ZEN TOOLBOX

First concept for the ZEN Toolbox for use in the development of Zero Emission Neighbourhoods
Version 1.0

ZEN MEMO No. 14 – 2018

Aoife Houlihan Wiberg, Daniela Baer | NTNU, SINTEF

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

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Norwegian University of Science and Technology (NTNU) | www.ntnu.no
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Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Tegn_3 , Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk (NTE), Smart Grid Services Cluster, Statkraft Varme, Energy Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m^2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Abstract

This memo presents a first draft of a concept for the ZEN toolbox, which should be used as a basis for further discussion and joint development with the other work packages. This concept is based on the results of the first year of work within work package 1.3 in the ZEN research Centre. This first concept should be understood as a starting point for discussion and as a basis for further development, with input from all the ZEN working packages and partners. The memo is one output from WP 1.3, in parallel with a report by Baer (2019) entitled *'Tools for Stakeholder Engagement in Zero Emission Neighbourhood developments. Mapping of tools in use in Trondheim, Steinkjer, Elverum and Bodø.'* In addition, a draft report has been prepared by Houlihan Wiberg (2018) entitled *'Architectural and Urban Tools for Planning and Design in ZEN. 'State of the art' planning and design tools for use in the ZEN pilot projects.'* Houlihan Wiberg and Baer prepared the draft report and the stakeholder memo independently, and this memo brings together and draws upon the findings of their previous work in a joint vision for the development of a user-centred architectural and urban toolbox for design and planning, operation and monitoring of a ZEN.

In this joint memo, a broad conceptual framework for the development of the ZEN Toolbox is presented. The concept is such that the toolbox should contain, at its core, a set of technical and non-technical tools for use in the planning, design, and monitoring of a ZEN according to the demand for diverse tools and approaches within the ZEN pilot projects and amongst the ZEN partners. The framework for the ZEN toolbox presents the connection to the ZEN Definition, categories, and KPIs and later describes the interconnection with other parameters which influence the use and application of the toolbox.

The design of the framework for the toolbox is deliberately broad and flexible, so that other tools currently being developed in the other work packages can be easily accommodated within the framework of the toolbox. Some of these tools will be developed within the ZEN Centre, whilst others are already in use in practice. An example of how selected tools may be integrated into the toolbox, together with an example of a user scenario, is described in the memo.

Future work will identify the most promising tools, including both those currently being developed within ZEN and those made by others, in order to make a more detailed analysis of expected tool usage and their inherent, associated challenges. This is needed in order to decide which tools need to be used and developed in the ZEN Centre and other related projects to assess a ZEN. This work will be coordinated with WP1.1, whose focus is on ZEN KPIs and data management as well as on the ICT architecture. This work will be coordinated with specific work packages to give an overview of the most relevant tools to be included in the core of the ZEN toolbox. The framework for the ZEN Toolbox should support and be usable by all the work packages and for use in the implementation of the pilot projects.

Content

1 Introduction

To plan, design, implement, and monitor neighbourhoods that have an ambition to become zero emission is a challenging task, since it requires the integration of a scientifically based GHG emissions approach in each stage of the development of a zero emission neighbourhood, herein referred to as a ZEN. Every small decision taken in the development or transformation process must be assessed with regard to its impact on GHG emissions in terms of spatial and mobility planning, the choice of materials, and the construction method. A first output of the ZEN Research Centre was the development of the ZEN definition and Key Performance Indicators (KPIs) (Kjendseth Wiik et al., 2018a). These will be used in the nine proposed ZEN pilot projects as a means to set ambition levels and to assess their progress with regard to achieving the zero emission ambition.

In addition, there is a need for tools that are designed to improve stakeholder participation in the planning, design, managing, and monitoring of ZEN developments. In accordance to the research being conducted within the project on *'Planning Instruments for Smart Energy Communities'* (PI-SEC, Nielsen et al., 2017), a tool is defined as an instrument used for a specific purpose.

A major barrier to the implementation of sustainability in design has been that existing tools and technologies often lack a common collaborative platform, lack interoperability, are time consuming and too complex for designers to integrate into design. Moreover, they are not designed to encourage stakeholder participation. The possibility to create 'access points' to connect these visualisation tools and immersive technologies into the framework of the ZEN Toolbox needs to be developed in order to enable their integration into existing design workflows. This would provide users with more efficient ways to perform complex environmental analyses. In addition, design reviews during the design process could be conducted by immersing diverse stakeholders in the virtual world of the digital twin, thus maximizing the user experience and feedback possibilities. High-performance visualisation and virtual prototyping capabilities would enable the user to review, analyse, and validate different design scenarios and performance simulations in real-time. This has huge potential to transform not only research and practice in terms of communication, thus increasing participation by diverse stakeholders, but also in education across diverse fields. Research shows that students engaged in an active learning experiences, such as VR have a more than a 75% retention rate, compared to 5-10% using passive learning methods, such as in lectures. Virtual and immersive technologies would enable them to develop and improve learning and problem solving in other settings such as in the workplace, in practice and to be involved in collaborative projects worldwide. Intelligent, real-time multi objective optimisation for future ZENs could be achieved through the integration of emerging AR and VR technologies in immersive environments for diverse and improved stakeholder participation (Houlihan Wiberg, 2018).

The goal of this memo is to provide a description of a first concept for the framework of the ZEN Toolbox for use by all work packages. It will provide the following:

1. A broad framework to accommodate different types of tools already in use as well as those that will be developed within the duration of the ZEN Centre. The framework for the tool integration proposal will demonstrate simple tool usage and interrelationship.
2. Improved stakeholder participation by developing a connection between the ZEN Toolbox and relevant parameters described in the following sections.
3. Improved stakeholder participation by using visualisation tools and technologies, i.e. *AR, VR,* and User Interfaces, i.e. *Dashboards*, and to facilitate the connection between the ZEN Toolbox and the parameters described in the following sections.

Chapter 2 will present how the ZEN toolbox relates to the ZEN definition and its KPIs as well as present the framework for the toolbox and the parameters relevant for it.

Chapter 3 presents an example for how tools can be integrated in the toolbox and an example of how the toolbox is usable by different stakeholders.

Chapter 4 presents the conclusion and chapter 5 future work.

2 Concept for ZEN Toolbox

This chapter presents the first concept for the framework of the ZEN toolbox. Section 2.1 presents the interrelationship between the ZEN definition and KPIs, and their relevance for the tools in the core of the Toolbox. In this section, the framework is presented on a more general basis, as shown in figure 1, by illustrating how the toolbox contains a core of tools which are connected to the KPIs as defined in the ZEN definition. A generic example is included to describe how the toolbox could be used in other countries outside Norway using more country specific tools.

