Information System Design Space for Sustainability

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Abstract. The interdisciplinary nature of human-computer interaction (HCI) makes it possible to contribute towards an improved thinking in design and the process of information system designs. It is, however, a challenging aim, because the transformation of different gathered knowledge from HCI to information system designers is not easy, there being multiple design solutions available. In this paper a design space for designing an information system aimed at sustainability is introduced and discussed. The design space could be seen as part of a new design process, or correlating with an existing design setting and consisting of nine different components that are explored elaborately through a design space analysis. Differently selected dimensions of the proposed design space imitate knowledge from HCI and the result thus reflects a support for successfully transferring knowledge from HCI to the information system (IS) designers for improving a design process.

Keywords: Information system design space · Sustainability · Design space

1 Introduction

The quest for sustainability is an omnipresent theme in research today. The sustainability problem could hence be undertaken by many research fields and many partial solutions developed in these fields could together make an impact and a significant change. The designing of artifacts, e.g. socio-technical systems like the information system (IS), is one of the predominant duties of human-computer interaction (HCI) and HCI is considered to be multidisciplinary. While HCI and IS can greatly use each other's knowledge, some cultural problems in fact prevent this from happening and even IS itself has its own research issues to handle regarding HCI [5]. Using design science to construct artificial creations is prescriptive research aimed at increasing system performance [19] and also may be used to solve human problems [15]. Thus, not only the HCI research community but also the IS research community stress the importance of design, e.g. Benbasat and Zmud [1] state that design is important. The designed system could therefore extend our problem-solving capabilities or, as Engelbart [4] writes, might bootstrap human intelligence. With a goal like sustainability to be achieved by IS design, there could be numerous design options in the hands of a designer. To realize different design dimensions is therefore important for the quality and success of a design for achieving the associated goals. The various available possibilities of design are seen within the concept of a design space, which

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is usually specifically intended for a particular product or process. The satisfactory formation of a design space is crucial for the success of a design and it is possible to explore different capabilities in design by making an analysis of design space [8]. Although there has evidently been research on how to design IS for sustainability, the focus has primarily remained within the scope of formulating new design principles, frameworks, and processes [17]. An absence of design space thus limits the scope for IS designers, who could otherwise resolve system design with sustainability. This was the rationale behind the research question of this paper: 'What are the dimensions of the design space of an IS design for sustainability?' As an answer to this question we conceived the proposal of a design space for IS design for sustainability by using a design space analysis. The proposed design space is structured and supported by the theoretical foundation and design concepts from HCI, thereby indicating the possibility of using knowledge from HCI to assist the issues of IS design. Theory, as a desirable output of design research, was identified by Walls et al. [24], and this paper contributes a matter of concept in this respect. Evaluation of the design is essential [21] which in this paper is made by following Halsteadt [6] in quantifying the properties of design process in a complexity measurement. This paper is structured into six sections. After this introduction, Section 2 briefly provides the background of sustainability within the context of IS design and elaborates the notion of design space. Section 3 displays the analysis of design space, illustrating and describing our proposed design space. Section 4 demonstrates a complexity analysis as an evaluation of the proposed design space. Discussions and future work possibilities are then presented in Section 5, followed in Section 6 by the conclusions drawn.

2 Background

2.1 Information System Design for Sustainability

The essential concept of this paper is to understand the design of an IS for sustainability by using a multidisciplinary HCI approach. The definition of 'sustainability' is not consistent everywhere, but varies depending on the research field and personal cognition and context. The focus of HCI and IS research is frequently one-dimensional and preoccupied with environmental sustainability [17]. In previous research the notion of Elkington's triple bottom line (TBL) [3] and Walker's quadruple bottom line (QBL) [23] have been acknowledged since many dimensions of sustainability must be considered. For example, the QBL acknowledged that sustainability could be related to social, environmental, practical, personal, and spiritual needs and that economic concerns only mediate the ability to satisfy those needs. Also, the dynamic interplay between the different dimensions is important. It is thus easy to harvest obvious low haning fruits, such as the reduction of energy in a device or system, but on the other hand, we might use it more and thereby not act in a totally sustainable fashion. For example, a smart home is often viewed to be sustainable at first glance [7], [18], [20] although the cost of the whole system is not always considered. It is possible to reverse or minimize the effects of different processes that impact sustainability. The rationale for this research is, therefore, that the knowledge of design space is crucial, giving options on how to design IS for sustainability, moving the IS design research frontier forward. To achieve this, a multidisciplinary approach like HCI is needed, since sustainability issues are very complex and dynamic. A holistic viewpoint is thereby needed. Therefore, establishing the design space for IS for sustainability could have huge implications for future systems and their ability to reach a specific set of sustainability goals.

