VISIONARY SCENARIOS FOR HOLISTIC PLANNING OF NEIGHBOURHOOD AND BUILDING ENERGY SYSTEMS

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ABSTRACT
This paper envisages future scenarios for holistic energy efficient design of buildings, which are integrated to neighbourhood energy systems. The scenarios consider foreseeable new technologies, ICT services and business models. The scenarios are presented as visionary stories of future situations. The stories include the evaluation of potential impacts and the needed progress beyond the state of the art. The user requirements for the visionary stories are identified. As examples, visionary scenarios stories for collaborative planning of neighbourhood energy systems and neighbourhood energy balancing in building design are presented.
Keywords: energy efficient buildings, neighbourhoods, design, holistic, future scenarios.

1 INTRODUCTION

The purpose of this study is to deepen the understanding of holistic, evolutionary and energy efficient (EE) planning and design of neighbourhoods and buildings. Especially, this paper focuses on developing future scenarios for integrating buildings with neighbourhood energy systems as efficiently and with as sustainable manner as possible. These kinds of considerations support among others the implementation of EU's nearly zero energy building targets [1]. The scenarios will consider foreseeable new technologies, ICT-based information services and business models. The work described in this paper is part of the EC funded project called DESIGN4ENERGY, which focuses on innovative and integrated evolutionary design methodology for energy efficient buildings, which are flexibly connected with the neighbourhood energy system [2].

The presented work deepens the earlier future visions for energy efficient buildings and neighbourhoods from the ICT roadmap for Energy Efficient Neighbourhoods (IREEN) [3], [4] and Roadmap for Energy Efficient Buildings (REEB) [5], and energy matching framework for Energy Positive Neighbourhoods [6]. These envisaged energy system scenarios are developed further with the Integrated Design and Delivery Solutions (IDDS) framework [7], which can support the iteration of future envisioning design solutions and team level communication, with the support from an advanced service platform that includes a BIM server. Collaborative environments can support multi-functional team in designing energy efficient building with a consideration of their neighbourhoods [8].

The key objectives for the EE building design methodology have been defined in the DESIGN4ENERGY project as: 1) holistic; 2) evolutionary, 3) adaptable for designing approaches and methods; 4) multi-disciplinary design practice in integrated processes, 5) providing an information service for decision-making, 6) value-adding & orientated towards energy-efficiency. In this project, the methodology is seen as a set of methods, rules and principles employed in well-defined procedures for designing cost effective energy efficient buildings and their assessment in a neighbourhood context. The main principle for the energy design is firstly to minimize the energy consumption, and secondly to design the needed energy mix (heat, electricity, and cooling). Passive energy design solutions are encouraged for the design team. [9].

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2 METHODOLOGY FOR DEVELOPING FUTURE SCENARIOS

A visionary story describes what happened in the future. It is an exemplary sequence of actions and tasks by stakeholders using models, methods, and tools. Visionary scenarios go beyond the state of the art of design/planning, ICT, business processes and models. The presented scenarios are examples and may not cover all needed ways of using the tools.

The visionary stories were developed using both Top-down and Bottom-up approaches. At first, the working process started by developing the vision and anticipated developments related to energy efficient design. This was followed by the visionary scenario development, consisting of the following steps:

1. Defining the scenario topics,
2. Drafting the trends/visions for each scenario,
3. Visionary scenario descriptions,
4. Finalising envisioned visions,
5. Analysing the user requirements in scenarios, including innovations related to ICT, business models and energy efficiency.

The visionary scenarios descriptions are structured as follows:

- Visionary scenario story
- Expected impacts of integrated planning
- Stakeholders
- Needed progress beyond State-of-the-art
- Different levels: Vision - scenario - use case
- User requirements (marked with underline in the stories) related to:
    - Guidelines for holistic planning and design
    - Databases of components and solutions
    - Information models
    - Decision support tools
    - Interoperability
    - Collaboration support
    - Contractual relations and business models

3 RESULTS: VISIONARY SCENARIOS AND RELATED USER REQUIREMENTS

In total, 10 visionary scenario topics were identified and developed [9]:

6. Collaborative planning of neighbourhood energy systems
7. Neighbourhood energy balancing in building design
8. Energy matching design
9. Integrated building design management
10. Decision support for design
11. Passive architectural design solutions
12. Building performance management
13. ICT and interoperability possibilities in design collaboration
14. Design with the micro climate and environmental point of view
15. Stimulating user interaction and behavioural changes of inhabitants

The following sections present the results in more detail, introducing two visionary stories in detail: 1) collaborative planning of neighbourhood energy systems, and 2) neighbourhood energy balancing in building design.

