An Iterative Information System Design Process Towards Sustainability

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Abstract. While bringing business and computer science into an improved alignment using the theoretical foundations of information and computation is one of the main aims of information science, improved design knowledge from other interdisciplinary research fields like human-computer interaction (HCI) could advance different information system (IS) design thinking and processes. Since structuring the IS design process for a sustainable result is challenging, a HCI viewpoint and focus on IS design could be beneficial due to the multi and interdisciplinary nature of HCI. In this paper an iterative design process for sustainable IS design conceptualized from HCI is proposed. The resulting design process highlighted the role of HCI in building knowledge in information science. This was achieved by showing the influence of different design choices on user behavior and in that way contributing towards generating reusable designs in different phases of the sustainable IS design process.

Keywords: Information system design · Iterative design process · Open innovation · Sustainability · Universal design

1 Introduction

Sustainability with its associated design and development problem is not a new issue in our society. The essence of sustainability is difficult to grasp if its complexity and multidimensionality are considered. Often the notion of sustainable development focuses on ecological design, a weakness of the modern approach to sustainability [10]. An IS can contribute to sustainable development in different ways. Since IS is a great force for productivity improvement [34] it can be designed in a sustainable manner and can act on its user to trigger sustainable behavior. One example is using persuasive technology to change the behavior of individuals through persuasion [28]. Nevertheless, the success of such an IS would typically depend on how it would be designed [47]. Since it is not possible to identify the boundaries of sustainability in an absolute way (a "wicked problem" [5]), it is a challenge to identify and select proper factors for sustainability in a system design scenario [12]. Therefore, the complexities of sustainability and its associated indicators bring new problems in the form of design challenges for IS.

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While the importance of thinking sustainability outside the scope of environmental issues is obvious from previous research [6,7], designing at the same time introduces a multitude of new and complex sustainability indicators [52]. For example, complicated issues like time and thresholds have been claimed to be an important indicator for sustainability [33]. The right indicator selection for sustainability, typically can determine a system's behavior since it would then be built to reflect the associated behaviors with different selected indicators. While the addition of complex indicators could result in an improved designed system for sustainability, to do this successfully the relevant design process should incorporate the suggested design principles. This brings the challenge of defining an appropriate IS design process for sustainability. A reason for this is that IS is not only conceptualized within the limitations of the software systems, but the embedded concept of design is growing. Thus, it becomes a new challenge for IS design to align business and computer science using theoretical foundations of information and computation [17,23] to keep up with unexpected and continuous change [9]. Since new sustainability indicators may not be restricted within the basic pillar of sustainability, they could originate from any discipline. This breadth of origin is a challenge for IS because there is a clear disciplinary gap in the research of IS design, regardless of it being a multidiscipline practice, and IS research should thus be prepared to tackle such a challenge. This problem could be handled by pulling knowledge from other disciplines, namely HCI, which is an interdisciplinary research field [14,15]. This paper displays how knowledge tailored from HCI could be used to fill an identified disciplinary gap in IS design research. The identified gap is the need for a design process for sustainable system design where issues with indicators as stated above can be resolved. The underlying research question for this research paper is therefore "how can we structure and support an IS design aimed towards sustainability". As an answer to this question, a design process solution is developed in the form of a theoretical framework that is based on previously established research. It is argued that by placing more emphasis on interdisciplinary research like HCI, new knowledge could be built for the study of IS design for sustainability. This paper is organized in six sections. A short background in Sect. 2 presents the underlying concepts of sustainability, IS design and design process followed by Sect. 3 where a theoretical framework in the form of an iterative design process is explained in detail. Based on the structure of this theoretical framework some design principles for the addressed iterative design process for sustainable IS design are then formulated and presented in Sect. 4. An extensive discussion and future work prospect in Sect. 5 identifies and revisits different roles of sustainable HCI (SHCI) for sustainable IS design. Finally, conclusions are drawn in Sect. 6.