2.2 Design Space and Its Importance

One of the primary reasons for using design space is the assurance of quality when a design space itself defines the operational flexibility. The design space could also be seen as a conceptual space of various plausible design possibilities. Bisjakar et al. [2], defined "design space" as a construct which is developed by the designer's own knowledge and experience in response to diverse external conditions. Design space analysis (DSA) is an established approach of looking into a design to act as a bridge between theoretical and practical design issues. DSA is an argumentation-based approach to design [8]. Frequently DSA is used in design rationale as a method of discovering why some possibilities were chosen during the design process [2] by using a protocol called "QOC" (questions, options, and criteria [9].) However, a design space is not a static construct and it may change through the cumulative knowledge learned by the designers together with the different conditions of a design project [2]. Therefore, understanding the proper combination and different interactions of variables as process parameters may be seen as the most important rationale behind creating a proper design space. The designers must decide how the design space should be described; it might vary from simple representation of changeable combinations to numerous complex mathematical relationships. However, the addressed design space in this paper is a reflection of the use of interdisciplinary HCI design knowledge for helping IS designers to realize how IS could be designed for sustainability. The design space described below is therefore in the form of a combination of different variables to achieve the success of IS design for sustainability.

3 Proposed IS Design Space for Sustainability

By using DSA, it would be possible to explore and comprehend the requirements of a design space aiming at IS design for sustainability (nine dimensions were identified as important for this). These dimensions were structured into four top-level dimensions' categories and were the results of a QOC analysis that was followed as in Figure 1. The QOC analysis for deriving the four top-level dimensions is displayed in Figure 2.

During a QOC analysis three operands are used, namely: questions, options, and criteria. Questions are taken from the information drawn from the scenario to explore. In our research the scenario consists of designing IS for sustainability. Often the hardest task in the QOC analysis is to find the question and help making it possible to use options to generate the questions in a heuristic way. We have used four ontological dimensions for the DSA, namely: information-collection, information-transformation,

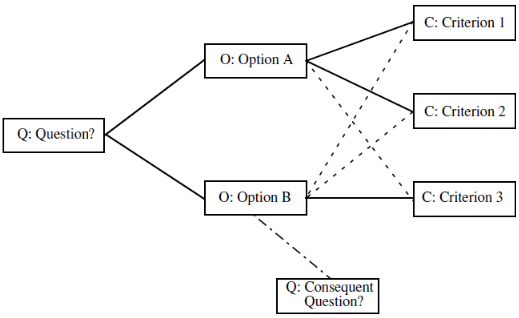

Fig. 1. Components of a design space using QOC notation (from [9])

