5,875	
				1,250	5,875	

*Room descripton comes from Sefaira.

■ U-value of envelope materials

Project Work	U-value (W/㎡K)					Note
	Wall	Roof	Floor	Door	Window	
Opt1-2	0.11	0.11	0.10	0.11	0.65	Goia et al., 2015

* The U-value refers to previous ZEB case study, the Living Laboratory in NTNU (Goia et al., 2015)

■ Unit Conversion Factors

btu / hour	0.29307107	watts
ft²	0.092903	㎡

■ CO2 emission factor of Norwegian power production

Energy Type	*Emission Factor (g/kWh)
Electricity	132
District heating	140

■ Energy demand and Total GHG emission (without PV)

Project	Total Energy Need (kWh/㎡/yr)	Total Energy Need (kWh/yr)	Total GHG emissions (kgCO2eq/yr)	Total GHG emissions (kgCO2eq/㎡/y
Opt1-2	89.69	112,109	14,924	11.94

■ Total Eergy Demand

	Total Enery Need (kWh/yr)	Rate (%)	
Heating	15,681.00	13.99	50.35
Cooling	22,933.00	20.46	73.64
Interior Lighting	34,234.00	30.54	109.93
Interior Equipment	22,822.00	20.36	73.29
Fans	16,439.00	14.66	52.79
Total	112,109.00	100.00	360.00

■ Total GHG Emissions

	Total Enery Need (kWh/yr)	*Total GHG Emissions (kgCO2eq/yr)	*Total GHG Emissions (kgCO2eq/㎡/y	Rate (%)
Heating	15,681.00	2,195.34	1.76	14.71
Cooling	22,933.00	3,027.16	2.42	20.28
Interior Lighting	34,234.00	4,518.89	3.62	30.28
Interior Equipment	22,822.00	3,012.50	2.41	20.19
Fans	16,439.00	2,169.95	1.74	14.54
Total	112,109.00	14,923.84	11.94	100.00

* It is assumed that all heating sources come from Distict heating(waste) while the others come from Electricity.

■ Peak Heating

Components	A block	
	Heating Loads	
	(W)	(kW)
Wall	-2,338.40	-2.34
Window	-1,720.70	-1.72
Door	0.00	0.00
Roof	-1,288.50	-1.29
Floor	-611.90	-0.61
Others	-61.40	-0.06
total	**-6,020.90**	**-6.02**

■ Energy Profile

Opt1-2	Energy Source	Energy Carriers		Delivered (A)		Total Generation (B+C)	
Operational Energy Demand	Heating	Delivered (A)		15,681			
	Elec.	Total Elec. Demand	Delivered (A)		21,047		
			Self-Consumption (C)			75,381	
		Exported (B)					16,175

PV Generation	91,556		Self Generation (%)	67.24%
PV Energy Use	75,381		Self Consumption (%)	82.33%

Opt2

■ Opt1-2 of New Kindergarten

Project Work	Building	Building Level	Heated floor area (BRA) (㎡)	Volume (㎥)	*Total Exterior wall area (㎡)	Note
Opt1-2	NEW	1 Story	1,250	5,875		
Total			1,250	5,875		

* Total Exterior wall area is a value of modelling from Sketch-up.

■ Room descripton

Building	Floor	No.	Room	BRA (㎡)	Volume (㎥)	Note(Height,m)
NEW Kindergarten	1st Floor	*Sefaira	*Sefaira	1,250	5,875	4.7
	Total			1,250	5,875	
				1,250	5,875	

*Room descripton comes from Sefaira.

■ U-value of envelope materials

Project Work	U-value (W/㎡K)					Note
	Wall	Roof	Floor	Door	Window	
Opt1-2	0.11	0.11	0.10	0.11	0.65	Goia et al., 2015

* The U-value refers to previous ZEB case study, the Living Laboratory in NTNU (Goia et al., 2015)

■ Unit Conversion Factors

btu / hour	0.29307107	watts
ft²	0.092903	㎡

■ CO2 emission factor of Norwegian power production

Energy Type	*Emission Factor (g/kWh)
Electricity	132
District heating	140

■ Energy demand and Total GHG emission (without PV)

Project	Total Energy Need (kWh/㎡/yr)	Total Energy Need (kWh/yr)	Total GHG emissions (kgCO2eq/yr)	Total GHG emissions (kgCO2eq/㎡/y
Opt1-2	90.30	112,879	15,041	12.03

■ Total Eergy Demand

	Total Enery Need (kWh/yr)	Rate (%)
Heating	17,639.00	15.63
Cooling	23,655.00	20.96
Interior Lighting	33,529.00	29.70
Interior Equipment	21,020.00	18.62
Fans	17,036.00	15.09
Total	112,879.00	100.00