4 COLLABORATIVE PLANNING OF NEIGHBOURHOOD ENERGY SYSTEMS

The collaborative planning scenario for neighbourhood energy systems describes an energy system planning tool, which have access to other tools and/or to the models, results and databases. This tool can enable the synchronisation of the plan among a multidisciplinary design team, with a capability for alerting changes in the plans. The tool also eases communicating of design choices to inhabitants and stakeholders, and enables a channel for easy feedback and user involvement. Originally, this idea has been drafted in IREEN project [10], and it is here deepened with describing the requirements for the tool and the planning process. [9]. The underlines in the story text show the identified user requirements.

4.1 Visionary story: Energy system planner at work

Andy Lewis is an energy system planner in the local energy company, which is owned by the Happyville City. He is designing a local energy system in a new Harbour area in collaboration with city's urban planners who are developing the city plan for the area.

Andy received an automatic alert yesterday about a significant update on the amount of buildings in the city plan. This changes the total energy demand, heat distribution losses and the available roof space for solar panels. Andy updates the model of the energy system in the planning tool according to these changes, and continues identifying the optimal energy solutions for the area.

Andy works with a planning tool linked with other planning tools and data sources (see Fig. 1) used by urban planners, including transportation route maps, detailed city planning maps, existing water and waste infrastructure, etc. In addition, the tool shows potential energy systems, networks and energy supply sources, supporting Andy to recognise the available options for local energy solution for the Harbour district.

As a next step, Andy compares potential energy system models with the planning (and/or) assessment tool and assesses the sustainability impacts on environmental, social and economic performance. He uses the tool to develop the optimal energy solution that fulfils the value criteria set by the municipal decision makers for the Harbour development.

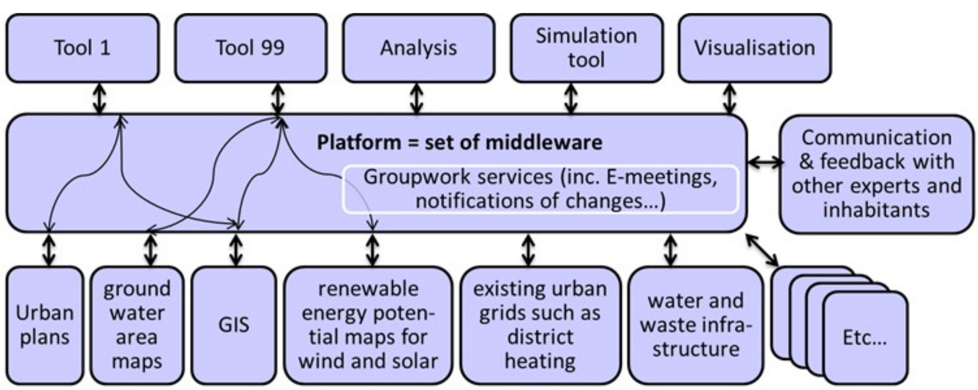

Figure 1: Visualisation of integrated planning tools and data bases.

Based on the impact assessment, the best option for the new district can be concluded as a district heating with water source heat pumps. The available roof areas should be utilised for solar electricity production. To maximise the potential for solar electricity yield from the area, Andy sends a request for urban planners to modify the city plan with adjusting the orientations of a few building blocks and thereby aligning their roof surfaces towards south. Moreover, Andy recommends to increase the thermal mass of buildings and use advanced hot water saving appliances to decrease the maximum peak heating demand to reduce costs of the heating systems.

Andy drafts required visualisations to show the implications of the suggested energy system and its impacts of the business-as-usual and the suggested option. This supports and visualises the communication of plans to the inhabitants, decision makers and other stakeholders, and offers also a communication channel to receive feedback from them related to the city and energy plans.

Simultaneously, Andy's design team partner, energy designer Max More is planning the modernisation of the energy system. Max targets to match the energy demand and supply in a neighbourhood. He has concluded based on the tool analysis output that this would require changes to the existing city plan regarding buildings use. Max discusses the request with City's urban planner Maria Hill, and they concluded that it would take two years to change the actual city plan for mixed use, but also adding of student housing or elderly homes would be possible in the shorter time frame.