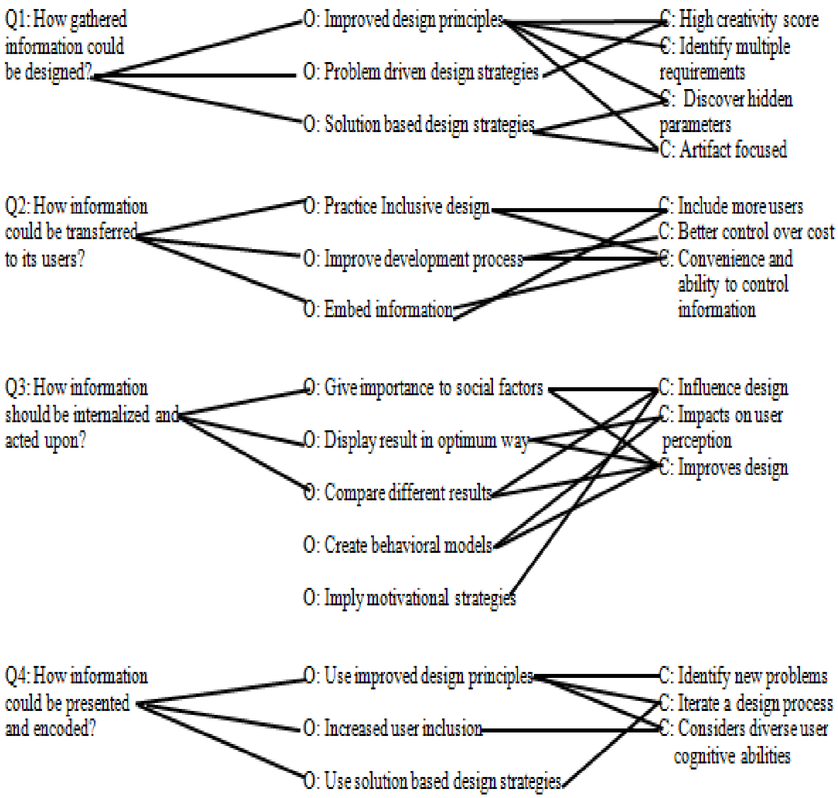

Fig. 2. Construction of a design space of IS for sustainability using QOC notation

processing of information, and information-presentation. These were selected as based on the standard information-processing method as the foundation. Questions were therefore drawn as based on these foundations. Next, we have “Options” that can be seen as answers to the questions. In Figure 1 we can see two different options to choose from: Option A and Option B. Option B generates a follow-up question that furthers more aspects of the design that may be considered. Options A and B have three different criteria that argue either for or against the possible options extended by the question (a solid line is positive and a dotted line is a negative relationship). Different IS design criteria were used to answer these questions, resulting with options from which it was possible to use heuristics to analyze criteria for selecting the correct options for a specific question. A total of thirteen criteria was used in this analysis (Figure 2). No negative criteria were used, since the scope of finding dimensions in a design space was focused on sustainability for IS, and not the opposite.

Based on our four ontological dimensions and the QOC analysis as presented in Figure 2, the four top-level dimensions of the proposed design space were summarized as follows:

How gathered information could be designed: Design Principles Dimension.

How information could be transferred to its users: User-inclusion, Development Process, and Embedding Information Dimensions.

How information should be internalized and acted upon: Behavioral models, Motivational Strategies, Social Factors, Presenting Results, and Comparison of the Result Dimensions.

How different information could be presented and encoded: User-Inclusion Dimension.

These four ontological dimensions and the identified nine principle dimensions were then shown to be supported by the seven sub-dimensions which the authors have identified from their previous studies of sustainability and system design in Table 1. These identified seven sub-dimensions should be considered to be the knowledge of HCI that could contribute to building IS design.

Table 1. Sub-dimensions of the design space and their sources

Sub-dimensions	Research Paper Sources	Research Contribution Type
Universality	[13]	Human-centered
Open Innovation	[12]	Human-centered
Persuasiveness	[14]	Human-centered
Cognitive Dissonance	[14]	Design Research
Design Life Cycle	[17]	Design Driven
Sustainable System	[10]	Design Research
Open Sustainability Innovation	[13]	Human-centered

The rationale behind using these seven sub-dimensions is that by their use human-centered design might be practiced in our design space. According to the design research quadrangle presented by Norman and Verganti [16], although the novel interpretation of meaning is not always possible, human-centered design (HCD) considers the practicality of design problems, which in return initiates and triggers incremental innovation. In this research our focused problem is the achievement of sustainability through an improved IS design. The meaning of sustainability is highly contextual, and to specify a novel meaning or to interpret this notion precisely is very difficult, if not impossible. Rather, it would depend on users and their current use of different artifacts. Diverse requirements would increase due to their use of the artifacts. On the other hand, our aim in this paper was never to innovate something totally new, but instead to make a contribution to the existing nature of the process of sustainability in IS design by supporting the argument of Norman and Verganti [16] on HCD, in that: '… the focus on current meanings and needs combined with the iterative, hill-climbing nature of the process, this approach serves to enhance the values of existing categories of products, not to derive entire new categories.' Besides, sustainability could be seen as a result of the different incremental development processes, justifying the rationale of using HCD for incremental innovation. Figure 3 below illustrates the design space resulting from our QOC notation. The four top-level dimensions supported by different sub-dimensions are discussed from Subsections 3.1 to 3.4. A theoretical framework for the design space is then shown in Subsection 3.5.

