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SUSTAINABILITY KEY PERFORMANCE INDICATORS' (KPIs) ASSESSMENT AND VISUALIZATION AIMED AT ARCHITECTS IN (EARLY) RENOVATION DESIGN PROCESSES

ALIAKBAR KAMARI, STINA RASK JENSEN, STEFFEN PETERSEN AND POUL HENNING KIRKEGAARD

Abstract

Proper data visualization can help architects to deal with design complexity by facilitating a better understanding of the design performances/-outcomes, and thereby contribute to making informed decisions. Based on this underlying hypothesis, this article aims to find out: what are the requirements of an effective visualization technique aimed at architects to visualize the outcome of simulation and assessment of renovation design options for multiple sustainability themes or Key Performance Indicators (KPIs)?

The article adopts a bottom-up approach, beginning by a) exploring and assessing multiple KPIs for renovation and b) surveying existing visualization techniques to illustrate the KPIs' evaluation outcome in the early design process, through conducting a focus group workshop with eight practitioners in Denmark.

It is concluded that architects are always looking for a strong narrative when developing design options to address the sustainability KPIs in their practices, and the narrative is different from project to project. In this light, effective visualization techniques should provide a good overview of the problem in question. At the same time data visualization should be functional, insightfulness and enlightening, in order for the architects to fully grasp and accept the evidence it depicts as useful inputs in the design process.

Keywords:
Data visualization; Key Performance Indicators (KPIs); Sustainability KPIs; Building Renovation; Decision-making; Early design; Design practice.

1. Introduction

The renovation of existing buildings gains increasing attention in many European countries (Jensen & Maslesa, 2015). The main drivers are related to the urgent need for significantly more sustainable societies such as mitigation of climate change, energy efficiency, environmental impacts, life-cycle cost, indoor climate, adapting to changing norms for living, as well as the challenges of rapidly increasing urbanization (BPIE, 2011).

No matter the driver, renovation of existing buildings should rely on a broad approach to sustainability, which seeks to minimize investment, operation and maintenance costs, as well as environmental impacts, while maximizing the building's adaptability, durability and resilience towards future challenges as well as a comfortable, healthier and pleasant indoor and outdoor environment (Kamari et al., 2018a). Consequently, renovation projects that aim to fulfil a broad definition of sustainability (as a globally desired design value) need to address a variety of topics, objectives and criteria simultaneously throughout the design process, or particularly in the implementation of an Integrated Design Process – IDP (IEA task 32; Moe, 2009; Keeler & Vaidya, 2016), which is a collaborative method for the development of sustainable design solutions. Many descriptions of IDP describe a certain "code-of-conduct" for better collaboration in the design team and a phased workflow. Still, they refrain from describing the actual design activities in the phases or how to facilitate the decision-making process (Kamari et al., 2018b). Well-informed decision-making, therefore, relies on the collection, analysis and communication of large amounts of diverse data. This task is further complicated if data needs to be understood by project stakeholders that have different educational backgrounds, expertise and experiences – which is often the case.

Studies into visualization techniques, like the ones illustrated in Figure 1, show that data visualization is increasingly seen as a powerful means to engage stakeholders with unfamiliar and complex subject matters, telling stories by curating data into a form easier to understand (Yau, 2011). They are designed to display data in a way that enables decision-makers to make visual analysis, exploration and discovery for informed decision-making.

Questions may arise, such as how to design visualizations to be understandable and effective for the stakeholders, and how to measure and evaluate their effectiveness. Answering these questions is a focal point for most – if not all – software developers interested in creating sustainability-focused or multiple criteria evaluation tools, and the answer is often missing.

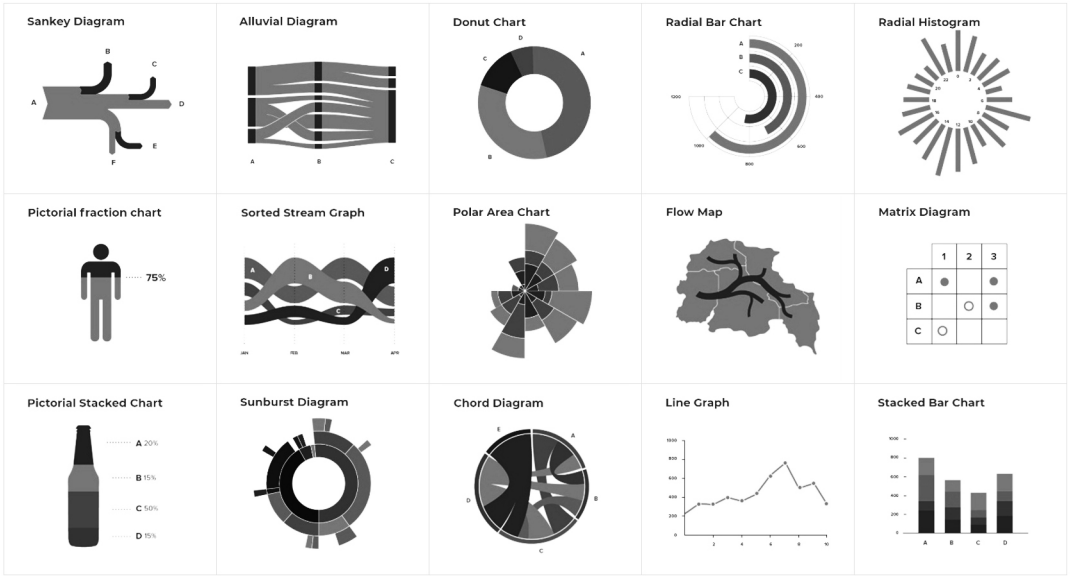


Figure 1
Examples of data visualization techniques (adopted from Fredio, 2019)

This article presents the results from an investigation into appropriate data visualization techniques for decision-making in the (early) design phase of building renovation processes. The focus is on finding what are the requirements of an effective visualization technique aimed at architects, to visualize the outcome of simulation and assessment of renovation design options for multiple sustainability themes or Key Performance Indicators (KPIs), such as investment cost, energy consumption, indoor thermal comfort, etc.?

The article adopts a bottom-up approach for the development and evaluation of visualization techniques in this article. The aim is not to stay at a "theoretical" level but to evaluate the effectiveness of the visualizations through discussions with potential end-users (who are architects and constructing architects, in the present study); in the following, we refer to "architects" since all participants work in architectural studios. This is done contrary to what commonly occurs, where the visualization techniques are used with less attention on who the end-users are, or how useful and effective the visualizations will perform in actual practices (Mourshed et al., 2013; Sharp et al., 2007; Buxton, 2007). In this perspective, the research work is structured through six stages, which are illustrated in Figure 2. Each stage is briefly described below.

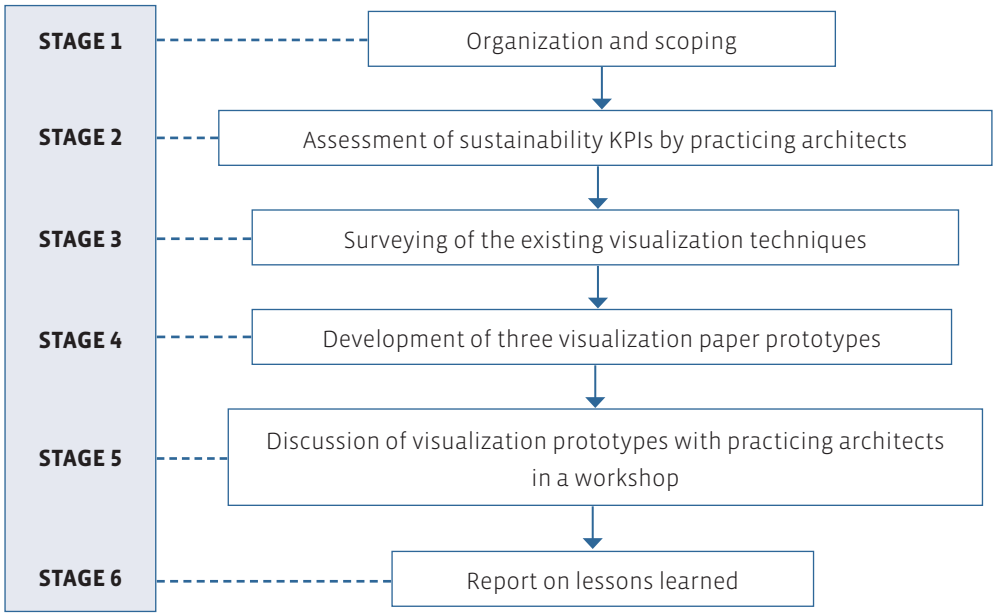


Figure 2
The structure of research development in the present article

Stage 1 aims to specify the project requirements via investigating the renovation process of social housing in a Danish context and provide a basis for the selection of sustainability KPIs to be used in the current research work. This stage reveals crucial spots for informing the architectural design process in contemporary renovation practice, where the process can benefit from appropriate data visualization techniques for decision-making, related to the evaluation of sustainability KPIs upon the development of alternative renovation design options. (In section 2)