4.2 Visionary story: Urban planning with energy efficiency and energy matching

City's urban planner Maria Hill is currently sketching a design for a new Harbour district, consisting of residential buildings, a shopping centre, offices, school, library, green parks and several car parks. The municipal council decided the development targets for high energy efficiency, local energy trading and matching of energy demand and supply.

Maria studies the context related information by using the GIS environment module. She considers local environment and natural lighting when designing the orientation of the blocks and the relation between various buildings types in support of the energy matching system. At this stage, Maria launches the GIS platform of the district to visualise the locations of various energy nodes in 3D. Next, she performs a preliminary analysis by searching reference neighbourhoods and buildings in the benchmark browser to check the performance and the operation cost of the solar electricity supply in the district. All energy performance data is linked to the BIM models of building mass alternatives.

Maria drafts a few potential what-if-scenarios for city plans for comparison, to formulate a starting point for developing a local energy trading concept. Maria requires support and collaboration in the further planning of the city plan options and their energy system from various stakeholders, such as network operators, energy producers end users and heat balance-sheet operators. This design team could be for example Max More from the local energy company, together with city's facility department representatives, in collaboration with the local construction companies and potential building owners. Moreover, the design team needs to investigate what-if-scenarios to reach a solution in terms of optimising the neighbourhood energy system, similarly to the work that Andy provided for the energy matching area previously. Potentially, also building facility managers could be involved to look into operational and maintenance issues.

4.3 Analysis: impacts, stakeholders, needed progress and user requirements

Integrated neighbourhood energy system planning is expected to reduce primary energy consumption, heat distribution losses, energy costs and emissions due to holistically and optimally planned energy systems. It can also shorten the planning phase, and provide more open planning process, with well estimated environmental, social and economic impacts. Integrated planning could also have possibilities for new business models based on the orchestration of stakeholder groups.

The main stakeholders in the integrated planning of energy systems at the district level are: Energy companies and energy service companies, energy planning consultants, urban planners, municipal decision makers, and local inhabitants.

In this scenario, progress beyond the state-of-the-art would be needed on data handling methods and tools, integration of existing tools (e.g. GIS integration to existing tools), and the development of business models for tools and use of tools needed.

Identified user requirements are listed in Table 1.

Table 1: User requirements for integrated planning of neighbourhood energy systems [8].

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Information models: Model of the neighbourhood energy system (in the planning tool)
Decision support tools: The tool supports the selection of the optimal energy solution based on the value criteria set by the local decision makers. It enables comparing different potential energy system models with the planning. Assessment tool for assessing environmental, social and economic performance and impacts. Visualisations to easily show the decision makers the implications of the suggested energy system and its environmental, economic and social impacts. Visualises the communication of plans to the inhabitants and other stakeholders, and supports a communication channel to get feedback from them related to the city and energy plans.
Interoperability: A planning tool linked with the different, other planning tools and data sources being used in city planning (such as transportation route maps, detailed city planning maps, existing water and waste infrastructure, etc.) The tool also shows available energy systems and networks, as well as possible energy sources.
Collaboration support: Support and collaboration in the further planning of the city plan and its energy system for all stakeholders and user groups. An automatic alert about updates in plans. Sending a request to responsible urban planners to modify the urban plan
Contractual relations and business models: **Possible new business models based on orchestration of stakeholder groups**

5 NEIGHBOURHOOD ENERGY BALANCING IN BUILDING DESIGN

This scenario envisages the how to balance neighbourhood energy system, and how it is related to the building design through integrated building modelling and simulation throughout the life-cycle. The scenario description targets to show how advanced simulation and modelling techniques could be used to improve the energy design practices. In addition, this scenario gives an example on the different stages of the community design from the energy system view point. Typically, the community life cycle is long and estimating the energy performance of the buildings and network is challenging at the various phases of the design process [9].

5.1 Visionary story

An energy designer Max More works together with the building architect and the building design team. Max's main responsibility is to solve energy related design challenges according to the clients' needs. His educational background includes cross-cutting elements about construction engineering, HVAC engineering, and energy production engineering, to understand both the demand the production side of the energy systems.