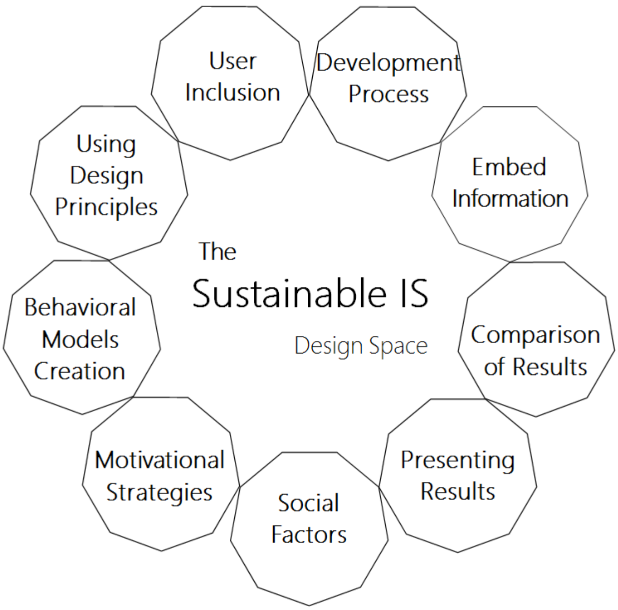

Fig. 3. A design space of information system design for sustainability

3.1 Information-Gathering

This dimension deals with the issue of information-gathering for the designing of the IS for sustainability. This could in a way be seen as the foundation of the design since the gathering of information will establish the designer's cognition and understanding of the context that surrounds the system. It is critical to identify the multiple requirements that probably will require comparison and must be weighted against each other because sustainability is a very complex issue. Something positive from one aspect could prove to be negative from another. It is also good to maintain high creativity since fresh solutions might be needed in order not to be rooted in obsolete thinking patterns. By using this unrestricted approach it should be possible to discover hidden parameters that might have an impact on the IS for sustainability, although it should also be stressed that the designer should not lose the focus of the design goal, namely the artifact that in the end will be the result of the design. The following dimensions in the process beginning with the information-transferring and ending with the information-presentation could require being iterated and returning to this dimension. Table 2 lists the associated sub-dimensions and their contexts with information-gathering.

Table 2. Sub-dimensions and their activities in information-gathering

Sub-dimensions	Actions in the Principle Dimension
Universality	Transferring views on universal design from a pragmatic to idealistic view
Open Innovation	Expanding the open innovation concept from simple to complex arrangements
Persuasiveness	Different cognitive model creation using focused and unfocused persuasion
Cognitive Dissonance	Controlling user's dissonance, through design to make information- gathering flexible
Design Life Cycle	Work on the definition phase of the design life cycle to understand the requirement
Sustainable System	Realize the meaning of sustainable system through the contextual information-gathering
Open Sustainability Innovation	Use an open innovation strategy for sustainable design outcome and imply the knowledge to understand users and their need in an improved way

3.2 Information-Transferring

The information-transferring dimension is about how the information from the IS for sustainability can be transferred from the system to the user (the reverse, how to transfer the information from the user to the system, is of course also important.) Here the practice of universal design is a cornerstone, since it will allow most users the ability to use the system with little effort and to find accurate information that they can use in their cognition; information that may be transformed into useful knowledge and will act towards the scheduled sustainable goal. It is crucial that the user has the possibility to control the information given to the system, such as security and anonymity since some information could be sensitive and should not be shared with others. Another issue concerns how to deal with the problem concerning control of expense, since information-gathering and storage of data could become costly. On the one hand, the technology to store data becomes cheaper, but on the other hand the process of collecting data becomes more intense and detailed, needing more storage. It might in that respect be seen as not acting in a sustainable way. Another problem is the amount of data that needs to be transferred. This issue could cause users not to use the system under certain circumstances, e.g. if high-speed internet were not available it could become costly and time-consuming to use the system. Table 3 lists the associated sub-dimensions and their contexts with information-transferring.