■ Total GHG Emissions

	Total Enery Need (kWh/yr)	*Total GHG Emissions (kgCO2eq/yr)	*Total GHG Emissions (kgCO2eq/㎡/y	Rate (%)
Heating	17,639.00	2,469.46	1.98	16.42
Cooling	23,655.00	3,122.46	2.50	20.76
Interior Lighting	33,529.00	4,425.83	3.54	29.42
Interior Equipment	21,020.00	2,774.64	2.22	18.45
Fans	17,036.00	2,248.75	1.80	14.95
Total	112,879.00	15,041.14	12.03	100.00

* It is assumed that all heating sources come from Distict heating(waste) while the others come from Electricity.

■ Peak Heating

Components	A block	
	Heating Loads	
	(W)	(kW)
Wall	-2,338.40	-2.34
Window	-1,720.70	-1.72
Door	0.00	0.00
Roof	-1,288.50	-1.29
Floor	-611.90	-0.61
Others	-61.40	-0.06
total	**-6,020.90**	**-6.02**

■ Energy Profile

Opt1-2	Energy Source	Energy Carriers		Delivered (A)		Total Generation (B+C)	
Operational Energy Demand	Heating	Delivered (A)		17,639			
	Elec.	Total Elec. Demand	Delivered (A)		23,308		
			Self-Consumption (C)			71,932	
		Exported (B)					6,527

PV Generation	78,459		Self Generation (%)	63.72%
PV Energy Use	71,932		Self Consumption (%)	91.68%

Opt1-1

Scope	
Databases Used	EPDs, EcoInvent v3.1
Lifetime of Construction (years)	60
Heated floor area - BRA (sqm)	1250
Functional Unit	1sqm over a 60 yr lifetime
Building Site	Oslo

Informasjon
Denne fanen viser totalresultatene. Resultatene er vist for hver bygningsdel ifht. NS3451:20 hver livssyklusmodul ifht. EN 15978. Arket er koplet, så det er kun nødvendig å fylle inn area C4). Det er anbefalt å bruke en bygningslevetid på 60 år (celle C3).Oslo er valgt som default byggeplass beliggenhet, men man kan også endre dette i celle C6. NB: Endring av byggeplass beliggenhet tar noen sekunder.

Building Element		A1 - A3	A4	A5	B4	B6	$kgCO_{2eq}$	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2$	$kgCO_{2eq}/m^2/yr$	Contribution
2 Building	20 Building, general										
	21 Groundwork and Foundations	205758				0	205758	3429	164.6	2.74	15.2 %
	22 Superstructure	148000				0	148000	2467	118.4	1.97	10.9 %
	23 Outer walls	463880				0	463880	7731	371.1	6.19	34.2 %
	24 Inner walls	44791				0	44791	747	35.8	0.60	3.3 %
	25 Floor Structure	18713				0	18713	312	15.0	0.25	1.4 %
	26 Outer Roof	14394				0	14394	240	11.5	0.19	1.1 %
	27 Fixed Inventory	0				0	0	0	0.0	0.00	0.0 %
	28 Stairs and Balconies	3681				0	3681	61	2.9	0.05	0.3 %
	49 Other	210000				0	210000	3500	168.0	2.80	15.5 %
	Construction		0	0			0	0	0.0	0.00	0.0 %
	Operation					247737	247737	4129	198.2	3.30	18.3 %
	$kgCO_{2eq}$	1109216	0	0	0	247737	1356953	22616	1085.6	18.09	
	$kgCO_{2eq}/yr$	18487	0	0	0	4129					
	$kgCO_{2eq}/m^2$	887.4	0.0	0.0	0.0	198.2					
	$kgCO_{2eq}/m^2/yr$	14.79	0.00	0.00	0.00	3.30					
	Contribution	81.7 %	0.0 %	0.0 %	0.0 %	18.3 %					

C	O	M	ZEB-COM	Production	Exported	On-site Energy	ZEB Balance
0.00	**3.30**	**14.79**	**18.09**	**-6.52**	**-3.14**	**-9.67**	8.42

Opt1-2

Scope	
Databases Used	EPDs, EcoInvent v3.1
Lifetime of Construction (years)	60
Heated floor area - BRA (sqm)	1250
Functional Unit	1sqm over a 60 yr lifetime
Building Site	Oslo

<u>Informasjon</u>
Denne fanen viser totalresultatene. Resultatene er vist for hver bygningsdel ifht. NS3451:20
hver livssyklusmodul ifht. EN 15978. Arket er koplet, så det er kun nødvendig å fylle inn area
C4). Det er anbefalt å bruke en bygningslevetid på 60 år (celle C3).Oslo er valgt som default
byggeplass beliggenhet, men man kan også endre dette i celle C6. NB: Endring av byggeplass
beliggenhet tar noen sekunder.