Stage 2 presents the assessment outcome of the sustainability KPIs in contemporary renovation practice in the Danish context by gathering the architects' opinion, so as to be used as input for the development of visualization techniques in the next step. The assessment is carried out through a so-called "most important in the centre" exercise, as part of a workshop with a focus group of eight ppracticing architects, constructing architects and anthropologists from three large Danish architecture consultancy companies (AART architects, Friis & Moltke and Cebra) in Aarhus, Denmark. Concerning the focus group study and particularly the selection and number of the participants, we used the recommendations from Krueger & Casey (2014), where the ideal size of a focus group (for most non-commercial topics) is recommended as five to eight participants. The session is conducted partly in English and partly in Danish. It is audio-recorded, and the organizers make notes during the conversation. (In section 3)

Stage 3 includes surveying existing visualization techniques for initial selecting and analysing visualization prototypes in this research study. As such, through a bottom-up approach, we begin with reviewing

literature on what are the characteristics of effective data visualization techniques, besides listing of different visualization techniques that have the potential to be used for demonstration and visualization of the data in the current research study (30 visualization techniques are identified). This helps us to develop a preliminary list of criteria that in the next step will be used to measure which of the listed existing visualization techniques are more fit for this project. The outcome proposes three visualization techniques that, in the next step, are developed to a "paper prototype" level. (In sections 4.1 and 4.2)

Stage 4 includes developing three "paper prototype" visualization techniques, based on the project requirements resulting from stages 1, 2 and 3. The "paper prototypes" are used to instigate discussions with the practitioners about which visualization technique functions best concerning their work process. (In section 4.3)

Stage 5 consists of discussing the "paper prototypes" through a focus group workshop with the same participants and the procedure described in section 2. In order to ensure an effective evaluation of the prototypes, the participants are initially presented with a detailed scenario (or situation) for the renovation of an existing building. Then we use a "feedback Capture Grid" – a structured way of organizing feedback – where participants in their group are obliged to express their likes, *criticisms*, *questions* and *ideas* regarding each prototype. The session is audio-recorded, and the organizers take notes during the conversation. (In sections 4.4 and 4.5)

Stage 6 addresses the lessons learned from the research findings in the article, discussing the development requirements for effective visualizations, workshop participants' findings and recommendations. (In section 5)

2. Renovation of social housing in a danish conetext

This article focuses in particular on data visualization in the (early) design stages of renovation processes (Kamari et al., 2017a, 2017b). In Denmark, social housing constitutes one-fifth of the total housing stock. A lot of the dwellings were built before the introduction of energy restrictions in the national building regulations in the late 1970s (Government, 2014, p. 56). Further, a considerable part of the social housing stock faces extensive renovation during the coming years, due to general wear and to secure attractive dwellings for a broad user group (Landsbyggefonden, 2014). In other words, there is a vast identified potential for synergies between multiple objectives when addressing this typology through renovation (Kamari et al., 2019a). However, these renovation projects often represent very complex tasks, which involve many stakeholders and agendas. They range from the specifics of repairing leaking roofs and

clapped-out waste pipes, to overall plans and political programs (Landsbyggefonden, 2014). In the context of this article, the renovation of social housing makes up a through-going case, in order to tie the concept of data visualization to a specific and topical context.

2.1 Crucial spots for informing the architectural design process

Renovation of social housing may be organized in many different ways. Depending on the tender format, various stakeholders may be included in the process at different stages. However, as a common denominator, renovation often includes multiple stakeholders, hereunder clients (refers to home associations in Denmark), architects, engineers, contractors, authorities, to name but a few (Rambøll, 2018). The architect may come into the project as a client-consultant, an external consultant or subcontractor depending on the tender format. In this article, the focus is not on the specific tender format, but rather on supporting the architect's role as a participant in interdisciplinary project teams in the early design phases, where the most defining decisions are made (COWI, 2018). Venancio et al. (2011) discuss that the support for these design decisions is often limited.

2.2 Sustainability criteria and their relevant KPIs for evaluation of renovation design options

Sustainability is based on modern information and communication systems (Afgan & Carvalho, 2002). There are always special interests to verify the need for a deep understanding of sustainability, through outlining a set of criteria and their relevant indicators (Afgan, 2010). As a response to this, there is a significant range of methods accessible for the appraisement of sustainability today (Haapio & Viitaniemi, 2008). They have been expanded in response to demands from the surroundings, primarily the environment, where the most recent assessment methodologies attempt to embrace and evaluate the *environment, economy and social* relations in a similar circumstance (Jensen & Maslesa, 2015). Many of the existing assessment methodologies and tools (Jensen & Maslesa, 2015) have been developed to design new buildings, but can be applied to renovation projects as well, and some are mainly intended or adapted for the building renovation context. BREEAM (by British Research Establishment), LEED (by U.S. Green Building Council) and DGNB (by German Sustainable Building Council) are some of the well-known examples of such existing methods.

While some scholars have argued that sustainability cannot be adequately defined (Butters, 2014), it is agreed that sustainability should be considered not just as another requirement in the design process, but as the basis for all design work in building design (or foundational in building design). Given the many values that sustainability as an umbrella-term covers (i.e., energy, pollution, material and water cycles, financial structures, health, land-use, flexibility, etc.), researchers and

professionals in building design are examining more closely the existing values in building design about stakeholders and pertaining disciplines, to cope with the interdisciplinarity of sustainability topics as a societal and cultural value (i.e., socio-diversity, identity, variety, involvement, sociality, etc.). This increases the importance of sustainability and extends its coverage even wider in relation to the "soft" and "hard" values and the existing trade-offs. Based on this perspective, the recent research by Kamari et al. (2017) about developing a new holistic sustainability decision-making support framework presents a set of holistic sustainability objectives and criteria for building renovation. The study (Kamari et al., 2017c) was inspired by some sustainability assessment methodologies using a consensus-based process, via Soft Systems Methodologies (SSM) and Value Focused Thinking. The outcome was a sustainability Value Map for building renovation consisting of three categories – *Functionality*, *Accountability* and *Feasibility* – with a total of 18 sustainable value-oriented criteria (see Table 1).

Table 1
Sustainability value-oriented criteria for building renovation (adapted from Kamari et al., 2017c)

Functionality	**Accountability**	**Feasibility**
Indoor comfort	Aesthetic	Investment cost
Energy efficiency	Integrity	Operation & maintenance cost
Material & waste	Identity	Financial structures
Water efficiency	Health & safety	Flexibility & Management
Pollution	Sociality	Innovation
Quality of services	Spatial quality	Stakeholder engagement & education

The majority of *Functionality* category criteria are quantifiable, while the *Accountability* category primarily includes qualitative criteria. The *Feasibility* category contains a mix of quantitative (i.e., cost criteria) and qualitative criteria, such as advantages in using an efficient renovation process by the key stakeholders' involvement (especially the building occupants). Each criterion can be decomposed into sub-criteria and linked to several KPIs (Kylili et al., 2016; Kamari et al., 2019b; Alwaer & Clements-Croome, 2010; Becker, 2004; Alwaer et al., 2008; Bell & Morse, 2003), which enables them to be measured either quantitatively ("*hard*") or qualitatively ("*soft*"). Table 2 summarizes the selected KPIs for assessing the renovation design options in the current study; nevertheless, the list can be extended in future research. The listed KPIs are assessed by practitioners in the next step (see section 3).

Table 2
Outline for the selection of KPIs for evaluation of holistic renovation design options

Criteria	KPIs	Evaluation [value measurement]
Energy efficiency	Energy consumption (Danish Energy Agency, 2017)	Reduction of energy consumption for heating measured in kWh/m²/year [less good]
	Energy frames defined in BR18 (Danish Building Research Institute, 2017)	Renovation energy classes (I and II) in kWh/m²/year [less good]
Indoor comfort	Indoor Thermal Comfort (Dansk Standard, 2007)	% in Class I, II, III according to EN 15251 [bigger better]
	Discomfort hours above 27 and 28 (°C) (Dansk Standard, 2006)	Number of hours [less good]
	Indoor Air Quality – IAQ (Dansk Standard, 2007; Dansk Standard, 2013)	% out of Class III according to EN 15251 [less good]
	DF (daylight factor), (VELUX, 2016)	0<DF<5 [bigger better]
Investment Cost	Investment Cost, (Molio, 2016)	Price of the procurement in DKK (Danish Krone) [less good]
Material & waste	Embodied energy (Bribián et al., 2011)	MJ/kg (megajoules of energy needed to make a kilogram of material) [less good]
Flexibility & Management	Productivity of lean construction (Aziz & Hafez, 2013)	Lean Construction Productivity Potential [bigger better]
Health & safety	Health, (Norback et al., 2014)	% regarding Energy improvement, indoor thermal comfort, air quality and their effects on Asthma, Allergy and Eczema diseases [bigger better]
Spatial quality	Daylight requirements according to BR18 (Danish Building Research Institute, 2017)	% ≥ 10 [bigger better]
	View-out quality, (Jensen et al., 2017)	% of openings relative to the total façade. Simplification of definition by Purup et al. (2017) introduced in this study to instigate discussions about including "soft" KPIs [client dependent]
	Degree of privacy, (Jensen et al., 2017)	% of openings area on façade regarding adjacent buildings [client dependent]

3. Assessment of the sustainability KPIs by practitioners in contemporary renovation practice

This section explores information about the common understanding of the listed KPIs in Table 2 by practitioners, concerning renovation practice in a Danish context. The information we present is based on years of research, previous cases of renovation projects that we have been involved in, as well as conducting the workshop with the practitioners working in architectural offices in Denmark. The exercise was named "most important in the centre". As such, the participants were divided into two groups of four people. They were asked to assume that they are participants in a turnkey contract competition, working in the early design stage of developing the renovation design options. Then, they were provided with the list of KPIs (as presented in Table 3, albeit in Danish).