Table 3. Sub-dimensions and their activities in information-transferring

Sub-dimensions	Actions in the Principle Dimension
Universality	Practice inclusive design and make the information available for possible user groups
Open Innovation	Use open innovation policy as a method for information transformation
Persuasiveness	Design and develop persuasive system, keeping wide ranges of user groups in mind
Cognitive Dissonance	Control user's dissonance to act accordingly towards the sustainability cause
Design Life Cycle	Use design and development phase; iterate to go back to requirement phase if needed
Sustainable System	Embed the identified sustainability parameters into the system during design
Open Sustainability Innovation	Use open sustainability innovation to recognize information that is required to be embedded into the design of an information system

3.3 Internalizing Information and Acting Upon It

This dimension is concerned with how the user will proceed once the accurate information is delivered. Here social factors such as norms are important. If the delivered information is not consistent with the user's attitude and behavior it will create cognitive dissonance. Such a dissonance could be useful in some IS to initiate a change, e.g. persuasive systems (see Mustaquim and Nyström) [14] but in other kinds of system the dissonance could be damaging and might lead to people avoiding the use of the system since it has caused discomfort for users. Such issues could probably be analyzed by creating behavioral models and implying different motivational strategies. Table 4 lists the associated sub-dimensions and their contexts with information-processing.

To act upon gathered information and the internalization of information, universal design can play a different role. Although universal design will not be used to design something in this dimension, it still may be viewed in a pragmatic way to analyze and centralize the gathered information in an improved way leaving an impact on changing user behavior. Understanding different types of users is important and universal design can be of use to the designers in realizing this. While open innovation in this dimension can make more people be involved in the process, open sustainability innovation can create new norms for triggering the preferred behavior. Realizing how a cognitive model would influence persuasion is important and will require iteration in the design life cycle to align different parameters for sustainability according to the user's requirements and views.

Table 4. Sub-dimensions and their activities on information internalization and action

Sub-dimensions	Actions on the Principle Dimension
Universality	Universal design could be used in a pragmatic way to find effective and efficient ways to change the behavior
Open Innovation	Use open innovation to get more people involved in reaching the sustainable goal
Persuasiveness	Understand cognitive model influence persuasion
Cognitive Dissonance	Depending on the system's function and goal it could trigger a change of behavior
Design Life Cycle	Changes in the context could make it needed to update or change information in the system requiring a need of iteration
Sustainable System	Make the sustainability parameters align with the user's beliefs
Open Sustainability Innovation	Use open innovation strategy to include external stakeholders and thus put an emphasis on creating a new norm that accentuates the preferred behavior

3.4 Information-Presenting

Information-presentation is crucial since the wrong demonstration of information could make it impossible for the user to acquire the information. The user could hence act incorrectly and opposed to how the system's sustainability goal was set. There is probably no optimum way in which to present the information; instead many optimum ways exist, and the system must be ready for depending on the users. Some users might require a lot of text information while others might prefer a visual display of the information. Here it would be of uttermost importance to include as many users as possible to be able to analyze their behavior and their differences in cognitive abilities. Based on this, the cognitive model could be redesigned by focusing on multiple user needs. Using diversified information-presentation the persuasion of the users becomes easier. Universal design concept in this case thus plays an important role for user inclusiveness. Open innovation can discover different users' choices for the specific product or goal regarding information, and how users would like to be presented with the result. Open sustainability innovation at the same time could be a key to realizing this in the context of sustainable products or design. If any information needs to be updated a change in the design is consequently required. The system development life cycle can be used in the evaluation phase for altering any design issues for achieving specific goals. One example would be when a system is used in different devices that present information in different screen resolutions; the text may be easily read on one device but become very difficult to read on another. Table 5 lists the associated sub-dimensions and their contexts with information-presentation.

Table 5. Sub-dimensions and their activities on information presentation

Sub-dimensions	Actions on the Principle Dimension
Universality	Use universal design to fully comprehend all the difference and obstacles that information-presentation could cause for some users
Open Innovation	More stakeholders involved should make the presentation of information better and more diversified for users to grasp
Persuasiveness	Keep the presentation diversified to make the persuasion more easy
Cognitive Dissonance	Difference in cognitive preference of information-presentation will be needed to be carefully considered and observed
Design Life Cycle	Make the maintenance, needed updates, and changes easy to do for improved result presentation
Sustainable System	Use the information-presentation in a positive way to commit the user to the system
Open Sustaina-bility Innovation	Keep the information as simple as possible without losing its importance