Max receives the consultant contract documents, including initial data and the draft program and the brief of the building development project. The building spaces will be used for trading and commerce services, as the location of the building is great. The documents include already the main criteria for the performance based design process. Performance is categorised in three levels: project, process and product. Criteria for energy optimisation are: life cycle cost (€/m^2), share of renewable energy (%), energy self-sufficiency (%), primary energy need for electricity, heat and cooling (kWh/m^2), and energy use reliability, including the reliability of local grid (%). Max's assignment is to prepare a proposal for the target setting. For this, he needs to run energy calculations and estimate target values for each of the criteria and conduct feasibility studies.

Max meets the client in order to clarify the background data regarding the optimal space usage. Client had an extraordinary situation, as they had no tenants and only very preliminary ideas for the intended use concerning the half of the permitted building volume of the site. The city plan was also open for the purpose of the use of the permitted building volume, allowing offices, public services, and facilities for trade, small industry, or sport. Max discussed with the client about the target values, including the expected profit from rents and selling of local energy produced and the key serviceability indicators for comfort, indoor quality etc.

It is a demanding task to set the target value for life cycle costs. Max has collected a benchmarking library for this estimation. He is capable to do reliable sensitivity analyses for future energy needs taking into account different financing variables, interest rates, changes in space use etc. He knows that the value he set for life cycle costs opens up several design options and solution for the design team in the concept design phase. Max has promised to make three feasibility studies from the investor view point: 1) Business as Usual, 2) Highly Energy Efficient, and 3) Highly Energy Efficient, which includes the heat trade with the local district heating grid. The heat trade was selected as a fresh interesting option, because the local district heating company is willing to test the free heat trade in their energy system and the client wanted to check the profitability of this kind of new operation model.

Max begins the work with the energy planning tool. The client had already also requested an architectural office to make a first sketch of the building size, orientation and the location on the site. The sketch contains the information of the site surroundings and site ground, which affect the renewable energy potential for solar, wind and geothermal energy. Architect has saved this sketch into the BIM server, so now Max imports it into his building energy simulator. Then he retrieves city plan information from the city model, and transfers it to the simulator. The building simulator tool contains several default databases for the design details, which are crucial for the energy analysis, but are not yet known from the building design phase. The default data is structured in the database at higher level using conceptual definitions such as “Typical new office building in Finland fulfilling the regulations” or “Highly energy efficient passive house in Germany”. The complexity of the detailed input data and investment costs for the simulation model is included in these conceptual definitions.

Max has to formulate a RFI (request for information) to the architect, because he noticed that the architect has not saved the latest IFC-file for the early energy simulations. Max sends the RFI through a collaborative working environment, which shows to him immediately that Jane from the architect office accepted the request. In 15 minutes, the missing file is uploaded to the server, with apologises from Jane. She had forgot to update the files, as agreed in the last design meeting. Max starts to import the file to his tool, with thinking “Well, these communicative tools and features in the working environment are getting quite handy”.

During the BIM-import, the tool asks for the conceptual definition of the building to be modelled. Max selects the existing type “Typical new built shopping mall in Finland”, which includes needed technical details to build an energy simulation model of the building. The tool suggested the weather information of “Helsinki City Centre weather station-Finland”, because it is the closest weather station nearby the construction site coordinates in the BIM-model. Max approves the suggestion. Next, the energy simulation can begin.

A part of the life cycle cost data is still missing. Max seeks the hourly price of energy products (district heating, electricity and district cooling) and the pricing of the bought and sold energy products from the local energy operators web page. The energy prices are listed from previous years, and Max chooses the price information from the last 5 years to get a more completed data for the analysis. He chooses the calculation period of 30 years and the interest rate for the capital investment according to the clients’ interview, in this case 8% to enable the life cycle cost calculation. The business-as-usual (BAU) case is now ready. Then, Max develops an option of the BAU-case to present the highly energy efficient shopping mall with heat trade business model. Max applies the reference settings from the database for this specific case. It seems that it has an excellent potential for demand side solutions to minimize the building energy demand. Also, on-site RES production with solar heat collectors seem possible solution, with providing a surplus energy during the summer. Max adjusts the mounting of the solar energy collectors on the roof. Now Max has two building designs ready. Similarly, he designs the third option for Highly Energy Efficient including the heat balancing with the local district heating grid.