To illustrate how more specifically ZEN could use the Toolbox, examples of tools which are in use by researchers and partners of the ZEN Centre are shown in Table 1. A key feature of the toolbox is its flexibility to integrate new tools, as such will be developed by ZEN during the course of Centre.

Section 2.2 will present the framework for the ZEN toolbox in more detail. An overview is included in Figure 3, which describes how the core tools are connected to the parameters which are described in more detail in section 2.3. This section will also describe how the choices made in these parameters influence the use and application of the toolbox.

Finally, chapter 2.3 describes each of the parameters included in the framework for the ZEN toolbox in more detail.

2.1 The ZEN Toolbox, the ZEN Definition, and the ZEN KPIs

The ZEN toolbox needs to be aligned with all the work packages in ZEN, not only with Work package 1, and to the ZEN Definition and KPIs. A report with a focus on how the ZEN toolbox could be used in real life cases/pilot projects will be an important future deliverable. It will describe the applicability of the toolbox to the pilot projects. The latter is referred to as the ZEN Toolbox guideline, indicated as an output from the toolbox indicated in yellow in Figure 1 below.

Concerning the organisation of the framework for the Toolbox, the choice of tools appropriate for a specific purpose depends upon a number of relevant parameters, such as stakeholders, contexts, scope, and phase of development. These are described in more detail later in this memo. Figure 1 shows a diagram of how the ZEN Definition, the Key Performance indicators (KPIs), and the core part of the toolbox, which contains the tools, are interconnected. See Appendix 1 for an overview of the ZEN categories, their assessment criteria and KPIs.

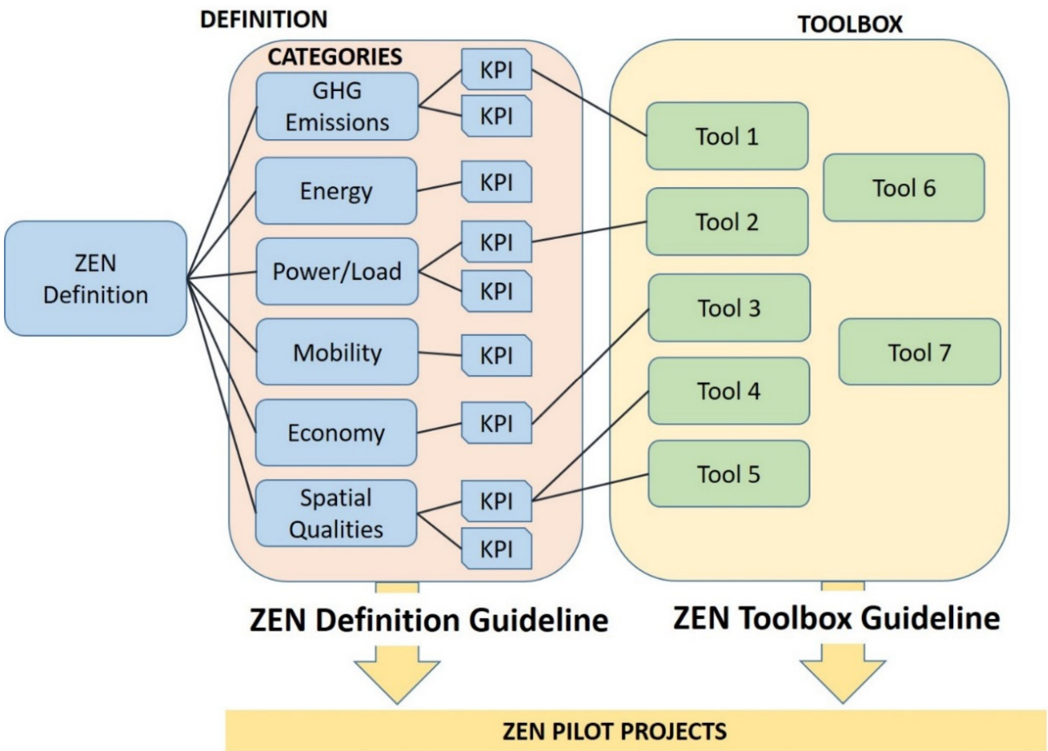


Figure 1. *Concept for the ZEN Toolbox and how it relates to the ZEN assessment criteria and KPIs.*

As shown in Figure 1, each ZEN criteria will be assessed through a number of KPIs. For example, GHG emissions can be measured in kgCO2eq per functional unit and percentage reduction compared to a reference case. Some tools can assess a multiple number of KPIs simultaneously, for example CITYBES, whilst other tools are designed to assess only one KPI, for example the ZEB Tool. The choice of tool is also influenced by a range of parameters other than the KPIs, which nevertheless are important for the planning and design of a ZEN. Many tools already exist, and others will be developed within the duration of the ZEN Centre. All of these tools should be included in the ZEN Toolbox.

Figure 2 below shows how specific tools used in the different work packages in ZEN could be connected to the different ZEN categories, criteria, and KPIs. It should be noted that these are examples of specific tools known to be used in the ZEN work packages. As mentioned above, new tools will be developed within the duration of the Centre, and the toolbox should be flexible enough to accommodate these tools in the future.