3.5 A Theoretical Framework for the IS Design Space

In Figure 4 a theoretical framework for the proposed design space was presented. The problem-identification phase initiates information-gathering and thorough information-presentation in a design; the sustainability goals aimed at by IS are reflected (the gathered information is transformed and processed before the presentation.) We also have the discussed HCI Knowledge Space that is built from the seven sub-dimensions to support four top-level ontological dimensions. It is important to note that new knowledge gathered from the HCI Knowledge Space contributes to each of the four top-level information phases (see Sections 3.1 to 3.4.) It is not important, however, to follow different phases of the design space sequentially and a specific dimension from the HCI Knowledge Space can start any of the four phases to continue further. The proposed framework should not be interpreted as a design process. This framework, however, can be used to support the design process of an IS for sustainability. Also, it is here important to mention the nature of sustainability goals which should be considered to be contextual. As mentioned earlier, sustainability is a complex and contextual issue. The proposed design space is certainly inadequate to cover all aspects of sustainability issues for IS. This theoretical framework should thus not be interpreted as a universal framework for design space. Therefore, rather than narrowing the scope exclusively within the economic or social dimensions of sustainability, the specification of sustainability problems could be contextualized according to the need for the successful use of the proposed design space.

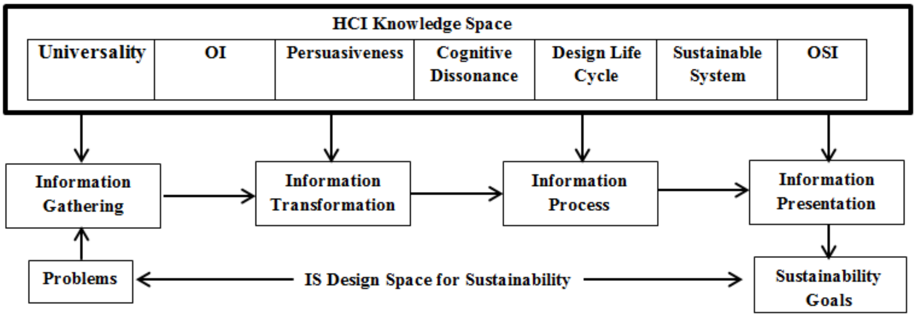

Fig. 4. A theoretical framework for the IS design space for sustainability

4 Complexity Measurement

The properties of a design process can be quantified by identifying the possible associated operators and operands as described by Halstead [6]. For a finite set of operators and operands denoted by Ω, the standard measure in a design is described as follows:

ρ: unique number of operators, N: unique number of operands
N_1: total number of occurrences of operators
N_2: total number of occurrences of operands
The size of the string is defined by,

$$\eta = \rho + N . \quad (1)$$

The length of the design form is,

$$L = N_1 + N_2 . \quad (2)$$

Structural information content,

$$H = L \log_2 \eta . \quad (3)$$

Minimal information content for denoting a design's most compact representation is,

$$H^* = (N+2) \log_2 (2+N_2) . \quad (4)$$

The level of abstraction for a design form is,

$$A = H^*/H . \quad (5)$$

The effort required to comprehend the design form is,

$$E = 1/A . H . \quad (6)$$

The time complexity measure is,

$$T = H^2/H^*.S . \quad (7)$$

We have used this method to measure the complexities of the proposed design space by comparing it with a reference design process for sustainability. The calculations of these measurements are described in the following subsections.

4.1 Analysis of the Reference Design Process

The reference design process is taken from Waage [22] who presented a sustainable process-product design for designers (targeting product designers and business decision-makers) following four phases of the design process (understanding, exploring, defining/refining, and implementing.) The four phases in the sustainable process for designers are: Phase 1: Establish the sustainability context by looking at issues related to a product or client. Phase 2: Define sustainability issues by analyzing and mapping sustainability. Phase 3: Assess by considering different pathways and their relation to a set sustainable goal. Phase 4: Act and receive feedback by making the product or service and then evaluate and assess it in terms of sustainability.