As a result of Max’s efforts, the client gets: 1) Target value setting for the criteria of energy efficiency, and 2) preliminary results of building energy simulation and planning feasibility studies with using advanced energy balancing techniques in the building. These can guide the client and the design team on finding the best possible energy efficient design with connecting the building to the neighbourhood energy balancing strategy. Max also suggests to the client what kind of building space uses would be most optimal from the energy matching point of view for that part of the building, which space use is not yet fixed.

5.2 Expected impacts

The neighbourhood energy balancing related to the building design is expected to improve the matching of energy supply and demand. This can lead to reduced peak power loads, and as a consequence, it can contribute to reducing emissions from energy production, because peak power is typically produced from fossil fuels with high emissions. Furthermore, energy balancing helps to optimise the energy use and minimise the energy costs of the building, and increase the share of local and on-site renewable energy supply [9].

5.3 Stakeholders

A liberated heat market could work similarly to a liberated electric market in Nordic countries, with the exception that the heat market can be only realised within a local district heating or gas network. This would require collaboration from producers, customers, network operators, and systems operators (see Fig. 2). The traditional large scale producers sell energy to customers connected to the district heating network. End users, that could also be small-scale producers (so-called prosumers) using e.g. solar collectors, micro-CHP (combined heat and power), boilers, or novel power-to-gas production units. They would buy heat or gas from other producers or sell heat or gas to customers through the network. The liberated heating energy market would also need the network operators that takes care of the temperatures, pressures and hydraulic balance of the energy network. A balance-sheet-operator is also needed to coordinate the heat contracts between producers and customers as well as to take care of reserve capacity, spot and future markets and billing [9].

Energy producer supplies thermal energy or gas through the energy network for its customers, with the following duties and rights [9]:

- The Producer makes an energy contract with customer and distribution contract with a network operator.
- The Producer must be connected to the network with a heat exchanger (or directly) before starting the energy supplying to the customer. The connection must be accepted by the network operator.
- The Producer must buy a connection charge accepted by a competition officer.
- The Producer supplies energy based on the contract into the energy network with contracted fixed effect or within contracted minimum and maximum effect in contracted period.
- The Producer supplies thermal energy in right temperature, which is normally with relation to the outdoor temperature or gas in agreed pressure level.
- The Producer is responsible for the reserve capacity within his contracts to consumers even if the supplier will leave the energy market before the contract is closed.

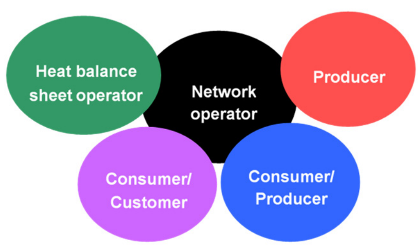

Figure 2: The heat trade actors in the local energy network [9].

A Network operator is responsible for the district heating or gas network. The local network service must be separated from production, but the Network operator can also make a contract with producers and make energy supply contracts with customers. The network operator has duties and rights as follows [9]:

- The Network operator will use, maintain and build the network.
- The Network operator keeps up the pressure, temperature and is responsible for the quality of the network's energy carrier (gas or water).
- the Network operator is responsible for network's reliability and security
- The Network operator will measure the input and output energy at the producers and the consumers within the network.
- The Network operator will connect or accept connection of producers and consumers to the network.
- The Network operator is responsible for peak and reserve capacity (peak production or storage) by his own or other actors' capacity based on contracts.
- The Network operator defines the energy transfer tariff, which will be accepted by a competition officer.

A Balance sheet operator coordinates the whole district heating/cooling system, and it has duties and rights [9]:

- Keep up the thermal load and energy balance sheet within the network.
- Keep up the connected load and inform the network system operator for the coming winter heat load period.
- Inform and control the network operator for the coming days.
- Control peak load and reserve capacity.
- Keep up the contract bank of producers.
- Keep up the heat exchange market; spot and future markets.
- Collect invoice data measured by Network operator and channel incomes to energy producers and the network operator.

Consumers are customers, who buy the energy and pay the bills. The customer has duties and rights [9]:

- The customer will be connected to the network with a heat substation designed for connected heat capacity (district heating) or with a normal gas connection. The Network operator will accept the connection design.
- The customer must pay a connection charge to the network operator accepted by competition officer.
- The customer's substation must work within agreed temperature and pressure limits. Minimum ΔT and Δp must be guaranteed.
- Consumer can change the energy supplier without any new connecting and measurement charge.