Table 3

Assessment of the KPIs for a renovation case

No.	KPIs	Relevant terms in contemporary renovation practice (Danish context)	Icons
1	Energy consumption	Energiforbrug (energy consumption)	
2	Energy frames defined in BR18		
3	Indoor Thermal Comfort	Overophedning (overheating)	
4	Discomfort hours above 27 and 28 (°C)		
5	Indoor Air Quality – IAQ	Ventilation (ventilation)	
6	Daylight Factor – DF	Dagslys (daylight)	
7	Investment Cost	Anlægsudgifter (investment cost)	
8	Embodied energy	Miljøpåvirkning (environmental load)	
9	Productivity of lean construction	Bygbarhed (buildable)	
10	Health	Sundhed (health)	
11	Daylight requirements according to BR18	Dagslys (daylight)	
12	View-out quality	Udkig (view out)	
13	Degree of privacy	Privatliv (privacy)	

Thereafter, we provided two target figures (A and B in Table 4) to each group, asking them to place the introduced KPIs on them, by answering the questions in Table 4. Moreover, the participants were asked freely to write names of new KPIs and add them to the ongoing exercise, in addition to those listed in Table 3.

In Table 4, the question "a" is intended to explore the "level of popularity" that refers to how often the KPI is incorporated in the design process to evaluate the developing renovation design options in current practice. Question "b" is intended to explore the "level of importance", which refers to how important the KPI is considered at the time of decision-making by architects. Table 5 illustrates the participants, as well as an example of the "most important in the centre" exercise outcome in the workshop. The images of the results (in high resolution) can be seen in Appendix B.

Table 4
"Most important in the centre" exercise – the questions

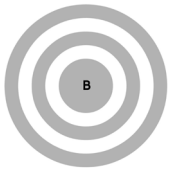
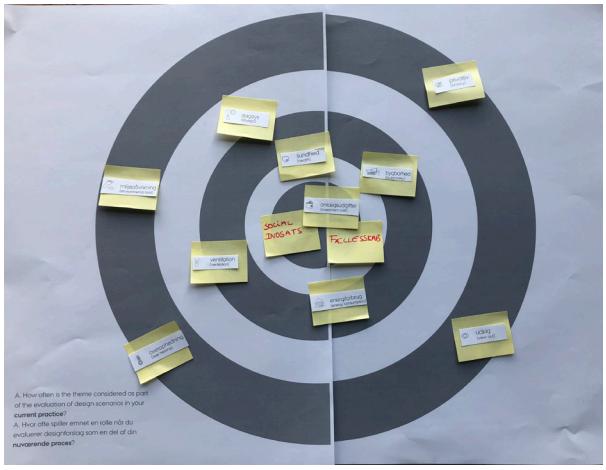
a) To what degree do you incorporate the themes (or KPIs) in your current practice? – centre = always evaluated – in-between (middle) = sometimes evaluated – periphery (outer) = not evaluated at all	
b) What level of importance do you attach to the themes (or KPIs)? – centre = must be evaluated – in-between (middle) = ought to be evaluated – periphery (outer) = no need to be evaluated	
Note: During the workshop, the term "theme" was interchangeably used for describing the "KPIs", as the term "KPI" appeared to be not usually used in the daily routine of the participants.	

Table 5
"Most important in the centre" exercise in the workshop, 13 May 2019

a) Group A – working on the exercise

b) Group B – working on the exercise



c) Example of the outcome of answering question "b" as stated in Table 4

d) Both groups A and B discussing the outcomes of the exercise in sum-up plenum

3.1 Findings of the "Most important in the centre" exercise

Findings from/summary of part "a" in Table 4: "To what degree do you incorporate the themes (or KPIs) in your current practice?"

The participants generally emphasized the project dependence of the question. In other words, the frequency of evaluation of KPIs as part of the design process relates closely to how much emphasis is put on the KPIs by the client/in the brief. Statement by one of the participants:

> *Investment cost, buildability etc.... if it is a competition, then these are parameters that should simply be within the target. Then we evaluate the different proposals we sit with, based on how we can differentiate us, create added value ... And there is a big difference if it is a competitive situation or in dialogue with users/client.*

In both groups, the KPI "overheating" was placed quite far out on the target. This does not imply that it is not considered – however, it is considered less than the other KPIs. As said by one of the participants: "If the engineer can solve it, then it is ok". This may indicate that the KPI is not always considered as an integrated part of the current practice.

Both groups have put "investment cost" and "buildability" in the centre. When it comes to the other KPIs, the placement on the target differs between the groups. From the plenum session, however, it became evident that both groups agree that the client's wishes/demands define the boundary conditions of the project. For this reason, one of the groups wrote "client wishes/demands" explicitly on the target. According to one of the participants, a competition project entails that "...There is a program that we should comply with, because we have to be conditional" ... "But within these wishes/demands there is a potential to make some of the themes very important, some more than others and some to a degree where they become the main narrative, the identity of the project".

In general, the term "narrative" was dominant in the discussions. "What differentiates a competition project is that there is a strong narrative attached to it" ... "that could be some of these themes. That is also why they were difficult to place, because it is dynamic. It is something we figure out together". In the words of this participant, the team is always looking for a strong narrative when developing proposals. This could be some of the KPIs in the exercise. But it could also be e.g., "social effort" or "community", as indicated by one of the teams. According to one of the participants, such KPIs "can be read as added value".

It became evident from the exercise that the architects seldom view themes (or KPI's) as isolated entities. Rather, they consider how different renovation measures (renovation design options) may support the overall narrative. This understanding that architecture is about entireties rather than isolated concerns has been addressed by several practitioners and scholars, e.g., Buro Happold (Happold, 2009).

Findings from/summary of part "b" in Table 4: "What level of importance do you attach to the themes (or KPIs)?"

The second part of the exercise focused on the level of importance the participants attached to the KPIs. In this exercise, one of the groups chose to put all the KPIs in the periphery, to signify that these could be considered a "plate" of ingredients. If the client has a special focus, one theme could become more important and be adapted to the project. The participants emphasized that a good dialogue with the client would make it easier to choose, for example, the three KPIs to focus on. This challenges the competition-based tender format.

As well, the term "narrative" appeared in the centre of the target, as did, for example, "social efforts" and "community". When discussing what means the architect can bring into play, in order to create a certain narrative, one participant mentioned the threshold as an important focus: "...I also think it is the threshold [kantzonen], e.g. in the stairway or on the terrain" (...) "for instance a small transition zone on the entrance floor, where you can impact/personalize exactly the entrance that you are using – through places to stay or something". "Community" was a recurring KPI in different scales – in the dwelling, in the building block, in the neighbourhood, etc. Privacy and community are two linked KPIs and there should be a gradient.

In general, the participants agreed that the intervention level defines the available "architectural toolbox". For example, "view out" was not placed in the centre by either of the two groups – the reason being mainly that the participants do not feel that they can influence this KPI so much in renovations. "It is kind of a given – and if we were to rank the KPIs, then this was probably not where [we would put our focus] ...". The participants stated that they could have ranked the KPIs differently if the scenario for the exercise was based on an even earlier phase.

In opposition to the first exercise, "investment cost" was put out in the periphery, because the participants found the "investment cost" to be less interesting than life cycle cost: "...because otherwise we can do it all over in 15 years again – and then it was probably not so (financially) sustainable after all". Environment and health are considered to be more central. This was a general pattern for the two groups, even though the placement of KPIs were seemingly different.

The overall outcome of the assessment of KPIs in the workshop helped us both get familiar with the common language that architects use during the design of renovation design options and to obtain adequate insights for the further development of the visualization prototypes in the next step of the work.

4. Developing and evaluating effective visualization prototypes aimed at architects for decision-making in (early) renovation design processes

4.1 Effective data visualization

The following sub-section exposes relevant literature that deals with a general overview of visualization as a discipline. Data visualization is a graphical representation of information and data. Many disciplines view it as a modern equivalent to visual communication (Friendly & Denis, 2006). It involves the creation and study of the visual representation of data. The goal is to communicate information clearly and efficiently to

users. Data visualizations present views of data that answer "what", i.e., what are our costs and profits, for different regions and different months or years? They are suitable for solving a finite set of questions and can be static or provide some level of interactivity for investigating those questions (Matthew, 2015). In terms of the value in data visualization, Moore (2017) discusses that visualization methods must provide *simplicity*, *clarity*, *intuitiveness*, *insightfulness*, *pattern and trending* (topic) capability in a collaborative process, supporting the requirements and decision objectives for the decision-makers.