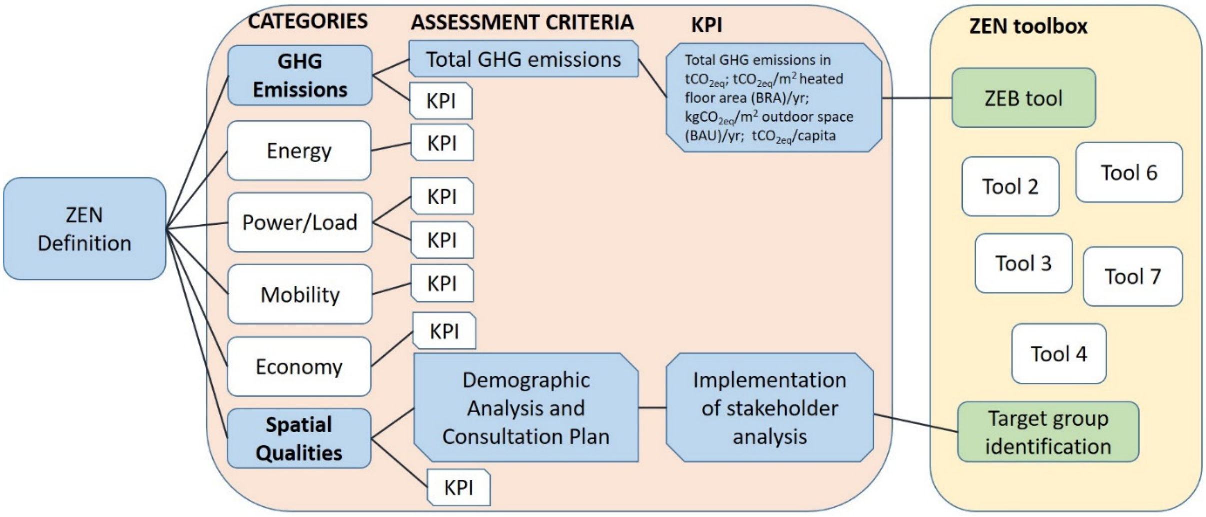


Figure 2. *Example of how some tools in the ZEN Toolbox can be used.*

A list of possible tools used in ZEN by a couple of selected stakeholders is included in Table 1. This list is indicative and should not be considered exhaustive. Another example of how the toolbox could be used by a selected stakeholder for a specific purpose can be seen in Figure 9 (at the end of the memo).

Table 1. *List of selected tools and stakeholders*

Selected stakeholder	Selected tool	Relevant category
Researchers	PI-SEC Planning Wheel	Spatial Qualities
	PI-SEC Indicator Tool	GHG emissions, Energy
	ZEB Tool	GHG emissions
	eTransport	GHG emissions Energy, Power/Load
	To be confirmed	Economics
	To be confirmed	Mobility
	GIS	Spatial Qualities, Mobility
Industrial and municipal partners	EFFEKT	GHG Emissions
	Fabric	GHG Emissions, Energy

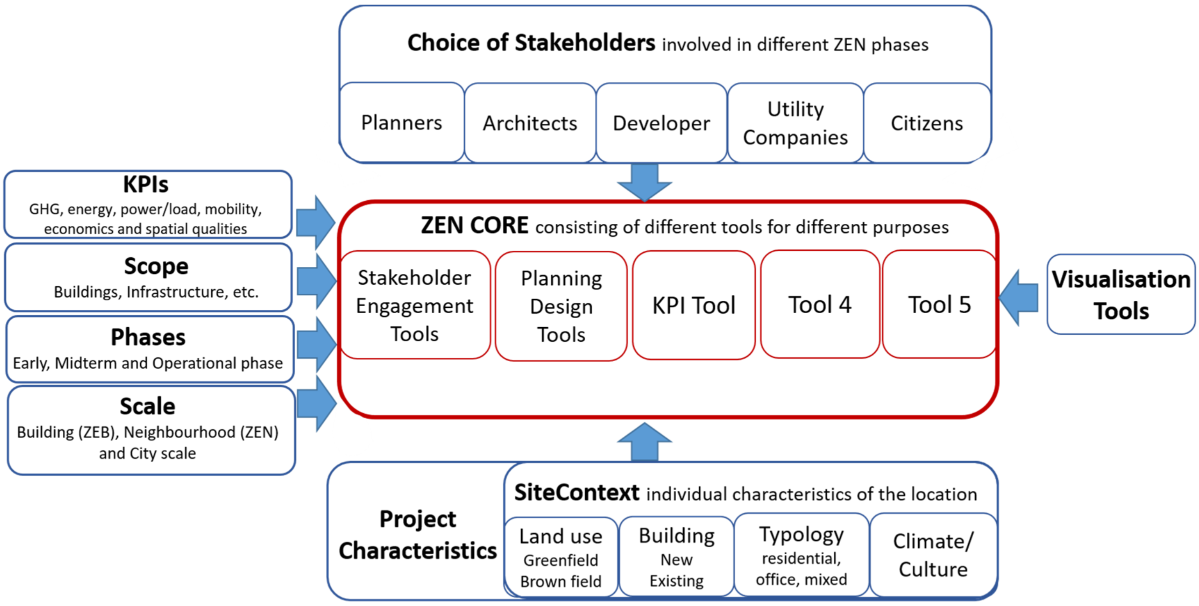
It is important that the framework of the toolbox, can be used in a generic way, to ensure the flexibility for other countries to use their own tools, data sources, databases, and to choose their own ZEN definitions, criteria, and KPIs relevant to their own ZEN designs in their own countries. For this purpose, the toolbox could instead include suggestions for generic tools instead of specific tools, as shown in the yellow box in Figure 2. For example, generic examples could include a description of the GHG Tool instead of the more specific ZEB Tool used in ZEN, or another example could be to include a description of an Energy Simulation Tool instead of EnergyPlus or Simien.

Different tools are used for different purposes. For example, some tools are used for analysing detailed data from one of the KPIs, e.g. energy consumption data from EnergyPlus or embodied emissions from materials in the ZEB Tool. Other tools analyse data from multiple KPIs simultaneously for use in planning and design, e.g. the CITYBES tool. Other tools may be used to visualize the data output from a different tool, e.g. the Fabric tool for neighbourhood planning. This tool is developed by Urbanetic and in use by the Bodø municipality. Finally, other tools may be used for specific purposes, e.g. they may be used solely for stakeholder engagement or monitoring purposes in the operational phase.

It is important that these tools are integrated in a flexible way in the framework of the ZEN toolbox so that they can interconnect with each other when needed but also function as stand-alone tools when required. The tools should also be accessible for different stakeholders with different ranges of expertise and for different uses depending on the selection of the different parameters as e.g. phase of ZEN development, KPI or context and project characteristics. These parameters will be described in the next section. There are also tools which are not covered within the scope of the ZEN Centre, but that nevertheless are important for the development of a ZEN, e.g. tools used for transportation planning.

2.2 Framework for the ZEN Toolbox

The report on the mapping of the ZEN pilot projects (Baer/Andresen, 2018) highlights the diversity in project characteristics and contexts in each of the ZEN pilot projects (see Appendix 2 and 3). It is important to take this into account. This requires flexibility in toolbox design, as it has to be able to integrate a variety of tools that can respond to different contexts and conditions. The parameters shown in Figure 3 influence the choice of tools.



Note: A blue arrow represents the 'Access Points' in ZEN Toolbox between surrounding parameters and tools contained in the ZEN Core.