2 Background

2.1 Sustainability and Information System Design

ISs are considered as human designed artefacts [32]. This socio-technical system is created to blend and integrate processes, people, information technology and software to work towards a set goal [55]. The view of sustainability in this paper is based on the World Commission on Environment and Development's [53] definition of sustainable development to meet the needs of the present without compromising the ability of future generations to meet theirs. By reversing or diminishing the outcome of diverse human-induced processes, sustainability could be attained. One of humanity's challenges at present is how to achieve sustainability, one threat is global warming [24] and its impact on health [57], another threat is the rise of global obesity [25,39].

Watson et al. [56] wrote 2010 a seminal paper that called for more research from the IS community aimed at sustainability. In the same issue of MIS Q, Melville [34] put forward a research agenda on IS in the context of environmental sustainability. SHCI has mainly focused on reducing CO_2 through system design [8], though more significant changes are called for to secure the quality of life for humans [27]. IS is now ubiquitous and plays a larger role in the daily life of most humans, and therefore including sustainability in the design of these ISs is essential. The topic of sustainability is researched in different research fields such as information systems, environmental informatics, information technology, and human-computer interaction [20,41]. If sustainability is considered during the design of a system, it becomes possible to reach a set sustainability goal and increase the resulting impact. Previous research has noted that the inclusion of sustainability at the design stage is not acknowledging as important in the current SHCI research [3]. What is missing is a holistic view; currently, the approach is to simply look at the energy use of a certain artefact (e.g., computer, electronic device or house) and thus limit the scope to an often-delimited system [41]. A limited studied system can at first appear to be sustainable, but if studied in the context of a larger system can be viewed as unsustainable.

At first glance a thing often considered as sustainable is the smart home where electricity use is monitored and the household's behavior is directed towards conserving energy, water and heating [16,43,51]. Although conserving energy, water and heating could be a set sustainability goal, the cost of the whole system (e.g., manufacturing the smart hub, sensors, etc. and the power these artefacts consume, maintenance cost and the expected lifetime of the system before it needs to be replaced) must also be considered. This cost could be calculated in a life cycle assessment (for LCA see Hendrickson et al., [18]). The LCA could then be used to decide if the benefit of the smart house outweighs its cost. Both the direct and indirect impact of smart technologies need to be considered when assessing the sustainability of the system [21]. It is easy to pick low hanging fruits like the reduction of energy utilization in a device or system, but on the contrary, one might use the device and the system more and thereby as a whole act unsustainably i.e. Jevons' paradox [26]. Tomlinson et al. [54] saw similarities with more efficient IT. Another study of the impact of ICT on environmental sustainability modeling from 2000 to 2020 found benefits slightly outperform disadvantages [1,22]. A smart system with the goal of reducing fuel consumption by giving the best fuel saving route and avoiding traffic congestion by getting real time traffic data, might lead to more driving. Because the driving experience will become better (more enjoyable because less time is spent in traffic jams), people might be tempted to abandon public transport and use the car more. Thus, there are complexities associated with designing systems aimed towards sustainability. In addition, the analysis level from micro to macro, starting with the individuals followed by family, community, society and state, should be considered globally since optimization at one level could harm another.

2.2 Design Process

In different research fields the term "design" itself has a different meaning, and the understanding of "design process" is therefore contextual e.g., Herbert Simon [46] stated that everyone designs who takes action aimed at changing existing situations into preferred ones. Generally, the design process should reflect a set of processes in the form of a flow where the target is to produce a desired goal by following the involved set of processes. Consequently, when a series of steps are followed to achieving a specific solution, these steps could be seen in the form of a design process. While Simon is blending a scientific approach with design, other researchers have opposite ideas, e.g. Schön [44] is rooted in pragmatism and sees that design is about problem setting and not problem solving. It could be argued that this development reflects a move from understanding design through the lens of scientific and engineering tradition towards a designerly-oriented design practice [48]. This paper's objective can be categorized as the theoretical advancement to enhance the theoretical core of HCI [48,49], Stolterman & Wiberg describes this as developing "innovative concepts that lead to intellectual development through definitions, conceptual constructs, and theories." One of the sustainable design movement originators, Victor Papanek [42] stated, "All men are designers. All that we do, almost all the time, is design, for design is basic to all human activity. The planning and patterning of any act toward a desired, foreseeable end constitutes a design process... Design is the conscious effort to impose a meaningful order."