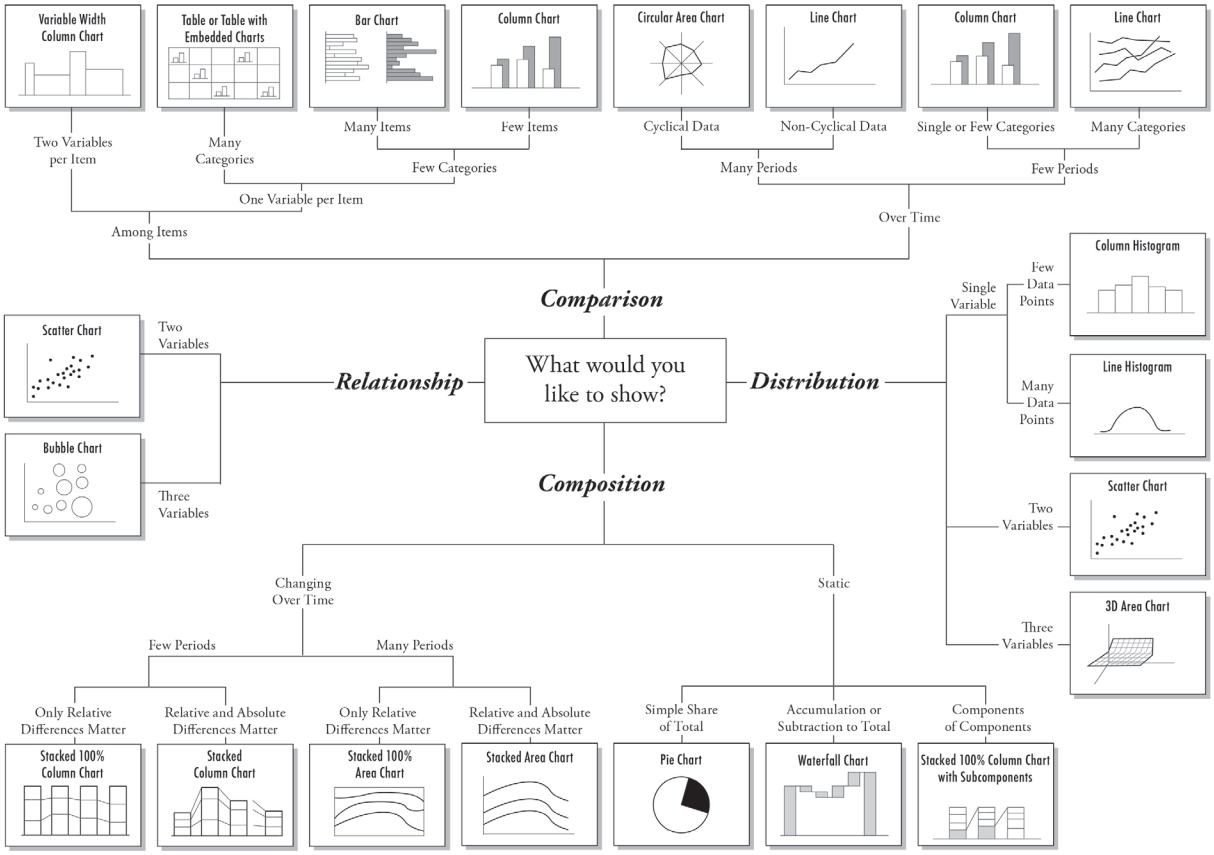
The main goal of data visualization is to communicate information clearly and effectively through graphical means. Abela (2013) reports that the central focus should be on "impact", which indicates that the entire purpose for the development of visualization techniques is to ensure *an impact on the audience*. To convey ideas effectively, both *aesthetics* and *functionality* need to go hand in hand, providing *insights* into a rather sparse and complex data set by communicating its key-aspects more intuitively (Friedman, 2008). Using visual elements like charts, graphs and maps, data visualization tools provide an *accessible* way to see and understand trends, outliers and patterns in data. Tufte (1983) defines "graphical displays" and principles for effective graphical display as follows: "excellence in statistical graphics consists of complex ideas communicated with *clarity*, *precision* and *efficiency*". The author (Tufte, 1983) states that graphical displays should:

- show the data
- induce the viewer to think about the substance rather than about methodology, graphic design, the technology of graphic production, or something else
- avoid distorting what the data has to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation or decoration
- be closely integrated with the statistical and verbal descriptions of a data set.

4.2 Surveying of the existing visualization techniques

According to Evergreen (2019), a considerable part of telling the right story is knowing how to pick the correct graph. To communicate information clearly and efficiently, data visualization uses statistical graphics, plots, information graphics and other tools. There may be more than one way to visualize the data, but what chart is chosen will depend on the data, the audience and the visualization's purpose (Simon, 2014).

For example, as demonstrated in Figure 3, the data can be visualized in various forms due to different purposes, such as *comparison*, *composition*, *distribution* and *relationship*.



For the current project, we began by collecting and listing different visualization techniques[1] that have the potential to be used for demonstration and visualization of the data in the present research study. 30 visualization techniques were needed before it was deemed that yet another technique would not bring any new format in relation to the objectives of the present research study. The collected techniques all had one feature in common: they are all capable of demonstrating or visualizing the multi-variant data, which is a necessity in the data visualization for the current research study, to deal with the multiple sustainability KPIs as discussed in section 3.

Figure 3
An example of chart suggestions – a thought-starter (adopted from Abela (2006))

1 In doing so, we have explored several existing visualization catalogues from the following sources:
- http://datavizcatalogue.com/blog/other-data-visualization-libraries/
- http://textvis.lnu.se/
- https://datavizcatalogue.com/
- https://treevis.net/
- https://datavizproject.com/
- https://www.slideteam.net/
- https://vcg.informatik.uni-rostock.de/~ct/timeviz/timeviz.html

The visualization techniques were listed as follows:

Arc Diagram	**Line Graph**	**Proportional Area Chart**
Bar Chart	Multi-set Bar Chart	Radar Chart
Bullet Graph	Network Diagram	Radial Bar Chart
Candlestick Chart	Nightingale Rose Chart	Radial Column Chart
Chord Diagram	Non-ribbon Chord Diagram	Sankey Diagram
Donut Chart	Open-high-low-close Chart	Scatterplot
Dot Matrix Chart	Parallel Coordinates Plot	Span Chart
Heatmap (Matrix)	Parallel Sets	Spiral Plot
Histogram	Pie Charts	Stacked Area Graph
Horizon	Population Pyramid	Sunburst Diagram

Subsequently, we evaluated the above visualization techniques more carefully to choose methods to be developed to a "paper prototype level" and thereby serve as a basis for instigating discussions in a workshop with practitioners. As such, based on the KPIs' assessment discussed in section 3, and based on the study of Abela (2006) in Figure 3, we evaluated the visualization techniques with regards to their capability of:

- presenting an overall *comparison* between renovation design options based on the evaluating KPIs
- demonstrating the *correlations* between the evaluating KPIs
- indicating *thresholds* related to the evaluating KPIs
- being *simple* and easy to understand
- being visually *pleasing*

To this end, we used the Likert scale, which is a measurement scale where the degree of *agreement* or *disagreement* is indicated in terms of a series of statements about stimulus objects (Malhotra et al., 2012), consisting of 1) strongly disagree, 2) disagree, 3) neutral, 4) agree and 5) strongly agree. Due to limited time, the authors did the initial screening; nevertheless, it could be even better to carry it out with different real practitioners. The full surveying table is presented in appendix A. As the outcome of this evaluation, the *Bullet graph*, *Radial Column Chart* and *Heatmap* (see Table 6) received the highest score. They were selected to be developed to a "paper prototype" level in the next step.

Table 6
The selected visualization techniques

Bullet Graph	Radial Column Chart	Heatmap (matrix)
		

4.3 Proposals for development of the selected visualization prototypes

Here, we develop the selected visualization techniques *Bullet graph*, *Radial Column Chart* and *Heatmap* to a "paper prototype" level, to be used in discussion with practitioners, considering which techniques and formats bring value to their work process and in which way. The choice to develop and use "paper prototypes", and not "digital prototypes", was due to the time limit. It was also more appropriate for the explorative study being carried out in this paper. It is worth mentioning that the "paper prototypes" were specially developed to instigate and facilitate discussions with practitioners and should not be treated as a final product, but rather as a sketch. To create the paper prototypes, we used the criteria according to McCandless (2014) and Cairo (2016), including the *goal* for visualization, required *information*, *story* (as described in section 4.4), *colour* and *visual form*. The development was done iteratively, through a team effort conducting a series of weekly meetings (six meetings in total) by the ReVALUE[2] research project partners (mix of architects and engineers) in the Department of Engineering, Aarhus University. The outcome is presented in Figures 4, 5 and 6.

2 Participated in by Brabrand Housing Association – with energy renovation in the Aarhus suburb of Gellerup – as well as DEAS, an administration company on the private rental housing market (for more info: http://www.revalue.dk).