Figure 3. *First concept of the ZEN toolbox and the parameters influencing the choice of tools.*

Several factors therefore need to be taken into consideration in the further development of the toolbox. The ZEN Toolbox would contain a core of different types of tools (technical and non-technical), which can be selected as a standalone tool or in different combinations depending on the following choice of parameters:

- Choice of stakeholders i.e. *planners, architects & engineers, researchers and citizens amongst others.*
- Choice of KPI(s) i.e. *GHG, energy, power/load, mobility, economics and spatial qualities*
- Choice of scope *i.e. building, infrastructure etc.*
- Choice of design phase i.e. *strategic long term planning (early), Tactical mid-term planning, implementation, and Operational phase.*
- Choice of scale i.e. building (ZEB), neighbourhood (ZEN) and city level
- Choice of site contexts and individual project characteristics i.e. *new and existing, greenfield and brownfield; building typology (residential, office, mixed use)*

2.3 Definitions of Parameters in the ZEN Toolbox

In the following section, the parameters are described in more detail together with the extent to which they influence the choice of tool(s) in the ZEN Toolbox.

2.3.1 Stakeholders

Stakeholders are defined as any individuals, groups or organizations, coming from different disciplines and with different needs, responsibilities, and resources. Examples of stakeholders who would use the toolbox include, amongst others, citizens, planners, architects, engineers, and consultants. Different stakeholders may have varying levels of expertise with ZEN on a more general level and KPIs on a more specific level, but all are involved and need to participate in the development of a ZEN. In addition, some stakeholders are only involved in the early planning phase, whilst others might only be involved in the operational phase and others may be involved throughout all phases. The aim of the ZEN toolbox should be allow sufficient flexibility to accommodate all the types and needs of the stakeholders.

2.3.2 KPIs

It is important to ensure that the tools available for planning, designing, analysing, and monitoring the KPIs used in the ZEN definition are integrated in a flexible way in the ZEN toolbox. The tools should also be accessible for different stakeholders with different ranges of expertise and for use with the different parameters described in this section.

2.3.3 Scope

Different tools offer different possibilities to include different scopes of application, for example the ability to include buildings, infrastructure, public space, or transport at different stages of ZEN development. The focus in ZEN to date has been limited to buildings and infrastructure, although it is anticipated that the scope will be extended. When developing ZENs, different stakeholders are involved in planning and design. For example, in new developments technical infrastructure, or a sewage system, is often planned, designed, and implemented before the buildings and public spaces. The different scopes do not only have different characteristics and demands to plan, design, and implement for, but need to also refer to the other ZEN phases, scales, and stakeholders that need to be involved.

2.3.4 Phases of design

Three phases of development have been identified and defined in ZEN to date. These range from the strategic long-term planning phase, to the tactical mid-term and implementation phase, and to the operational phase. As found by Baer and Andresen (2018), each of the ZEN pilot projects sit within each of these different stages (Baer, Andresen, 2018; see Appendix 3). The choice of tools is highly dependent on the ZEN phase of development, as each phase incorporates different scopes, stakeholders, and KPIs etc. Some tools can only be used in a particular phase, whereas others are highly flexible for use in different phases.

2.3.5 Spatial Scale

The tools may also have a different application with respect to the spatial scale of the ZEN project. For example, this could be at the building (micro-level), neighbourhood (meso-level), or city (macro-level) level. Some tools can be used at one or more scales. Municipal planning mainly follows a hierarchical approach, from planning on a city level (macro-level), to a geographically more limited area such as in the municipal sub-plan (meso-level), and to a relatively small area in the zoning plan. The ZEN phases and spatial scales are thereby interconnected: In the strategic long-term planning phase for the neighbourhood development, mainly the city and neighbourhood level are referred to, while within the mid-term planning and implementation phase planning and design phase, the whole neighbourhood or geographical area is included. Project planning for buildings is also referred to in this phase.

2.3.6 Project characteristics and context

2.3.6.1 Project characteristics

As previously stated, each of the ZEN pilot project developments have a specific project characteristic, which is dependent on various factors, for example:

- System border of the neighbourhood
- Thematic scope i.e. building, infrastructure, energy system, transport
- Timeframe, size of project
- Ownership (private/public)
- Stakeholders involved
- Stage of development i.e. strategic planning to implementation and operational phase

2.3.6.2 Context

Each of the pilot project is located in a different local context, which is referred to as a set of conditions relative to a specific geographic area, which in our case is the area of a ZEN pilot project site. Geographers divide these characteristics into physical and human characteristics of a location. The physical features might include the local climate, landscape, and location. The human characteristics include the culture of the people living in that place and all the ways they interact with it, for example when building a city or designing a park. The context in which a ZEN pilot project is placed is characterised by several factors:

- new or existing land use area
- climate, culture
- location
- proximity to urban system and transportation network
- existing function1 and typologies i.e. residential, commercial, recreational

3 Integration of Tools in the ZEN Toolbox and Use Scenario

3.1 Example of a Classification of possible tools for use in the ZEN Toolbox

This chapter presents an example for how tools can be integrated in the toolbox. There are different ways to integrate the technical and non-technical tools, depending on the selection of surrounding parameters. As an example, one of the stakeholders, for example a planner, architect and a citizen, provides a scenario to demonstrate the use of the toolbox.

The tool integration proposal in the core of the ZEN Toolbox will build upon the proposal by Krogstie and Ahlers (2018). Figure 4 below shows a workflow diagram below shows an example of simple tool integration and interrelationship.

[1] *The function of an area is its main reason, or purpose for being. In urban areas, this relates to the purpose of a land use for residential areas, recreation, industry etc.*

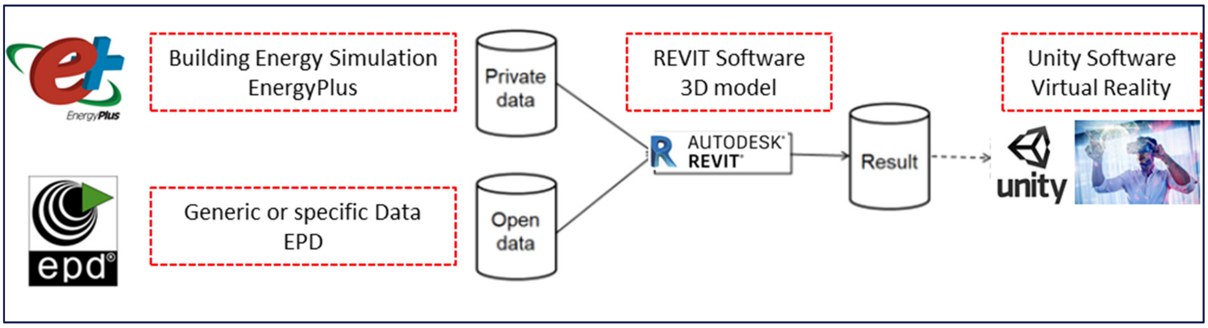


Figure 4. *Example of Simple Tool Integration in the ZEN Toolbox core.*

A detailed description of work conducted to date within ZEB and further development is described in detail in the draft ZEN Toolbox review (Houlihan Wiberg, 2018). The objective of the draft ZEN tool review was to map the 'state of the art' in order to understand which tools are available and which are of interest to the development of the ZEN Toolbox. The draft review identifies those tools and emerging technologies, which contain key features, which be of interest for the visualization of data in such as a way as to improve stakeholder participation in ZEN design. The report found that there are a plethora of tools and technologies available, and a first attempt to classify them in different categories is shown in the diagram in Figure 5.