In this paper the design process is perceived as an IS design process that involves several steps. Nevertheless, designers and engineers often omit following these steps in a sequential manner and instead frequently return to a step as they require and then proceed over to the next step. This is the core idea behind an iterative process, as design is inherently an incremental and iterative activity [19]. One important challenge of the design process is designing the process itself. To be precise, to gain a successful outcome from a specific design process, the associated steps in that process need to be designed accordingly. Thus, in order to support an IS through specific factors, then the overall design process of that system should be tailored accordingly for the end system to act as a cause for those factors. The need of an IS for sustainability should thus take us back into an initial requirement of forming the prosper design process. As discussed in the introduction section, the interdisciplinary nature of HCI can give us a better understanding on how to do this. The following section illustrates and explains the proposed iterative system design process in detail.

3 Proposed Design Process

The proposed design process is shown in Fig. 1 in the form of a theoretical framework. The underlying concept and rationale behind this framework originates from the five previous studies referred to in Mustaquim and Nyström [35–38] and Nyström and Mustaquim [41]. The theoretical framework of this research is principally based on the notion of universal design (UD) and advancing its concept. UD was created as an answer to changes in demography; since people live longer, more people live with disabilities, and these limitations require the design and construction of environments and products that meets the need and rights of all citizens [50]. UD has already become a popular design philosophy in HCI for focusing on accessibility issues, outside of its traditional sphere, UD could also lead to user empowerment [29]. Frameworks, cognitive models and design principles were derived under the context of sustainability, open innovation (OI) and open sustainability innovation. The results of the addressed five published articles were condensed here in structuring the theoretical framework. The rationale behind the construction of this framework is described in Subsect. 3.1 while different phases of the framework are illustrated and described in detail in Subsect. 3.2.

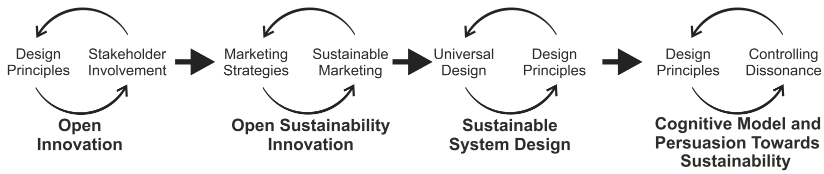

Fig. 1. Proposed iterative design process for sustainable system design.

3.1 Foundation of the Design Phases

Fiksel [12] has exemplified several conventional sustainability indicators under the economical, ecological, and social dimensions of sustainability. These indicators are considered, and it is showed how they would fit within the context of the theoretical framework. The four triggers from the framework were derived and concluded from previous research [35–38, 41] shown in Table 1, where respective research articles are referred to with the identified triggers. Table 2 then shows a matrix of different sustainability indicators parallel with their corresponding triggers from the theoretical framework. The underlying rationale behind the selection of four triggers is principally focused on the concept of user-centered design. Increasing the possibility of including users in a design process would increase the possibility of the designed product to more appropriately fitting the needs of a desired user group. For sustainability, this user-centered concept can have a direct influence on the usability of a product and can therefore enable the designers to understand the associated interaction process and thereby assess any adverse effects caused by the use of the product [58].

Since the result of a sustainable system design can be benefited by adding complex requirements that are adaptable in the corresponding design phases, how each of the four different triggers are used as design phases in the proposed framework (Fig. 1) would reflect different indicators (Table 1) which will now be discussed here.

Table 1. Four triggers of the framework and their corresponding research.

Triggers of the Framework	**Adapted From**
OI	[35]
Open Sustainability Innovation	[38]
Sustainable System Design	[36, 41]
Cognitive Model and Persuasion Towards Sustainability	[37]

Table 2. A sustainability indicator matrix with associated triggers.