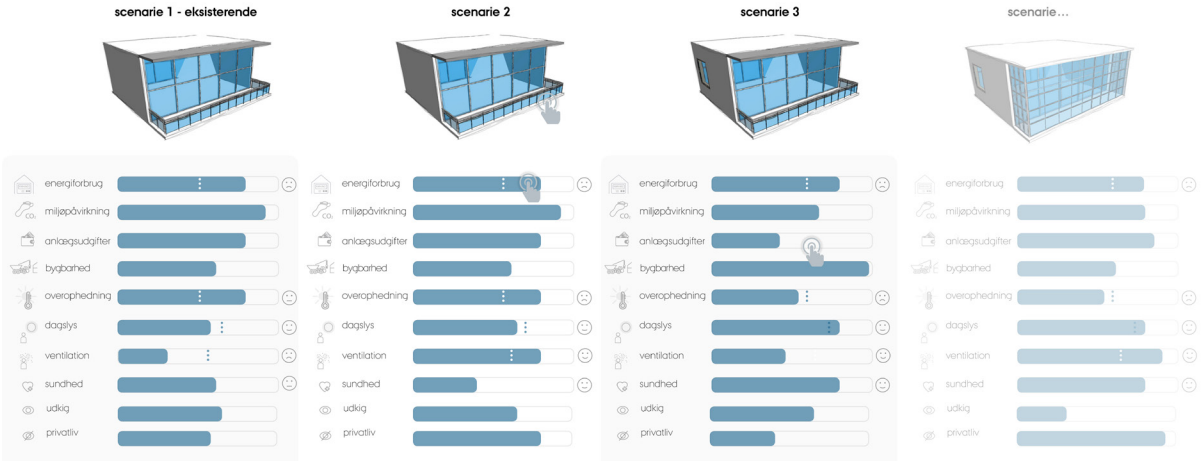


Figure 4
The visualization prototype A – Bullet graph

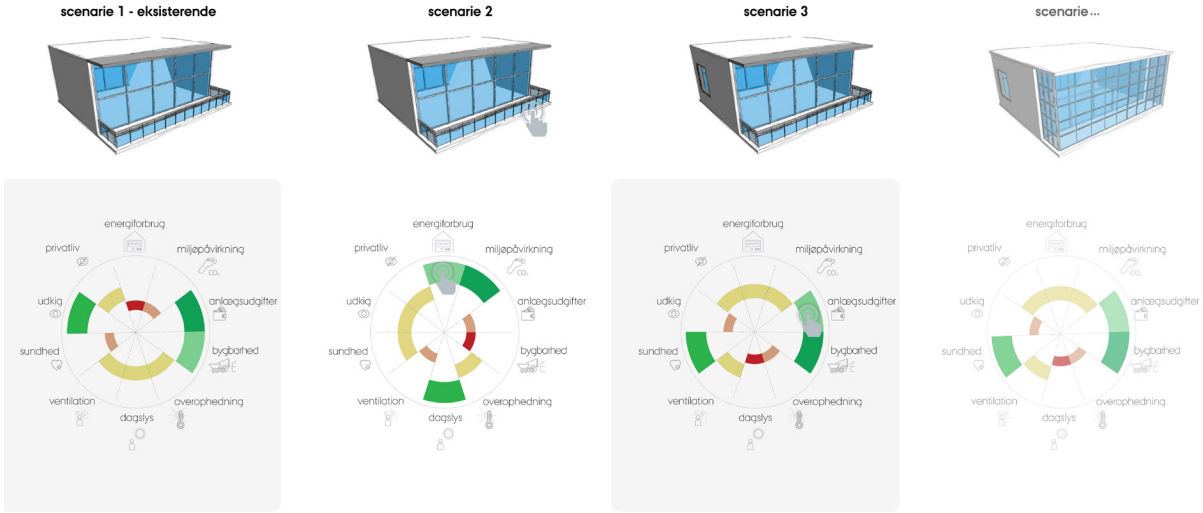


Figure 5
The visualization prototype B – Radial

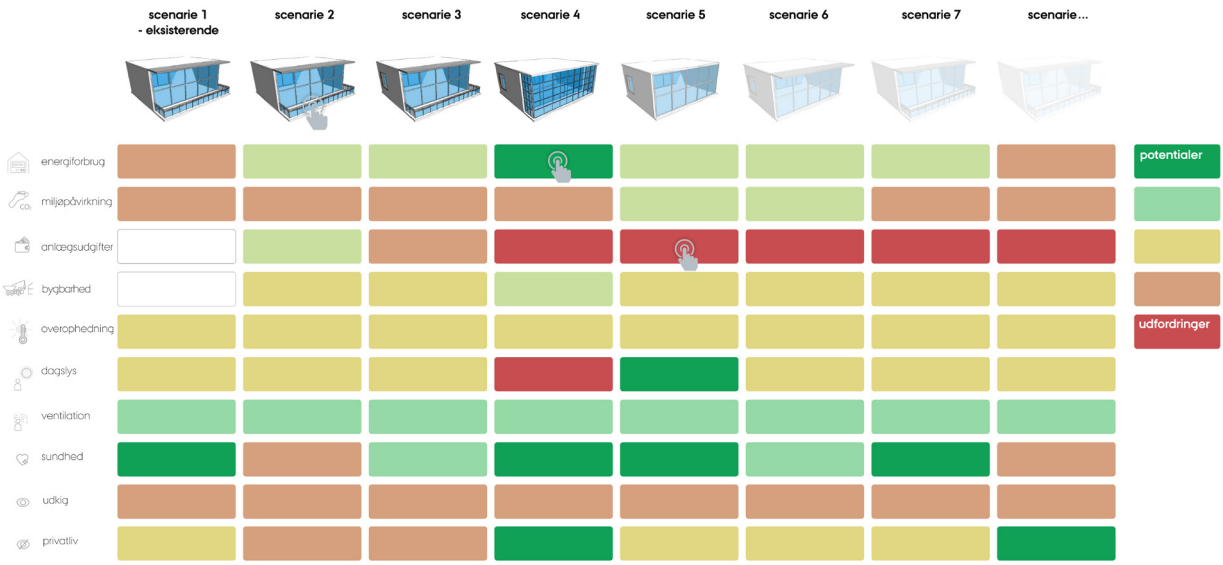
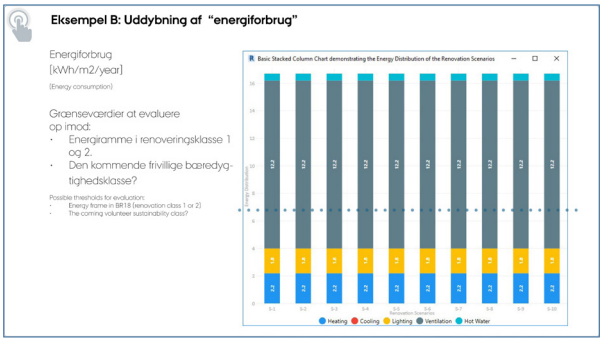


Figure 6
The visualization prototype C – Heat-map Column Chart

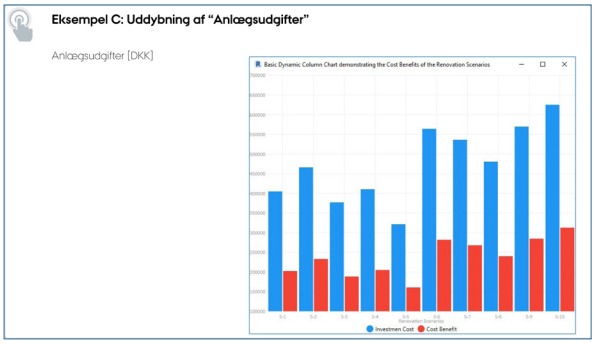
The three developed prototypes serve a variety of functions and information that include the demonstration of many generated renovation design options (horizontally) and providing a comparison between them via the visualization of the evaluation outcome of KPIs (vertically). Besides, the visualization techniques are designed to equip the user with further information, which can be reached using a mouse click or hovering the mouse indicator (as marked on Figures 4, 5 and 6 by) either on the design options, or the evaluating KPIs (see Table 7).

Table 7
Further information about the design options in the developed visualization techniques

a) The technical details of the generated renovation design options



b) Investment cost of the design options



c) Energy consumption of the design options

4.4 Evaluation of the visualization paper prototypes with practitioners

Discussion of visualization techniques and formats based on the three paper prototypes was carried out as the second exercise in the workshop with the focus group of eight practitioners. The participants were divided into two groups of four people. In order to ensure an effective evaluation of the prototypes, the participants were presented with a detailed scenario (or situation) for the renovation of an existing building and were asked to imagine themselves in that situation at the time of evaluating the visualization prototypes. The scenario was presented as:

a. Renovation process: The participants should envision partaking in a competition project in the early design stage.
b. Design options: The participants are enabled to (via the use of a tool) rapidly generate holistic renovation design options and evaluate them for multiple KPIs (as discussed and presented in section 3).
c. Existing building: The renovation task targets development of renovation design options for an apartment/unit in a large residential building. The selected apartment/unit is a multifamily, residential building block located in Aarhus, Denmark. The building block forms part of a social housing area, consisting of 9 identical building blocks

built-in 1967–1970. The existing front façades are of glass, and the side façades are of concrete. Figure 7 illustrates the renovation case.