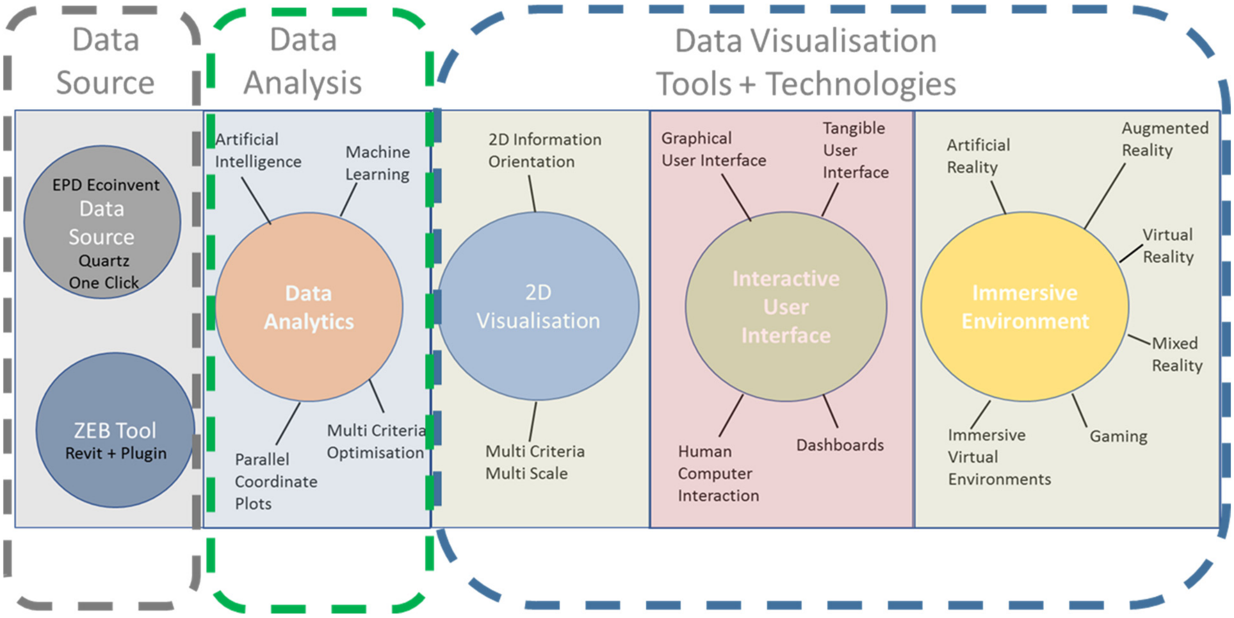


Figure 5. *First classification of the different tools and technologies reviewed for possible use in the development of the ZEN Toolbox*

With the exception of the ZEB tool and data source, it was concluded that the other categories of tools and technologies are highly versatile and can all be used in all phases of design and planning and incorporate some aspect of visualization which improves diverse stakeholder participation in the design process. Broadly, these can be classified into tools which provide a source of data, and the ZEB Tool, whose main use is to assess environmental impacts. This information is then used to improve processes and support policy and to provide a sound basis for informed decisions. The potential for visualising data from such data sources is high using the visualisation tools and technologies highlighted in Figure 6.

The second group are tools used for Data Analysis, such as artificial intelligence (AI), machine learning, parallel coordinate plots and multi criteria optimisation. In the design of buildings, AI provides the opportunity to save time and computational resources by reducing the search space for a design variable through elimination of the alternatives, which are not favourable, based on pre-defined rules designated by the design experts. In addition, machine-learning methods help with finding the patterns in the design alternatives and cluster them into groups to reduce a designer's efforts for make a decision among different geometrical or material options. Integrated with appropriate visualization tools, other stakeholders could also review design alternatives to provide insights. Such reduction in the time and resources for the designer and integration of the more stakeholders in the decision-making processes would likely lead to better and more efficient buildings, which would then help both achieving ZEN objectives. (Ghahramani, 2018) Parallel coordinates are also an example of visualisation and is a common way of visualizing high-dimensional geometry and analysing multivariate data. The maturation of building energy performance simulations and the advent of more powerful computers now allow application of design optimization processes to inform building design. (Ajiiz, 2017)

The third classification of tools and technologies are those used for data visualisation. For example, in the case of virtual reality (VR), this technology could be used both before, during and after the ZEN building process. In the planning phase, one could visualize ZEN's KPIs in a 3D model and showcase this to diverse stakeholders to improve participation. There exists already a lot of technology, which has great potential to ZEN. The challenge is not necessarily what to use, but how to use it. VR has opened a door of endless possibilities to showcase great ideas and visions to stakeholders, relevant to ZEN by visualizing KPI's in a virtual space. Cheap VR headsets makes it possible to distribute applications free of charge, so that people with interest, such as ordinary citizens, could download and experience scenario's in their own home and in their own time. The drawback is the potential high price of producing good VR-experiences. For collaborative work Augmented Reality (AR) and Mixed Reality (MR) makes it possible to share ideas by showing the same 3D models to all participants, and let users discuss, point and share ideas and thoughts. HoloLens enables users the ability to participate in and interact with the building process by utilizing a digital twin of the building where one could confirm that the building is identical to the plan. Finally, gamification bridges the gap between stakeholders, architects and clients by providing a common ground where people with no expertise could still be able to communicate ideas, thoughts or wishes to those with understanding. Games also has a huge potential to educate people by incorporating facts and promoting a common goal. (Mathiesen and Løvhaug) With the tools already available in the ZEN Toolbox, converting our models and data to utilize this new technology is possible and holds significant potential to improve stakeholder participation.

Figure 6 shows one example of how a workflow for a combination of tools and technologies within the ZEN Toolbox could interconnect with a visualisation technology such as virtual reality (VR). Building upon research previously developed by Heydarian & Burcin Becerik-Gerber (2017), a workflow is proposed which shows how the output results from a Building

Performance Systems (BPS) could be viewed by diverse stakeholders in an Immersive Virtual Environment (IVE) using (VR). This would help communicate complex data or to visualize the ZEN KPIs in a way that is easy to understand, thus improving stakeholder participation in the process.