Sustainability Indicators [9]	**Associated Triggers in Framework**	**Corresponding Life Cycle Phases**
Customer Retention Business Interruption Direct Costs Revenues Contingent Costs	**Open Innovation** **&** **Open Sustainability Innovation**	Definition Level, Identifying the Target Design
Material Consumption Energy Consumption Local and Regional Impacts Global Impacts	**Open Sustainability Innovation** **&** **Sustainable System Design**	Development Level, Policy Alternation as Required
Quality of Life, Peace of Mind Safety Improvement Health, Wellness and Disease Reduction	**Cognitive Model and Persuasion Towards Sustainability** **&** **Sustainable System Design**	Operational Level, Action and New Problem Identification

Both OI, and open sustainability innovation consider stakeholders to build new knowledge in design for organizations where the latter specifically focuses on sustainable creation. Relationships with stakeholders and different interruptions of business due to the stakeholder involvement could be taken care of by the [35] policy. Several direct costs associated with product design and development could be controlled by advancing the marketing policy in an organization where open sustainability innovation can play new key roles. Similarly, for different types of tangible and intangible revenues, it will be possible to make stakeholders understand about the potentiality through open sustainability innovation. Organizations on the other hand, can have better control on different types of dependent costs too, when OI and open sustainability innovation are practiced. It is important to note here that the way OI and open sustainability innovation are perceived as a result of previous researches [35,38] does not mean only using stakeholders to generating new business or design ideas, but as part of an identification phase of any big design process where target design could be identified. Now, as discussed in Subsect. 2.2, the contextual meaning of design is very important to realize here and therefore for the trigger of OI and open sustainability innovation, a reasoned purpose (ex. sustainability) was seen to be the design problem.

Development and policy alternation as required could happen when a sustainable system design life cycle is followed. Different impacts on local and regional levels could be handled using open sustainability innovation principles, once again by looking at design from the perspective of a specific cause. Complex environmentally associated issues like material and energy consumptions together with broader global impact realization could be handled by policy alteration during the development phase. A system development life cycle, specifically meant for sustainable system design, [41] would allow this to happen smoothly.

At the operational level of a design process, proper actions should be taken to achieve a goal and thus new problems could be identified. Complex social issues like improving the quality of life, creating a trusting community and peace of mind, different safety improvement and health related issues are societal sustainability indicators that are not achievable in a short time. These issues could be reflected through the use of a design where action could take place by the practice of any improved designed cognitive model [37]. Persuasion and persuasive system design for sustainability could be considered to handle these complex long-term issues. On the other hand, a sustainable system design life cycle could be followed to identify and select these complex goals to be design challenges [37]. The selection of the right design principles [37] would help towards achieving these goals and if new problems arise, they could be addressed in an iterative manner by going back to the required design phase.

3.2 Structure of the Triggers as Design Phases

Four different triggers (see Table 1) were considered to be individual design phases in the proposed framework (see Fig. 1) and their structures are described here.

OI: Consider UD and its principles to generate required OI design principles. Increasing stakeholders' involvement for a successful OI is the challenge here. The business strategy must be aligned with the innovation strategy. By allowing stakeholder involvement in the innovation phase an organization will be able to better capture the added value that innovations can bring, innovated both internally and externally. If OI is practiced and implemented in the business strategy a business could thus gain a competitive advantage, e.g., the toy manufacturer Lego uses OI in their Lego Mindstorms product and allows the users to develop new features [2]. If more stakeholders are involved, the gap between research and development will be reduced since the research department will not be locked and isolated in secret research facilities limiting their scope and connection with user needs. When more stakeholders are involved the research network can be expanded and discover things that could otherwise not be realized as important to develop earlier.

Open Sustainability Innovation: To consider the improvement of marketing knowledge by selecting the correct design principles. Initiates open sustainability innovation by motivating stakeholders to participate in sustainable product or service development. The challenge here is the appropriate selection of design principles. The adoption is crucial for an innovation to become successful thus the marketing mechanism and the triggers of it must be understood, e.g., the video recorder system VHS was not technically superior to its main competitor Betamax (on the contrary) but was adopted by movie companies and consumers and hence became the standard video system [30]. Once this is understood and a marketing strategy is implemented it would be possible to use these triggers to enhance the marketing into a winning mix that will make the adoption of the innovation a success. The future participation in the open sustainable innovation will be assured since more people want to participate in the advancement of a successful and recognized innovation. Caution must be taken since the market is in constant change and a winning marketing mix today could be inappropriate tomorrow.