5.4 Needed progress beyond state-of-the-art

Currently energy simulations are dilatory in their nature, and the simulations are done too late in the design process to adequately effect on the project level decision making. Tools do not exist for easily defining thermo-hydraulic model of the energy trading as a whole. If modelling is used for the district heating network, the models are unconnected. Today, the energy companies use stand-alone network models to solve some initial or critical stages of network flows, mainly design points. The network design practice is based more or less on the rules of thumbs. The building simulations are at the current practice independent and are mainly used at the design process to analyse the indoor climate and energy consumption of buildings. Also, the renewable (wind, solar, geothermal) energy production models are separate.

In the future, the energy trading will present a new business situation, which can be dealt with by several alternative business models. Energy services will be provided in the lowest cost level and with the lowest emissions to the environment and with the highest renewable energy penetration to the system. The design and analysis tools are practical and support the life-cycle design and maintenance of the heat trading business environment. The user interface for various actors is map-based and personalized according to the needs of the role. New holistic design will have new procedures and some of the old ones will disappear. Identified user requirements are listed in table 2.

Table 2: User requirements for neighbourhood energy balancing.

Guidelines for holistic planning and design The main criteria topics for the performance based design process, and performance categorisation available. Target value setting for the criteria of EE, e.g. for life cycle costs (LCC) available.
Databases of components and solutions A benchmarking database containing the detailed input data and investment costs for technical details of the simulation model
Information models An interoperability data model between the tools (architect sketching tool and energy simulation tool).
Decision support tools Ability to find an optimal energy efficient design when the building is connected to the neighbourhood energy balancing strategy. Ability to suggest what kind of building space uses would be most optimal from the energy matching point of view for that part of the building.
Interoperability Ability to retrieve city planning information from the city model (or city plan), and transfers it to the simulator so that the effect of the surroundings (e.g. solar shadings) and terrain on the energy performance can be modelled. Access to the historical hourly price of various energy products (district heating, electricity and district cooling) in the neighbourhood and pricing of the buy and sell energy products from the local energy operators. Access to the weather data. Ability to export the building sketch as the latest IFC-file for energy designer for the early energy simulations into the BIM server (Architect). Ability to import the building sketch from the BIM server into the building energy simulator (Energy Expert).
Collaboration support Ability to formulate a RFI (request for information) to the architect through collaborative working environment and ability to see when the architect office opened the request.

6 CONCLUSIONS AND DISCUSSION

In this paper, we explain the methodological approach of understanding user requirement for tools and processes, information and guidelines for EE design, with visionary scenarios. The methodology uses narratives in a form of a scenario story. This enables to define the needs for tools, their features and level of interoperability as well as processes, integration and collaboration.

We present a set of visionary scenarios developed for holistic energy efficient design of neighbourhood and building energy systems. Two scenarios are presented in detail: 1) collaborative planning of neighbourhood energy systems, and 2) neighbourhood energy balancing in building design. Both of them consists of visionary stories of future situations describing how new collaborative technologies, ICT services and business models could be used. The stories include the evaluation of potential impacts and the needed progress beyond the state of the art. The user requirements for the visionary stories are identified.

The holistic design strategy establishes a link between neighbourhood level and building level design views. This is executed firstly in the design area of building energy performance, and also in the local energy systems studies. Secondly, also local environmental systems of the neighbourhood are taken into account in the design area of building indoor environment performance. Thirdly, the local societal systems are integrated to design solutions configurations of design alternatives in the design area of the usability performance of the building.

These scenarios are an important study topic, because new concept design tasks are needed for neighbourhood level EE design and energy matching. Currently the question is, whether it is more natural to widen the process of city planning for EE concept design, or does the design tasks have a place in the program development or in the feasibility study of the construction project. Model based information management tends to enable more accurate and detailed information earlier in the process flow. This phenomenon supports the idea that areal EE concept design could be part of areal city planning or strategic program development.

These visionary scenario stories have been further utilised in the development of the DESIGN4ENERGY holistic and EE building design methodology as enhanced vision of holistic design and planning and functionalities and tools of the collaborative platform (envisioned databases, information models, decision support, interoperability and collaboration support) [11]. The process enabled finally to define enchanted visions of the areas of methodology, platform and from a bases for Envisioned business models and services.

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