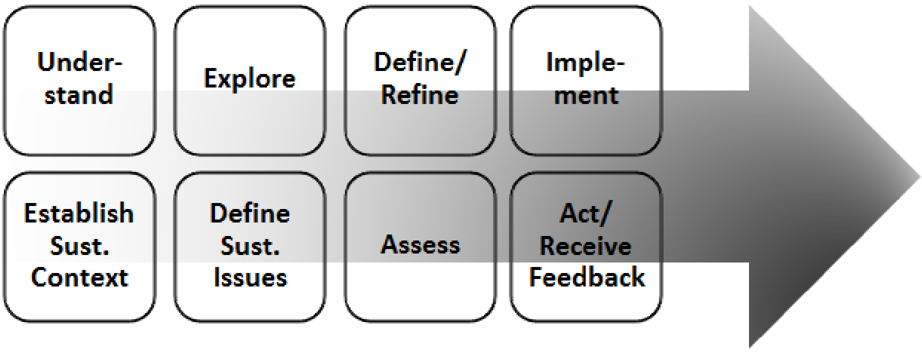

Fig. 5. A reference design process for sustainability (from [22])

The design process in Figure 5 can be represented using the following form of first-order predicate calculus:

$$(\forall x)(\text{UNDERSTAND}(x) \Rightarrow \text{CONTEXT}(x)) \wedge (\forall x)\ \text{SUSISSUES}\ (\text{EXPLORE}, x) \wedge ((\forall x)\ \text{DEFINE}\ (\text{ASSESS}, x) \vee (\forall x)\ \text{REFINE}\ (\text{ASSESS}, x)) \wedge (\forall x\ (\text{IMPLEMENT}(x) \rightarrow \exists y.\ \text{ACT}\ (y, x)), \wedge \forall x\ (\text{IMPLEMENT}(x) \rightarrow \exists y.\ \text{FEEDBACK}\ (y, x)))$$

From the equations 1 to 7 we calculate the following:

$\rho = 9$, $N = 11$, $N_1 = 61$ and $N_2 = 22$

$\eta = \rho + N \Rightarrow 9+11 \Rightarrow 20$

$L = N_1 + N_2 \Rightarrow 61+22 \Rightarrow 83$

$H = L \log_2 \eta \Rightarrow 83 \log_2 20 \Rightarrow 358.643$

$H^* = (N+2) \log_2 (2+N_2) \Rightarrow 22 \log_2 24 \Rightarrow 100.76$

$A = H^*/H = 100.76/358.643 \Rightarrow 0.280$

$E = 1/A.H \Rightarrow (1/0.280) X\ 358.643 \Rightarrow 1280.86$

$T = H2/H^*S \Rightarrow (358.643)2/\ (100.76\ x18)$ [considering $S=18$]

$\Rightarrow 128625/1813.68 \Rightarrow 70.91$

4.2 Analysis of the Proposed Design Space Framework

The theoretical framework of our proposed design space (Figure 4) could be summarized as the following first-order predicate calculus form:

$(\exists x.\ PROB(x) \wedge \forall x.(PROB(x) \rightarrow IG(x)) \wedge \forall x.(IG(x) \rightarrow IT(x)) \wedge \forall x.(IT(x) \rightarrow IP(x)) \wedge \forall x.(IP(x) \rightarrow IPR(x))) \wedge (\forall x.(PROB(x) \rightarrow HCIKS(x))) \rightarrow (\forall x.(IPR(x) \rightarrow SUSGOALS(x))$

Therefore by following the equations from 1 to 7 we get:

$\rho = 7$, $N = 8$, $N_1 = 82$ and $N_2 = 29$
$\eta = \rho + N \Rightarrow 7+8 \Rightarrow 15$
$L = N_1 + N_2 \Rightarrow 82+29 \Rightarrow 111$
$H = L \log_2 \eta \Rightarrow 111 \log_2 15 \Rightarrow 423.9$
$H^* = (N+2) \log_2 (2+N_2) \Rightarrow 10 \log_2 31 \Rightarrow 49.5$
$A = H^*/H = 49.5/423.9 \Rightarrow 0.116$
$E = 1/A.H \Rightarrow (1/0.116).423.9 \Rightarrow 3654.31$
$T = H2/H^*S \Rightarrow (423.9)2/ (49.5 \times 18)$ [considering S=18]
$\Rightarrow 179693/891 \Rightarrow 201.67$

Table 6. Complexity measurement parameters for two design processes

Cases	ρ	N	η	N_1	N_2	L	H^*	H	A	E	T
Using Reference Process	9	11	20	61	22	83	100.76	358.643	0.280	1280.86	70.91
Using Proposed Design Space	7	8	15	82	29	111	49.5	423.9	0.116	3654.31	201.67

As seen from Table 6, measurement of time complexity and the effort required to comprehend the design form of the proposed model is higher than the reference model as expected. However, the level of abstraction and the structural information content values for the proposed design space do not indicate a bigger margin when compared with the reference framework. It could be concluded from this analysis that since adding new dimensions from HCI in our proposed model increases its complexity and therefore more effort and time will be needed to imply the design space, it would still be possible to see the different dimensions from an abstract point of view of the design, keeping the structural information content-value controlled. Empirical analysis in quantitative study with statistical operations on data will further this conclusion.