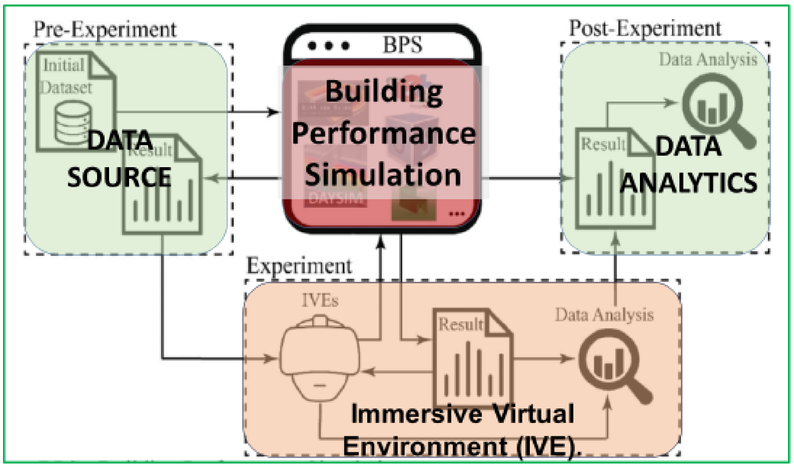


Figure 6. *Diagram showing the workflow between data source, building performance simulation, data analytics and immersive virtual environment (IVE) adapted from Heydarian & Burcin Becerik-Gerber (2017)*

Figure 6 shows how the bidirectional relationship between the Building Performance System (BPS) and the Immersive Virtual Environment (IVE) could be envisaged in the ZEN Toolbox. This concept could be thought of as being representative of the three first tools, which before the findings of the ZEN tool review report were thought of as separate tools for visualisation, stakeholder participation, etc. However, the findings of the review found that the tools and technologies are highly versatile, with many of the tools being used for all three of these functions and much more flexible than originally thought.

3.2 Scenarios to demonstrate the ZEN Toolbox in use

A scenario is proposed in this section to demonstrate the use of the ZEN Toolbox by, for example, a planner. In this scenario, the user is a planner from a municipality that has been tasked with developing a zero emission neighbourhood. The planner would like to involve a diverse group of non-expert stakeholders early in the design process. As can be seen in Figure 8, the user would selected ‘Planner’ as the stakeholder type in Box A. The user then selects the ‘Phase’ of the project, which in this case would be ‘Early phase’ design in Box B, and the ‘Level’ of the project, which in this case would be ‘Neighbourhood~ Meso’ in Box C. Then, in Box D, several contexts need to be selected. In this scenario, for ‘Context’, the planner will select new build, green field site, and for ‘Scope’, the planner will choose ‘Extended’~ ‘building, infrastructure, and technical’.

After these selections are made, the Toolbox will then automatically check, using AI or machine learning, if there is any conflict with any planning regulations or applications. If there are any conflicts etc., these will be highlighted by a ‘red flag’ box, which will describe what issues the user should be aware of. The use of AI and/or machine learning could select which tools are most appropriate based on the selections made in boxes A to D.

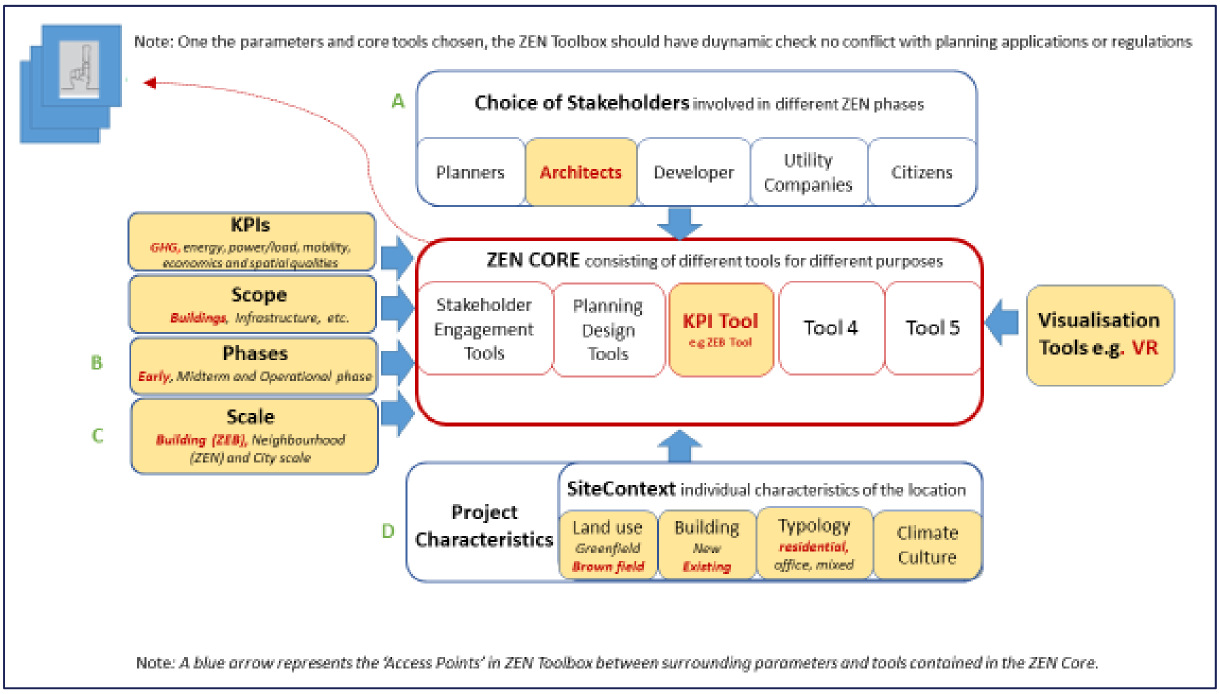
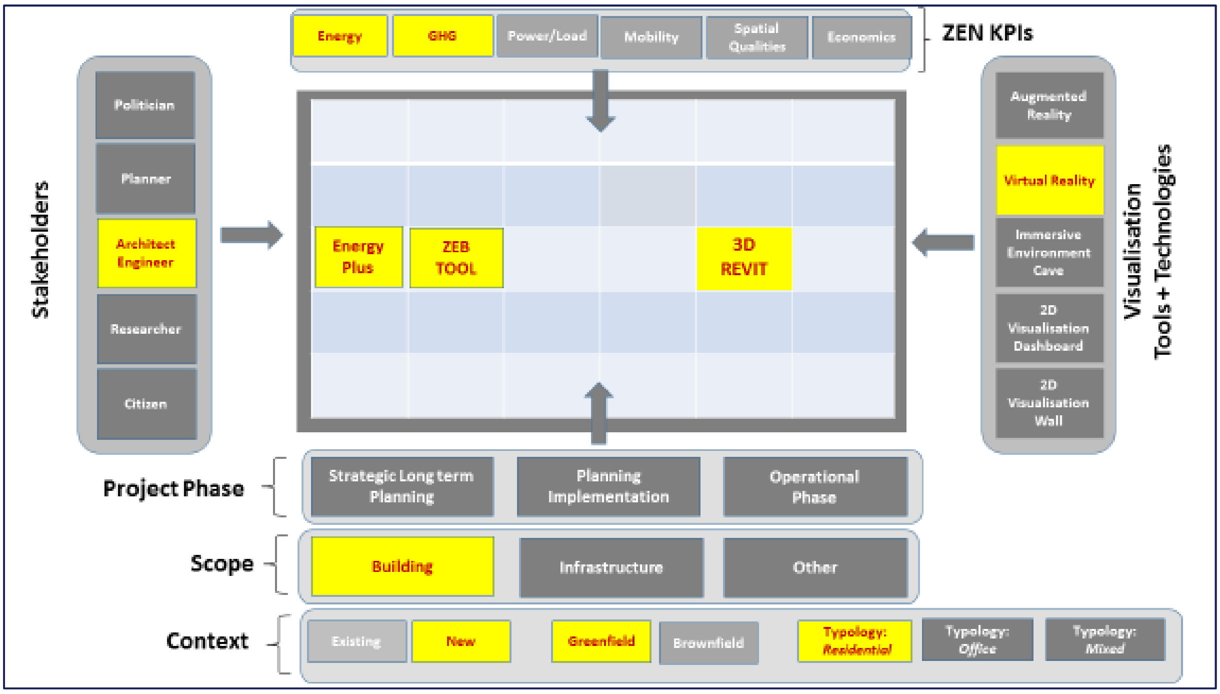