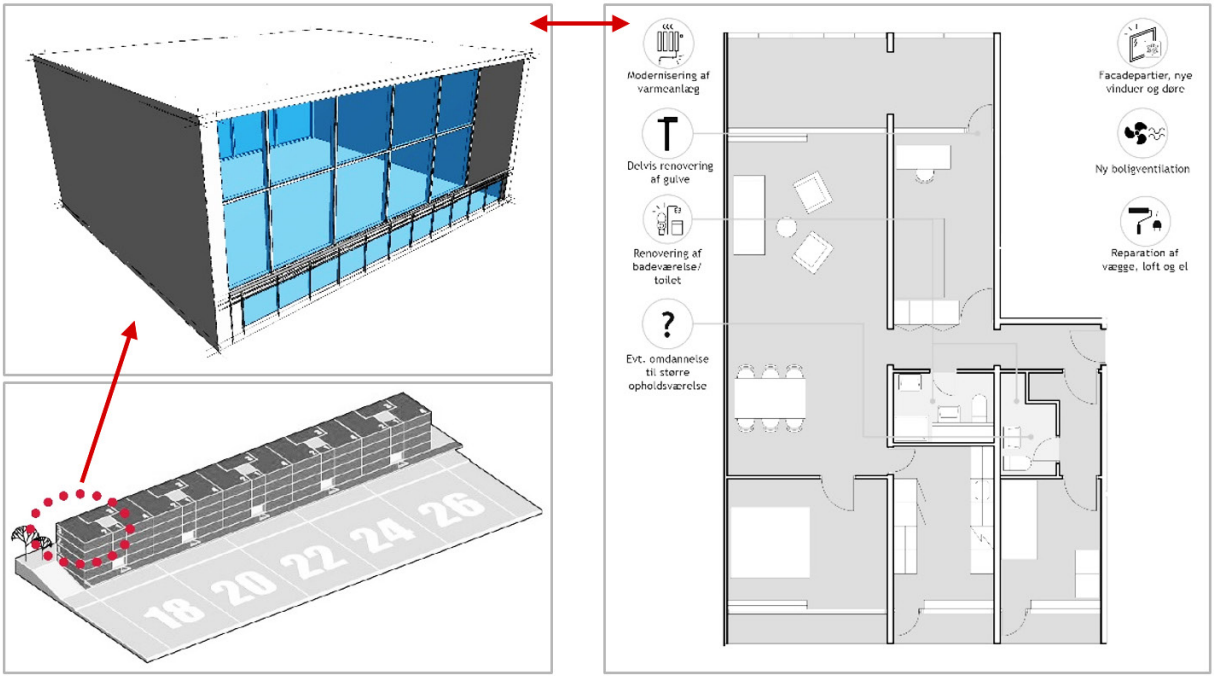


Figure 7
The apartment/unit renovation case (source [floor plan and axonometric view of apartment block]: the drawings were made by Pluskontoret architects for Brabrand Housing Association).

Right after the presentation of the above scenario to the participants in the workshop, a so-called "feedback Capture Grid" (Interaction Design Foundation, 2019), as illustrated in Figure 8, was used as the basis for the discussion.

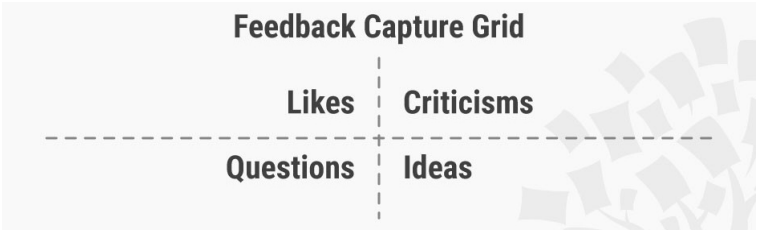
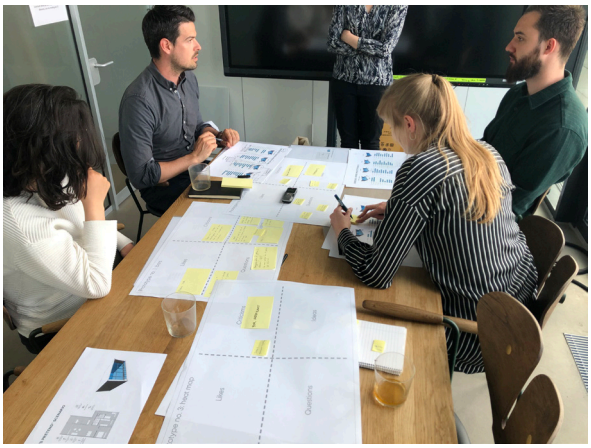


Figure 8
The "feedback Capture Grid" – a structured way of organizing feedback. Source: Interaction Design Foundation (2019)

Hereafter, the participants in their group were obliged to express their *likes*, *criticisms*, *questions* and *ideas* regarding each prototype. They were asked to consider which prototype will function best concerning their work process. Table 8 illustrates the participants performing the exercise in the workshop.

Table 8
Evaluation of the prototypes with the practitioners in the workshop, 13 May 2019, Aarhus

a) Group A – working on the exercise



b) Group B – working on the exercise

c) Both groups A and B discussing the outcomes of the exercise

4.5 Findings of the "paper prototype" exercise

Based on the data collected from the use of the "feedback Capture Grid" in the workshop (for detailed collected feedback see Appendix C), the most positive attitude was directed towards prototype A – the *Bullet Graph*, as the participants argued that it gives the best overview and is the easiest to read.

As a general comment, the participants would have liked to get more info about the meaning of the individual KPIs (e.g., when hovering the mouse over a theme). This proved especially relevant for the "soft" KPIs (e.g., view-out quality); however, it was a general concern.

The participants requested a higher degree of consistency in the way results are displayed. For instance, it would improve the readability of "success" if the data were displayed in the same direction. "At the moment, increased energy consumption is a negative thing, whereas increased health is positive" was mentioned by a participant. Further, in the presented prototype, level 1 (Figures 4, 5 and 6) is based on horizontal bars, whereas the sublevels (e.g., for energy consumption) are based on vertical columns (option C in Table 7).

The participants found the "smiley" system in prototype A to be superfluous. Inspired by prototype B (radical column graph), the participants discussed the value of introducing colours. This was a source of disagreement, as group A argued that colours could make it easier to read if a design option performs "well" or "bad". Participants in group B were, however, pleased with the current colour setting – but also talked about using red to signify if the target had not been met.

As part of the discussions, the participants requested that the explanatory images for each design option was made simpler – for example, into 2D or 3D pictograms instead of model images – as these "just confuse things and make people focus on specifics such as the mullions". Moreover, some participants requested the ability to click themes "on" and "off" as part of the interface.

In addition to "pure" data visualization, the workshop exercise sparked a discussion on the included KPIs as well. One participant stated that it is "…nice to get numbers on some of the qualitative themes [KPIs]". Another participant said that "If 'they' [the individual KPIs] are to be addressed equally, they should also be represented equally". This served to underline the value of simultaneously addressing the traditionally more "hard" and "soft" values. However, the participants stated that some of the qualitative aspects are very contextually dependent, and that there may be KPIs, which are more "suitable" for objective evaluation than others, for example acoustics, the ability to furnish the spaces ["møblerbarhed"], etc. The participants further suggested to include the following KPIs (or themes): How the building is perceived from the surroundings (not only considering the individual dwellings), the transition zone, running/operational costs, flexibility within the dwelling, access to the exterior, maintenance and payback economics (e.g., Loans 10, 20, 30 years).

5. Discussion

The main findings of this article, (i.e., the "most important in the centre" exercise in section 3.1 and "paper prototype" exercise (in section 4.5), can be combined into *a list of requirements for the development of effective visualization techniques* to support the decision-making in (early) renovation design processes with multiple KPIs. As such, effective visualization techniques in this regard requires to be:

- *Intuitive*, being simple and easy to understand (using colours will be very effective, in this regard)
- *Truthful*, to demonstrate the truthiness, concerning the KPIs' simulation and assessment outcomes
- *Insightful*, to reveal the thresholds/co-relations related to the multiple sustainability KPIs
- *Flexible*, to be independent of the design process and being adjustable to project requirements (being project-dependent)
- *Functional*, to include an accurate depiction of the data and let architects do meaningful operations, which also includes the demonstration of the outcome to the other stakeholders, in addition to that of the clients
- *Practical*, to enable architects to compare the renovation design options based on the evaluating KPIs
- *Comprehensive*, to include the evaluation of more sets of holistic sustainability KPIs in the visualizations (demonstration of the life cycle cost and environmental analysis were strongly demanded)
- *Balanced*, to include "soft" and "hard" KPIs simultaneously and in an equal manner, besides a clear definition of them
- *Beautiful*, being attractive, intriguing and even aesthetically pleasing to the users
- *Enlightening*, given that architects can grasp and accept the evidence it depicts, it will change their minds for a better decision

6. Conclusion and future study

Renovation of social housing represents a complex task involving many stakeholders with different and, most of the time, conflicting agendas. This article has assumed that the development and application of proper data visualization techniques can help navigate this complexity by supporting more informed decision-making in the early design phases, when alternative renovation design options are being developed and assessed.

The article began by presenting an overview of KPI's definition and assessment by practitioners, relevant to the renovation of social housing in a Danish context. Then, it explored existing visualization techniques and subsequently developed three visualization prototypes, which formed the outset for focus group discussions with eight practi-

tioners working with the renovation of social housing in Denmark. The visualization's objective was to help the architects comprehend the effects of a broader number of KPIs and to develop the most appropriate renovation design options for the social housing renovation projects at hand. The experience resulted in gathering reliable feedback that can be integrated into the further development of visualization techniques, incorporating the evaluation of multiple sustainability KPIs in the future.

The workshop's participants reported that the study was exciting and that it was helpful to be involved in the co-creation of effective visualization techniques aimed at their real work process. The conclusion of this research study is that architects are often looking for a strong narrative, when developing design options (especially in the early design stages) to address the sustainability KPIs in practice, and it varies from project to project (firmly client-dependent). In addition, they seldom view KPIs (or themes) as isolated entities. Rather, they consider how different renovation measures (or renovation design options) may support the overall narrative. In the light of this, the visualization techniques more effective for architects are those that can provide the best overview of the problem in question (be flexible on visualizing data project-dependent) and at the same time be functional (being accurate and easy to comprehend), visually pleasant, truthful (demonstrates the truthfulness) and enlightening, given that when architects grasp and accept the evidence it depicts, they will change their minds for a better decision.