Sustainable System Design: Use UD principles to trigger sustainable system design. The challenge is to find out the correct system development life cycle for sustainability. Since the sustainable system design could be in constant flux due a dynamic and constantly changing world, it is necessary to use the UD principles for the sustainable design. The system could be developed following the SDLC. Different phases of SDLC need to be adjusted to fit the dominant goal of the sustainable system to be ready for changes and iterations due to goal changes as well as changing user behaviors.

Cognitive Model and Persuasion Towards Sustainability: Use design principles for persuasion and different cognitive models to persuade system development towards sustainability. A challenge is understanding what behavior that needs to be altered. The design of a system will be used to gain social transitions towards sustainability by acting as an agent and persuading users in one focused direction. It is therefore important to understand what drives and motivates the users of a system and then use appropriate design principles to persuade and motivate them towards a justified sustainability goal. The human mind is very complex and difficult to decipher and understand and if one behavior is changed, it could influence other behaviors that were not initially intended which could contribute to or be counterproductive in reaching a sustainable goal.

4 Design Principles

Norman [40] argued that regarding design, one important thing should not be forgotten and that is "Design is art... We do not know the best way to design something". Thus, design principle merits should work as guidance. The proposed design process contributes to understanding the complex sustainability achievement issues through IS design and the purpose of this paper is not to show empirical evidence to judge the success of the design process. However, with proper theoretical design process in hand it is still a big challenge for system designers to grasp the essence unless design principles exist as guidelines on how to practice a design process. In this section design principles are therefore proposed and discussed that would be ideal to successfully practice the iterative design process in Fig. 1 for sustainability. A matrix for identifying design principle's properties was drawn and shown in Table 3 followed by the descriptions of seven design principles in Subsect. 4.1.

Table 3. Identification of different design principle's properties.

Design Process Phases	Design Principle's Properties	Sustainability Identifiers
Open Innovation	Stakeholder involvement and design principles	Customer Retention, Business Interruption, Revenues
Open Sustainability Innovation	Marketing strategies and stakeholders' involvement	Direct and Contingent Costs
System Design Sustainable Design	Universal design and life cycle of sustainable system design	Material and Energy Consumption, Local, Regional and Global Impacts
Cognitive Model and Persuasion	Design principles for PSD and stakeholders	Quality of Life, Peace of Mind, Safety Improvement, Health and Wellness

4.1 Design Principles for Iterative Design Process for Sustainability

Factors and properties identified from Table 3 are summarized in the form of the following seven described design principles.

Principle 1: Use OI for a better control over tackling business interruption and customer retentions – By taking a holistic view on sustainability and using

OI, a business will be better prepared and perhaps gain absorption capacity for new innovations to understand customers better. Thus, it will be able to bridge interruptions and change/adjust the sustainability goal to fit future needs and maintain customer loyalty.

Principle 2: Practice OI at a small-scale system level for improved control on different associated costs and revenue – By limiting and scaling OI into smaller units it becomes easier to control, and therefore the associated risks will become lower and provide better predictions of costs and revenues.

Principle 3: Policy alternation on strategic marketing by involving stakeholders in the knowledge gathering process using open sustainability innovation – If the right marketing triggers are used the adoption of the innovation will be successful followed by customer retention and active participation in future sustainable innovations This will give a competitive advantage followed by revenue and profit.

Principle 4: Use UD and its extended concept for designing a system to enable ecological actions for sustainability – Using UD actively when designing systems should allow the designer to find and discover system generated actions that are beneficial for sustainability.

Principle 5: Follow the sustainable system development life cycle for designing a complex sustainable system reflecting on global sustainability triggers – SDLC is easy to understand and could be the foundation when designing sustainable systems, although other methodologies like agile development could be used if necessary, depending on the scale, complexity, time, and resources. Global sustainability triggers will also have an impact on the designing of the system.

Principle 6: Use a contextual cognitive model for persuading the involved stakeholders towards social sustainability – Stakeholder behavior is dependent on context and to frame the right contextual model will make it possible to relatively easily persuade the stakeholder in the right direction.

Principle 7: Design a persuasive system for stakeholders for changing their dissonance on complex social phenomena like community, health and wellness – If the right persuasion is used the stakeholder will feel liberated and committed to keep on acting towards a sustainable goal. This could have a positive impact on social life and health.