Figure 7. *Diagram showing possible use scenario of the ZEN Toolbox*

The toolbox could then 'light up' and identify the best combination of tools and technologies for the purpose identified by the user, in this case the planner. It is suggested, for this purpose, that a combination that would be most useful would be AR,VR together with HCI (human computer interaction) in the form of a dashboard which could visually communicate quantitative and qualitative data simultaneously in a simple, user friendly way.

In order to demonstrate how these tools and technologies could be integrated into the ZEN Toolbox, a use scenario is described in Figure 9. This figure represents a further development of the ZEN Toolbox we presented earlier in the memo and takes reference from the Zachman framework™ for enterprise architecture, which provides a matrix to organize a structured set of essential interconnected components. In our case, this organization matrix is very similar to our original framework for the ZEN toolbox but offers us a way to organize the core set of tools, which need to operate in a stand-alone way, or can be interconnected, depending on the choice of surrounding parameters.

Figure 8 below shows an example of a further development of the ZEN toolbox concept example of how the choice of visualisation tool can connect to the ZEN Toolbox via an access point. For example, the architect or engineer would select themselves as a category of stakeholders, they would then click that they would like to get feedback on energy and GHG ZEN KPIs only and click on these two icons, and then they select the other parameters, i.e. building scale, building only scope, residential, new build, and Greenfield site. They would like to use VR to visualize the results. The relevant tools would then be automatically selected from the core tools, which in this case would be a combination of the ZEB Tool and EnergyPlus.



Note: The grey arrow represents the 'Access Points' in the ZEN Toolbox between surrounding parameters and tools contained in the ZEN Core.

Figure 8. *Further development of the concept of the framework for the ZEN Toolbox using the Zachmann Framework for Enterprise Architecture.*

To conclude, the ZEN Toolbox needs to be highly flexible to integrate different types of tools and technologies, which could be selected in different combinations depending on the stakeholder type and other context specific parameters, e.g. scale, phase, and physical context particular to a ZEN pilot project.

4 Conclusion

This memo presents a first concept for the development of a framework for the ZEN toolbox to serve as a basis for further discussion and joint collaborative development with the other work packages within the ZEN Centre. In particular, this memo presents a framework for the organization of the ZEN Toolbox, which integrates a plethora of tools for use in the design and planning of a ZEN. The Toolbox contains access points to connect with the various parameters, which will influence the choice of tools for use in ZEN. This memo presents a framework for a ZEN toolbox which contains a core of selected tools and surrounding parameters. It is concluded that the ZEN toolbox should provide enough flexibility to enable different tools to be used either alone or in an interconnected way, depending on the unique selection and combination of the different surrounding parameters. This flexibility and openness is particularly important when dealing with ZENs, since each of the pilot projects are so diverse particularly in relation to the surrounding parameters.

The ZEN Toolbox would contain a core of different types of tools (technical and non-technical), which can be selected as a standalone tool or in different combinations depending on the following choice of parameters:

- Choice of ZEN KPI(s) i.e. *GHG, energy, power/load, mobility, economics and spatial qualities*
- Choice of stakeholders i.e. *planners, architects & engineers, researchers and citizens amongst others.*
- Choice of scale i.e. building (ZEB), neighbourhood (ZEN) and city level
- Choice of site contexts and individual characteristics i.e. *new and existing, greenfield and brownfield; building typology (residential, office, mixed use)*
- Choice of design phases i.e. *strategic long term planning (early), Tactical mid-term planning, implementation, and Operational phase.*

Some of these tools will be developed within the ZEN Centre, whilst others are already in use in practice. The next steps will be to single out the most promising tools (both within ZEN and tools made by others) and make a more detailed analysis on expected usage and challenges in these tools. This work will form a basis for the choices of the most appropriate tools to use and develop within the ZEN Centre and other related projects.

It should be noted that tools are not the only primary instruments to getting to zero; there are many emerging technologies that can greatly support low-energy outcomes. These tools and emerging technologies hold great potential to deploy existing digital technologies to create interactive systems between buildings and the environment and to engage occupants. However, it is clear from the draft Tool review, that there are many technology gaps where more research and future work is needed to develop and realise the citizen centred architectural and urban toolbox for ZEN.

5 Future Work

Mapping and evaluation of the tools in use

To identify appropriate tools to support a successful ZEN development, the tools in use in the pilot projects have to be mapped and evaluated in all phases of ZEN development. The integration of these tools and their interconnection need to be considered within the framework of the ZEN Toolbox.