An essential limitation of this study concerning the conducted workshops was a somewhat condensed process, as well as the number of participants and their backgrounds. It would have been valuable to allow for more time for the exercises and for the results of the "most important in the centre" to be integrated with the organization of the subsequent exercise of "paper prototypes". Moreover, running a workshop with a bigger/smaller number of participants with different backgrounds may result in different outcomes. In this study, we have focused on architectural firms/offices. However, despite the fact that architects play a significant role in the early design stages of renovation or new building design projects, similar studies should be repeated with different project stakeholders (i.e., besides architects, also engineers, contractor and clients) if the goal is to perform an Integrated Design Process – IDP.

6.1 Future study

Future research work on developing more appropriate visualization techniques for the renovation context may include a more elaborated bottom-up approach, with repeated focus group studies and usability tests. This entails fundamental research in developing and exploiting techniques that are mainly developed to be used in different design stages in the AECO (Architecture, Engineering, Construction and Operation) sector.

In essence, the outcome of this research work and similar work can be used by software developers to give direction, if the goal is to develop effective visualization techniques for the decision-support in the AECO sector. At the time of writing this article, based on current research work, and as part of the ReVALUE research project, the selected visualization technique (Prototype A – the Bullet Graph in Figure 4) has been developed and implemented for the visualization of the simulation data for a tool named PARADIS (Kamari et al., 2019c; Kamari et al., 2020). PARADIS is being developed for the rapid generation and evaluation of renovation design options to be used by architects in the early design stages of renovation. The aim of applying such a tool is to promote iterative decision-making methodology. Further, the aim is to promote time-saving, improvement of the accuracy and quality of the final decision, as well as assisting architects in encouraging stakeholders to accommodate holistic renovation scenarios in the early design stages of the renovation projects.

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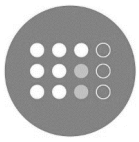
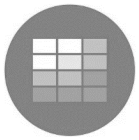
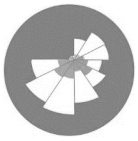
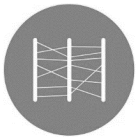
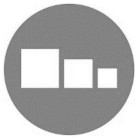
Appendix

Appendix A

– Matching the visualization purpose and its qualities with the correct visualization technique[3] for decision support in the integrated renovation design process.

3 The images of the visualization techniques have been used from "The Data Visualization Catalogue", link: https://datavizcatalogue.com/

N	Visualization Techniques – name –	Enable comparison	Visually pleasant	Demonstrate correlations	Indicate thresholds	Simplicity	Visualization Techniques – image –
1	Area Graph						
2	Bar Chart						
3	Bullet Graph						
4	Candlestick Chart						
5	Chord Diagram						
6	Donut Chart						
7	Dot Matrix Chart						
8	Heatmap (Matrix)						
9	Histogram						
10	Horizon						

N	Visualization Techniques – name –	Enable comparison	Visually pleasant	Demonstrate correlations	Indicate thresholds	Simplicity	Visualization Techniques – image –
11	Line Graph						
12	Multi-set Bar Chart						
13	Network Diagram						
14	Nightingale Rose Chart						
15	Non-ribbon Chord Diagram						
16	Open-high-low-close Chart						
17	Parallel Coordinates Plot						
18	Parallel Sets						
19	Pie Charts						
20	Population Pyramid						
21	Proportional Area Chart						

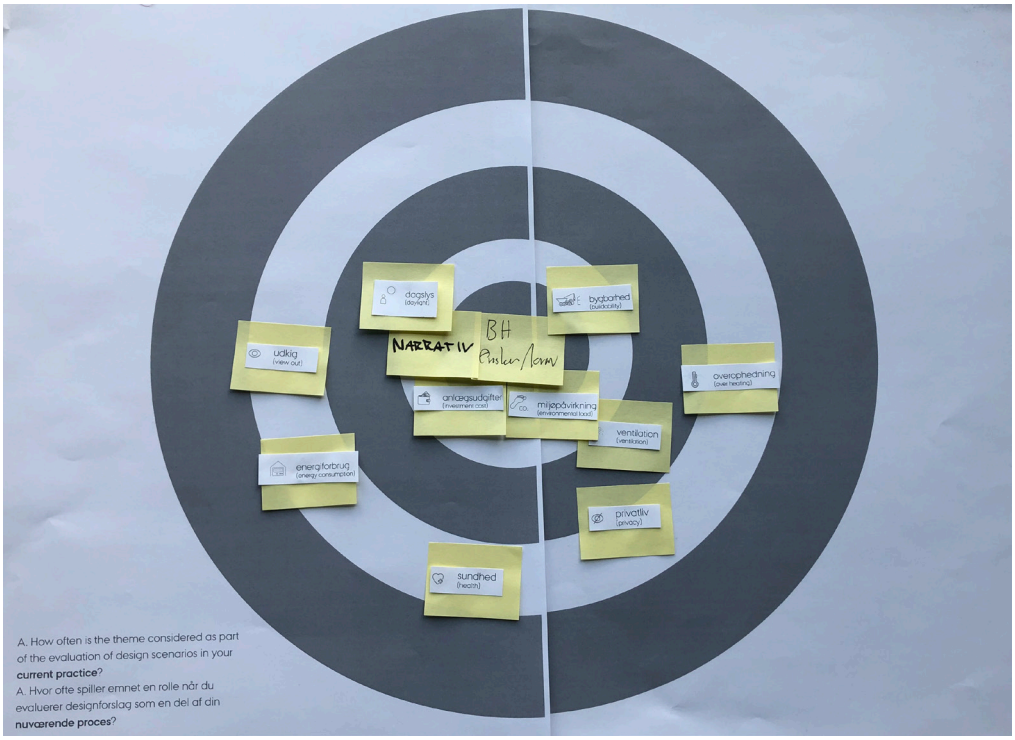
N	Visualization Techniques – name –	Enable comparison	Visually pleasant	Demonstrate correlations	Indicate thresholds	Simplicity	Visualization Techniques – image –
22	Radar Chart						
23	Radial Bar Chart						
24	Radial Column Chart						
25	Sankey Diagram						
26	Scatterplot						
27	Span Chart						
28	Spiral Plot						
29	Stacked Area Graph						
30	Sunburst Diagram						

Appendix B

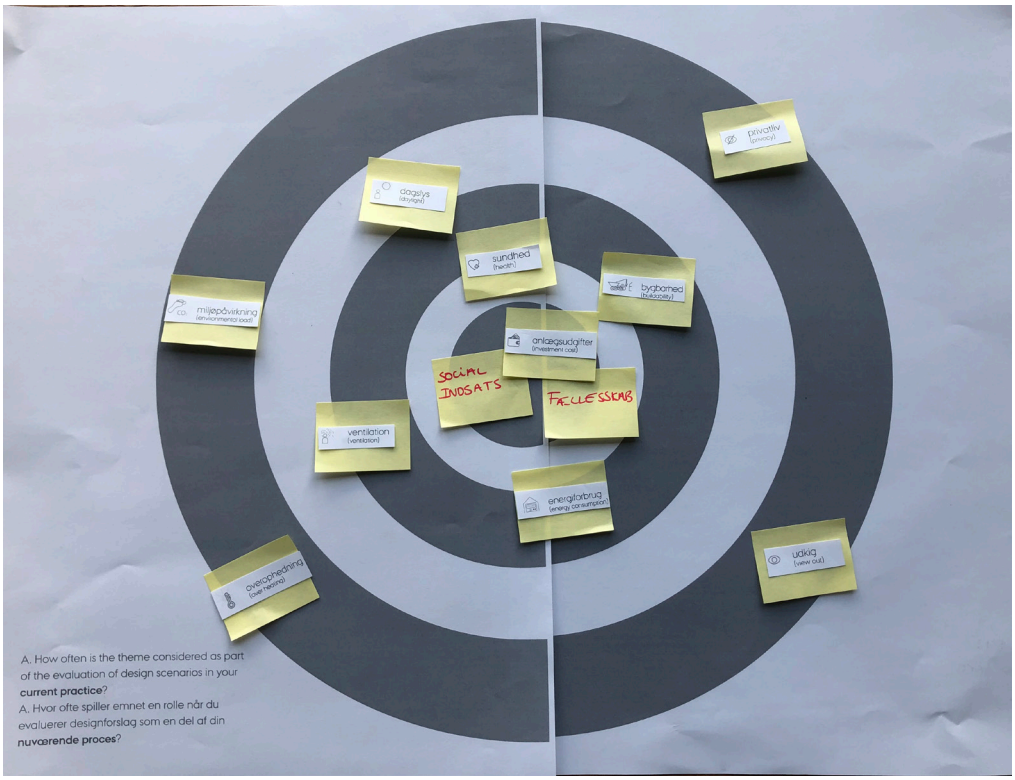
– Outcomes of the "Most important in the centre" exercise as implemented in the workshop, 13 May 2019 (related to Section 3 in the article).

Question 'a': To what degree do you consider the themes (or KPIs) in your current practice?