5 Discussions and Future Work

The proposed design process in this paper is unique since it is process focused. That is to say, the emphases is on how to design the process itself in an improved way. Existing design processes or system development life cycles found in the literature are very abstract and do not clearly specify what to do for a particular design challenge. For example, if a classical system development life cycle is followed then it is difficult to interpret what each stage of the life cycle would mean for a design aiming to overcome sustainability challenges. The strength of this paper is therefore the formulation of the iterative design process which could specifically tell the designer what to do in each of the different phases to reflect sustainability through design. In the introduction section it was mentioned that when the emphasis on sustainability is considered outside the scope of ecological dimensions, complexity arises, and design then becomes more challenging. One of the problems associated with this issue also therefore is, a shift towards product-focused sustainability and ignoring different associated processes. While IS design focuses on improving artefact design, it does not ignore the associated process. The use of the proposed framework can thus be crucial for looking into the issues of process related sustainability since each of the individual phases of the proposed framework considers sustainability as its separate outcome. That is, each phase is a trigger for sustainability and was shown to address a specific set of sustainability indicators. Also, Fiksel [12] argued that the success of a system's design with an explicit emphasis on sustainability would highly depend on the proper consideration of the associated subsystems. The proposed design process is considered to appropriately follow this argument, since individual design phases was taken into action as subsystems with an ambition of a comprehensive sustainability accomplishment.

The belief that human-computer interaction can be important when searching for a solution for complex and imminent problems that our society is challenged by can be traced back to Douglas Engelbart [11] who wrote about bootstrapping human intelligence; by doing this human capability would be extended (what he called augmentation). HCI could be considered as multidisciplinary [15] and have the possibility to challenge difficulties that humans are experiencing and find novel solutions that solve these problems. Sustainability in the form of sustainable IS design is an urgent task that could benefit from an approach based on sound HCI theorizing. The fundamental basis of this paper's theoretical framework is HCI based and is a good example of this argument. Norman [40] found a conflict between practice and research that he called a research-practice gap.

This paper is positioned as a theoretical paper with large connection to practice and with practical implications for the designing of sustainable ISs. This research does not focus on problems with new technology as Norman [40] described to be the predominant research in HCI; instead, an iterative design process was built to tackle an imminent important problem to drive the next needed product cycle. Since the pioneering research paper "Sustainable interaction design" by Blevis [4], the important role that HCI plays in sustainability has resulted in a steep increase of papers written in the SHCI research field [6,41,45]. This paper is adding to this accumulated knowledge and brings new perspectives on how to reach sustainability by using HCI. The shape of sociotechnical ISs and society as a whole is influenced by the social process of design. Fuchs and Obrist [13] and Mankoff et al. [31] highlights the importance of research that considers social, environmental and economic issues in design, evaluation and implementation issues and the developed theoretical framework considers these issues and brings a holistic and dynamic framework to use when designing sustainable ISs.

The next step is to evaluate and explore how the proposed iterative process would behave in a system design and how (and where) it could fit in an existing setup of a system. Design principles validation is also another important area that needs to be completed parallel to the design process verification. Only after doing these empirical studies, will it be possible to finetune a particular phase of the design process. One starting point of doing this could be to apply the framework in a small-scale setup and then test on a complex system. Existing design life cycles or processes can be compared together with this proposed design process and then conclusions could be drawn for justifying the feasibility of using a specific design process. This way the design process is a tool to quantify sustainability for an organization running a precise system. Finally, one long-term ambition of the proposed design process could be to measure and compare the sustainability of a system from where different policy makers of an organization could realize how to line up their available resources properly.

6 Conclusions

This paper has explored the scope of sustainable IS design by introducing an iterative design process. The theoretical framework is based on previously conducted research that evolved into an iterative design process in the form of a framework. The process was then explored and explained within the context of different complex sustainability identifiers. Seven design principles were then extracted and concluded from the design process theoretical framework. The role of SHCI concept was finally revisited to understand the perspective of sustainable IS design. The interdisciplinary nature of HCI is therefore concluded to play a crucial role in filling the disciplinary gap in IS research. Placing strong emphasis on describing different HCI design choices in order to understand its result on design process is thus needed. This would build cumulative reusable design knowledge for IS design as presented in this paper.

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