Connecting KPIs and Tools

Future work in the ZEN Centre has to identify which tools are available to plan, design, analyse, and monitor the KPIs of the ZEN definition. These could be tools already in use or tools that need to be developed, or are currently under development, in the ZEN Centre. It is important that all work packages are involved in identifying potential gaps in these tools which will be used for integrating for ZEN performance assessment. The design of the toolbox needs to be easily accessible and usable and will involve close collaboration between WP 1, WP 2, and WP 6. Further work needs to be conducted on the design of the framework for the ZEN Toolbox which will involve close collaboration with WP 1.1 in order to develop the associated ICT platform. An understanding of which tools are used in ZEN and how they can function either as stand-alone or interconnected tools is a necessary next step in the development in order to integrate science-based knowledge on GHG emissions into the diverse practice-based neighbourhood design and planning instruments. Further work needs to be conducted on the design of the access points in the ZEN Toolbox.

Identification of stakeholders and user demands

Future work in the ZEN Centre must focus on which stakeholders are involved in ZEN development, as they are the potentially users of the ZEN toolbox. It will be necessary to identify the needs and level of expertise of these respective stakeholders and to establish their involvement in the different ZEN phases. It is important that this knowledge will be integrated in the further development of the ZEN toolbox and to ensure that it is in aligned with the needs of the stakeholder using the toolbox.

Visualisation technologies for use in ZEN Toolbox

Further work is needed to investigate and explore further how existing and emerging XR technologies, such as Augmented Reality (AR) and Virtual Reality (VR) and User Interface (UI), such as dashboards, can be adapted for use in ZEN and improving diverse stakeholder participation. This testing will be conducted using ZEN pilot projects and will involve close collaboration with WP 6 (ZEN pilots). This work with visualisation of ZEN KPIs is currently being conducted using these technologies together with some Masters students.

Emerging immersive environments, such as, Augmented Reality (AR) and Virtual Reality (VR) technologies have a strong potential to play a leading role in the design of ZENs in the future. Intelligent, real-time multi objective optimisation for future ZENs through the integration of emerging AR and VR technologies in immersive environments for diverse users. These emerging technologies have the potential to change our understanding of an important existing scientific or engineering concept or educational practice. Augmented Reality (AR) technologies are used nowadays in a broad range of applications due to advances in mobile computing performance and advances in tracking algorithms. Mass-market applications still mainly exist in the areas of training and education, manufacturing, marketing, and entertainment. In the field of construction and architecture, research suggests the integration of AR with building information modelling and information data. Most work concentrates on establishing a real-time communication link between life cycle information of a building and on-site activities. This includes design and planning, construction, and maintenance. (Houlihan Wiberg, 2018)

The main focus of further work will include the following:

- Generate new knowledge in how emerging immersive technologies, such as, AR&VR can be adapted and integrated with our existing science-based knowledge on GHG emissions, energy and indoor environment, to provide user friendly, interactive feedback on performance, as well as, spatial qualities in the design of sustainable and healthy hospitals of the future. How can these new methods/tools be used to improve communication and participation from diverse stakeholders?

- How can intelligent visualization and immersive environment methods improve environmental performance feedback in the design process and increase uptake in design practice and improve stakeholder participation?
- How can these be techniques be integrated into a Multi Criteria, Multi Scale tools for use in ZENs to generate different design options?
- Conduct a *state of the art* review of emerging AR&VR technologies, human computer interfaces (HCI), data visualization for integration in the development of the ZEN Toolbox.
- VR & AR~ Further extend selected existing software's for immersive virtual reality environments including HTC Vive, Oculus Rift, Zspace and further development of existing open-source wearable augmented reality (AR) systems.

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7 Appendices

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

Appendix 1: *ZEN assessment criteria and KPIs covered in ZEN definition guideline. (Kjendseth Wiik et al., 2018, p. 21)*

	City population (1.1.2017)	Project owner	Area size in m^2	Planned/Existing function	Construction	Status/Phase
Elverum - Ydalir	14 877	Public (Municipality)	430 000	Residential area with a school and kindergarten (planned)	New construction: 1 000 dwellings (ca. 100 000 m^2), a school and a kindergarten	Implementation
Oslo - Furuset	666 759	Public (Municipality)	870 000	Multifunctional sub centre with 1 400 dwellings and 3 800 inhabitants, 213 100 m^2 (existing)	Retro-fitting/upgrading and new construction: 1 700 – 2 300 dwellings and 2 000 – 3 400 work places (up to 160000 m^2)	Implementation and Operation
Bergen - ZVB	278 556	Private (Developer)	378 000	Residential area with a kindergarten and additional services (planned)	New construction, 720 dwellings (92 000 m^2), a kindergarten and additional service functions	Planning
Trondheim – NTNU Campus	190 464	Public (NTNU/ Municipality)	339 031	University Campus (existing)	Retro-fitting and new construction (ca. 136 000 m^2)	Planning and Operation
Trondheim -Sluppen	190 464	Public / Private	275 000	Multifunctional sub centre with a mobility hub (planned)	Retro-fitting and new construction	Planning and Operation
Steinkjer – Former NRK site	12 744	Public (Municipality)	11 113	Kindergarten and dwellings (planned)	Re-use and new construction of 10-12 dwellings	Planning
Evenstad - Campus	2 530 (Municipality)	Public (University)	61 000	University campus (existing)	Building stock in use: 10 000 $m^{2,}$ no further construction planned	Operation
Bodø – New City – New Airport	51 002	Public (Municipality)	3 400 000	Multifunctional city centre extension with residential and business areas (planned)	Re-use and new construction: 2 800 dwellings in the first construction stage	Planning

Appendix 2: *The eight pilot projects of the ZEN centre at a glance. (Source: Baer, Andresen, 2018)*

ZEN Pilot project	Strategic long term planning phase	Tactical mid-term planning and implementation	Operational Phase
Sluppen in Trondheim	in process	-	in process, existing neighbourhood
"New City – New Airport" in Bodø	in process	-	-
ZVB in Bergen	Completed and waiting for approval	-	-
Furuset in Oslo	completed	in process	in process
NTNU Campus in Trondheim	completed	in process	in process, existing neighbourhood
NRK estate in Lø, Steinkjer	Not relevant	in process	-
Ydalir in Elverum	Not relevant	in process	-
Evenstad	Not relevant	completed	in process

Appendix 3. *Phase of Development of the eight ZEN pilot projects. (Source: Baer, Andresen, 2018)*

VISION:

«Sustainable neighbourhoods with zero greenhouse gas emissions»

Research Centre on

ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

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