Building Element		A1 - A3	A4	A5	B4	B6	$kgCO_{2eq}$	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2$	$kgCO_{2eq}/m^2/yr$	Contribution
2 Building	20 Building, general										
	21 Groundwork and Foundations	205758				0	205758	3429	164.6	2.74	14.3 %
	22 Superstructure	148000				0	148000	2467	118.4	1.97	10.3 %
	23 Outer walls	463880				0	463880	7731	371.1	6.19	32.3 %
	24 Inner walls	44791				0	44791	747	35.8	0.60	3.1 %
	25 Floor Structure	18713				0	18713	312	15.0	0.25	1.3 %
	26 Outer Roof	41231				0	41231	687	33.0	0.55	2.9 %
	27 Fixed Inventory	0				0	0	0	0.0	0.00	0.0 %
	28 Stairs and Balconies	3681				0	3681	61	2.9	0.05	0.3 %
	29 Other	0				0	0	0	0.0	0.00	0.0 %
	49 Other	210000				0	210000	3500	168.0	2.80	14.6 %
	Construction		0	0			0	0	0.0	0.00	0.0 %
	Operation					298754	298754	4979	239.0	3.98	20.8 %
	$kgCO_{2eq}$	1136053	0	0	0	298754	1434807	23913	1147.8	19.13	
	$kgCO_{2eq}/yr$	18934	0	0	0	4979					
	$kgCO_{2eq}/m^2$	908.8	0.0	0.0	0.0	239.0					
	$kgCO_{2eq}/m^2/yr$	15.15	0.00	0.00	0.00	3.98					
	Contribution	79.2 %	0.0 %	0.0 %	0.0 %	20.8 %					

C	O	M	ZEB-COM	Production	Exported	On-site Energy	ZEB Balance
0.00	3.98	15.15	19.13	-7.96	-1.71	-9.67	9.46

Opt2

Scope	
Databases Used	EPDs, EcoInvent v3.1
Lifetime of Construction (years)	60
Heated floor area - BRA (sqm)	1250
Functional Unit	1sqm over a 60 yr lifetime
Building Site	Oslo

Informasjon

Denne fanen viser totalresultatene. Resultatene er vist for hver bygningsdel ifht. NS3451:20
hver livssyklusmodul ifht. EN 15978. Arket er koplet, så det er kun nødvendig å fylle inn area
C4). Det er anbefalt å bruke en bygningslevetid på 60 år (celle C3).Oslo er valgt som default
byggeplass beliggenhet, men man kan også endre dette i celle C6. NB: Endring av byggeplass
beliggenhet tar noen sekunder.

Building Element		A1 - A3	A4	A5	B4	B6	$kgCO_{2eq}$	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2$	$kgCO_{2eq}/m^2/yr$	Contribution
2 Building	20 Building, general										
	21 Groundwork and Foundations	205758				0	205758	3429	164.6	2.74	14.0 %
	22 Superstructure	148000				0	148000	2467	118.4	1.97	10.1 %
	23 Outer walls	463880				0	463880	7731	371.1	6.19	31.6 %
	24 Inner walls	44791				0	44791	747	35.8	0.60	3.0 %
	25 Floor Structure	18713				0	18713	312	15.0	0.25	1.3 %
	26 Outer Roof	41231				0	41231	687	33.0	0.55	2.8 %
	27 Fixed Inventory	0				0	0	0	0.0	0.00	0.0 %
	28 Stairs and Balconies	3681				0	3681	61	2.9	0.05	0.3 %
	29 Other	0				0	0	0	0.0	0.00	0.0 %
	49 Other	210000				0	210000	3500	168.0	2.80	14.3 %
	Construction		0	0			0	0	0.0	0.00	0.0 %
	Operation					333160	333160	5553	266.5	4.44	22.7 %
	$kgCO_{2eq}$	1136053	0	0	0	333160	1469213	24487	1175.4	19.59	
	$kgCO_{2eq}/yr$	18934	0	0	0	5553					
	$kgCO_{2eq}/m^2$	908.8	0.0	0.0	0.0	266.5					
	$kgCO_{2eq}/m^2/yr$	15.15	0.00	0.00	0.00	4.44					
	Contribution	77.3 %	0.0 %	0.0 %	0.0 %	22.7 %					

C	O	M	ZEB-COM	Production	Exported	On-site Energy	ZEB Balance
0.00	**4.44**	**15.15**	**19.59**	**-7.60**	**-0.69**	**-8.29**	11.30