5 Discussions

The design space of IS design for sustainability, structured using a DSA in this paper, has revealed some interesting points. As mentioned in the introduction, there may be many possibilities in designing IS for sustainability, and selecting the right one is a challenge. The proposed design space adds value to this issue by showing that there could be several alternatives showing different relations between them. An improved design solution was concluded here in the form of our proposed design space. It should be noted that the goal here was to represent the structure of a design only, and as McLean et al. [8] stated, QOC should not be considered as a stand-alone representation. The proposed design space should instead be considered to be a tool for the designers—at least at this stage of the research.

One weakness about the QOC analysis worth indicating here is that we considered only positive criteria. It would be interesting to see how different criteria that are considered to be obstacles to the design of IS for sustainability might change the QOC analysis. It would also be an interesting topic to explore whether it would be possible to categorize the negative criteria or not. Our research question could therefore be answered by stating that the dimensions in a design space of an IS designed for sustainability could be seen from our proposed design space, for which different sub-dimensions from HCI knowledge were used in a HCD approach to support the ontological dimensions of a design process.

A few words about evaluation are also worth mentioning here. The design space concept is extremely complex, but at the same time is a useful thing. It is important to note that the evaluation process as shown in this paper did not involve any users and was performed using complex mathematical models only. It was not within the scope of this paper to involve a large study of users.

The focus of the design space as presented in this paper could easily be generalized and contextualized, as mentioned earlier. Although our theoretical frameworks supporting the nine identified dimensions have originated from HCI research, we believe that the design space still should not be exclusively generalized to be HCI-focused. We believe that this paper is an example of how the multi- and interdisciplinary powers of HCI could be used as a cross section with other research disciplines like IS. The research question in this paper was formulated within the context of IS and sustainability, in which the domain of HCI research and the knowledge acquired from it was seen as a tool for resolving the addressed problem. Example of similar work could be seen in [11].

Similarly, the application and usefulness of the proposed design space also could be seen as a contextual subject matter. One typical example may be to use the design space in different phases of a system development life cycle aimed at sustainable IS development. Identifying new requirements may be seen as an important use of the design space, which can be applied to both the existing and new system developments. What a particular IS is able to do for different sustainability goals could also be identified and evaluated using this design space. It is, however, important that different parameters to the evaluation or identification should be limited within the selected or identified context of sustainability for IS.

One of the significant challenges of sustainability and its achievement by IS design might be the maintainability of the outcome. While the future work built in this paper's design space of IS for sustainability may be in the form of used case studies of existing systems and by analyzing them with the proposed design space, one important research would be in maintaining the design space itself. In doing this, verification of the design space would thus be the first step. The complexity measurement we have illustrated is based on mathematics and not on any user data, which might be seen as another weakness and therefore should be taken to the next step by running empirical studies. There is a large gap associated with a design space developed in a research lab and transforming the knowledge to a commercial scale. Therefore, during maintenance and the verification of the design space, new important variables could be identified. Further verification or maintenance study will introduce complex mathematical relationships, function, etc. for realizing the critical dimensions that must be either included or excluded. Only then could the design space be taken a step ahead within the context of multi-scale sustainability problems that could be achieved by designing IS accordingly.

6 Conclusions

In this paper a design space of IS design for sustainability was structured and proposed. The DSA method was used to identify a set of variables that were included in the design space. The design space was built on four principle ontological dimensions and supported by seven sub-dimensions originating from the previous research knowledge from HCI. The proposed design space was preliminarily evaluated in terms of the measurement of its complexity by using first-order predicate logic to comprehend it by comparison with a reference model. The rationale behind the formulation of design space lies in using interdisciplinary design concepts from HCI. The proposed design space is specifically for IS design for sustainability, which, according to the knowledge of the authors, is not evident at present. The proposed design space in this paper can bridge the gap between designers and policymakers to support the improved application of an IS for sustainability. Additional verification of the proposed design space would therefore be the next research step to advance the knowledge for IS designers.

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