Group 1

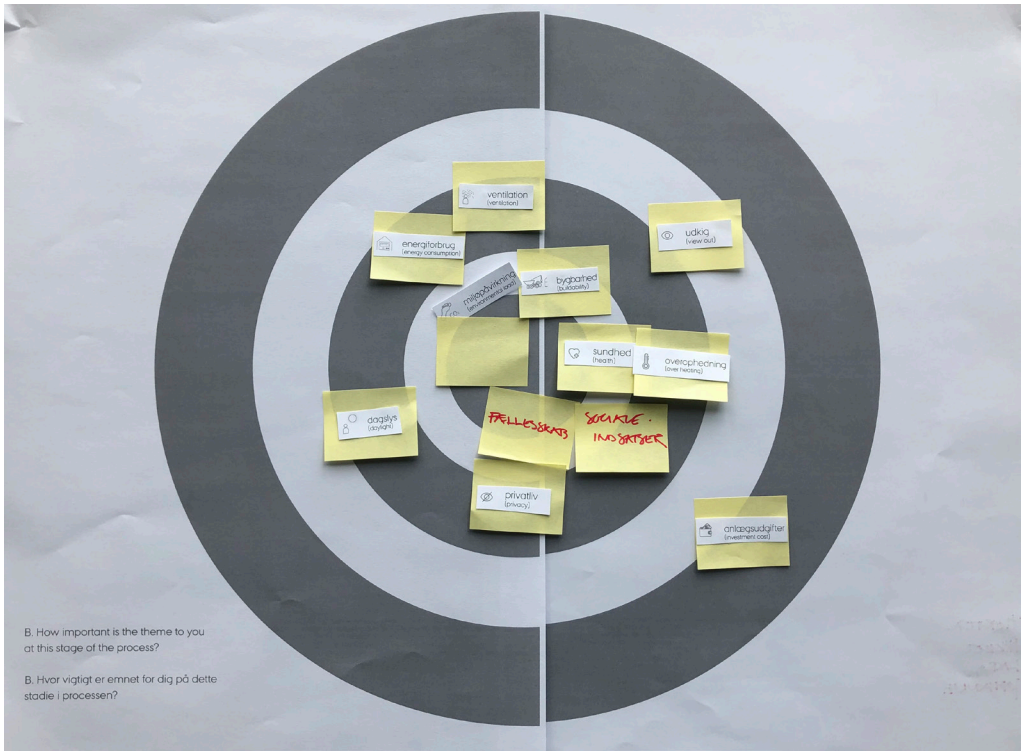


Group 2

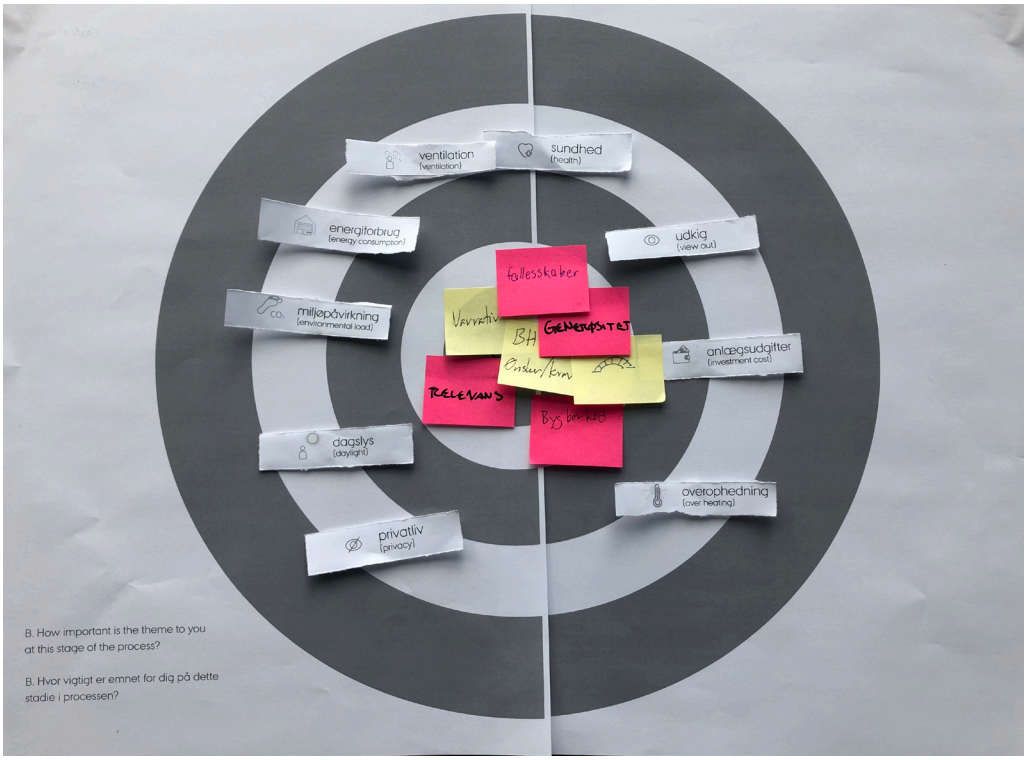


Question 'b': What level of importance do you attach to the themes (or KPIs)?

Group 1



Group 2



Appendix C
– The captured evaluation feedback by application of "feedback Capture Grid" from the participants

Prototype A – Bullet Graph (see Figure 5 in article)

Likes:
- The prototype gives the best overview of the three prototypes. (by both Groups A & B)

Questions/comments:
- If the KPIs are intended to be addressed equally, they should also be represented equally. (by Group A)
- Cool/nice to get numbers on some of the qualitative KPIs (by Group A)
- Some of the qualitative KPIs are very contextually depended. (by Group A)
- Direction of bar? Better to rotate in the second and third levels. (by Group B)
- Increased energy consumption = bad (by Group B)
- Increased health = good (by Group B)
- Cost information in terms of economy? Do we have the possibility to make inputs/put in numbers ourselves? (by Group B)

Criticisms:
- Looks like you can toggle the bar itself. (by Group A)
- Is it good or bad that the bar is "filled" or "empty"? (by Group A)
- You lose the overview if there are more scenarios. (by Group A)
- The underlying data? What underlying info is needed in order to compare two scenarios? (by Group B)
- The smiley icons are not needed. (by Group B)

Ideas:
- When you hoover the mouse indicator on an icon, you get an elaboration of what e.g. "miljøpåvirkning" [environmental impact] means. (by Group A)
- Suggestion for KPIs: Adgang til det fri (access to the exterior), Møblerbarhed (ability to furnish), flexibility in the dwelling, running costs/operational costs. (by Group A)
- Include the ability to click themes "off" and "on" in the interface (sorting of themes + prioritization) (or you could be able to click turn "on" that function). (by Group A)
- Be consistent in the type of graphs. Now: prototype A is based on horizontal graphs and the sublevel for energy is based on vertical (columns). (by Group A)
- Provide the option of adding more KPIs. (by Group A)
- How big deviations from the target do we accept? (maybe add a function to sort out/discard the scenarios which do not meet the self-chosen targets). (by Group A)
- Introduce relative numbers on the individual themes and a total weighted sum. (by Group A)
- Use colour codes to show if it is "good" or "bad". (by Group A)
- Can a program evaluate aesthetics? (by Group A)
- Be consistent in terms of if right/left side of the bar is good/bad. (by Group A)
- Suggestion for KPIs: Investment + life cycle cost, Møblerbarhed (ability to furnish) (by Group B)
- Would be nice if sliders were mutually dependable (note: this comment may be a result of a misunderstanding of the "slider" principle – that the participant thought that you should slide the bars. Instead the bars are a result/consequence of a scenario, which was explained to the participants). (by Group B)
- Leave out the detailed images, so the assessment does not get too aesthetical – rather have pictograms. (by Group B)
- For technical details of the renovation scenarios, knowing that it is roof, façade etc. that is being renovated (could be text). (by Group B)

Prototype B – Radial Column Chart (see Figure 6 in paper)

Likes:

- N/A

Questions/comments:

- Not the goal that everything is green but to take choices. (by Group B)
- The understanding of how much the program "guesses" and the needed inputs. (by Group B)
- Difference between red and light red? (by Group B)
- Definition of the KPIs? Could be e.g. an info box. (by Group B)

Criticisms:

- Difficult to read (by both Groups A & B)
- Difficult with colour scale – because: what do the colours mean? Does it have a low priority or is it an objective standard? (by Group A)
- We need to know about the technical information of the renovation scenarios if it is roof, wall etc. (at level 1). (by both Groups A & B)

Ideas:

- Tick box for each parameter, which can be turned on/off. (by Group B)
- Images at the top: maybe diagrams instead of model? (by Group B)
- Gradients (by Group B)

Prototype C – Heatmap (see Figure 7 in paper)

Likes:

- N/A

Questions/comments:

- N/A

Criticisms:

- Does it become too over-simplified in that there are only 5 colours? (by Group A)
- What happens in the column next to the one I am looking at, influences my understanding. (by Group A)
- I accidently evaluate "it all" (whether there are many red colours across the scheme) rather than the individual scenario up against the others. (by Group A)
- It looks too abstract (by Group B)
- Difficult to compare (by Group B)
- Lacks overview in terms of threshold/benchmark (e.g. BR18) (by Group B)

Ideas:

- N/A

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