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DESIGN FOR SUSTAINABLE BEHAVIOR: OPPORTUNITIES AND CHALLENGES OF A DATA-DRIVEN APPROACH

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Abstract

The article stems from the main informative gaps of Design for Sustainable Behaviour and discusses the paramount role of a data-driven approach to inform design. The article stresses how quantitative data can address global sustainability, determine behaviours to modify, measure the impact of new learned sustainable behaviours as well as support the definition of behaviour change strategies, widening the spatial and temporal scales to communities and longitudinal studies and reducing unpredictable biases coming from tacit knowledge externalization and interpretation.

Keywords: sustainable design, data mining, human behaviour, user-centred design

1. Context and objective

Sustainability is the challenge of our time, recognized worldwide as a complex and global issue. United Nations define the sustainable development as (Brundtland et al., 1987):

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

This definition gives emphasis on the future and this report also includes a list of sustainable goals. In its current version, the list consists of seventeen Sustainable Development Goals (SDGs) that defines the sustainable challenges to be achieved by 2030 with the aim of ensuring the future of living species. Beyond environmental sustainability (e.g. climate change, clean water sanitation, life below water and on land), social (e.g. elimination of poverty and hunger, good health, education quality, gender equality). and economic goals (e.g, decent work and economic growth, investments in infrastructure and technological progress, reduction of inequalities) are also stated. Policies for sustainability surely play a big role in meeting these objectives, but citizens need to implement a mind-set change, adopting sustainable behaviours as well. In fact, although a technology can be designed with the aim of making it sustainable over its entire life cycle, sustainability can be tremendously influenced by user behaviours (e.g. electric kettles are optimized to reduce energy consumption, but users commonly do not use the right amount of water they have been designed for).
As Tromp et al. (2011) state, a change in the behaviour of individuals is needed but it could happen that users are unmotivated when individual interests are not aligned with the collective ones, as the achievement of the SDGs (e.g. bike riding instead of car driving addresses collective interests by reducing emissions but collides with individual interests of comfort and efficiency). Interests can also collide at

different spatial and temporal scales (Giampietro, 1994). Individual interests can be in conflict with the community ones, and the latter with those ones of the nations (e.g. paying less taxes is advantageous for a family but it is not for the nation, duties on trade can favour some groups and not others).

In this context, designers have a major responsibility for the development of sustainable solutions. Eco-design is an already well developed thread that aims at developing products, processes and services with a smaller environmental footprint, in every stage of their life cycle. In recent years, some designers and researchers have been also focusing on Design for Sustainable Behaviour (DfSB), an approach to develop solutions that are not simply less environmentally harmful or demanding, but that trigger a change in the user, substantially modifying its behaviour. However, the impact of DfSB is still uncertain as, so far, designers have to make a lot of critical design decisions according to their interpretation of relevant goals (e.g. to figure out what could be a right target to address for sustainability). Design needs to be informed in order to make appropriate decisions that are not just based on designers' intuition. Yet, information can be typically derived from users' observations or collected opinions. These activities can be also affected by unpredictable biases that lead to ineffective actions. The authors claim to shift the responsibility from designers' intuition to strategies based on evidence from data, under the assumption that data can pave avenues to support designers to make informed design choices based on quantitatively measured user behaviour and also allow the verification of the impact of proposed solutions. As the society is already permeated by data, which are progressively becoming more and more available, the alignment between sustainability and data will play a key role to achieve global sustainable developments.

Starting from an exploration of the current methodological gaps of DfSB, the authors have identified the informative gaps that emerge from the use of a knowledge-driven design. The paper, therefore, proposes a new framework to inform the design activity based on a data-driven approach, exploring the main opportunities to address global sustainability through the study of user behaviours on large spatial and temporal scales and discussing the potential challenges of its implementation. The next section clarifies what data, information and knowledge are, what their role in the design activities is, together with a definition of data-driven design activities. The third section summarizes the main methodological gaps of DfSB as for the literature. Section 4 shows how a data-driven approach can be capable of informing designers' choices and what are the main opportunities to make this possible and the challenges to be faced to make the approach effective, reliable, respectful of users and still capable of addressing the SDGs.

2. On data and how to inform design

Nowadays, data and information streams permeate the society so much that these two concepts are becoming so inflated that often people use them as synonyms, despite they are not. One of the first definition of data and information is provided by Ackoff (1989), who made an attempt to formalize their relationship with reference to knowledge and wisdom. More recently Rowley (2007) structured data and information in the so-called DIKW pyramid (Data Information Knowledge Wisdom), proposing their stratification and hierarchy. Bottom-up, data are unorganized and unprocessed sets of discrete units that collect objective facts or observations. They have no meaning until framed into an appropriate context and their nature could be quantitative (i.e. it is possible to run simple operations with them, like defining relationships of order or count them) or qualitative (i.e. categorical descriptions). Information collects processed and organized data to make them meaningful and relevant (useful) in the context of collection or reuse. Knowledge, indeed, belongs to the personal sphere and several processes can breed it, such as the synthesis of multiple sources of information over time as well as study, learning and experience. As for knowledge, also Wisdom pertains to the individuals. It is the top layer of the DIKW pyramid and it is the result of the way humans use knowledge to formulate judgments, make an inference and create a set of values (Spiegler, 2003). Both knowledge and wisdom, therefore, pertain to the individuals, but it is just the former that can be formalized/externalized outside the personal sphere in a more objective way. Indeed knowledge gets typically distinguished between tacit and explicit. Explicit knowledge is what can be explicitly stated (thus turned into information). Tacit knowledge is what one knows, but cannot be expressed in a codified way. Smith (2001) stated that tacit knowledge is a highly personal and subjective form of

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knowledge that cannot be found in manuals, books, databases or elsewhere than individuals. Externalization is the process that transforms tacit into explicit knowledge (Nonaka et al., 1994). On the contrary, the interpretation of reality, of what happens into the external world and that gets transformed into tacit knowledge, takes the name of internalization (and this process appears to be particularly similar to the push-pull process that characterizes interpretation in the situated FBS framework proposed by Gero and Kannengiesser (2004).

2.1. The importance of a data-driven approach to inform the design

Data are pervasive to the design activity. On the one hand, they are needed to organize, process and formalize the designers' knowledge into documented models of solutions. For instance, PDM systems collect product data mainly as 3D/2D models to facilitate their reuse in an industrial context; PLM systems support the whole life cycle of solution from its conception to the manufacturing stage and beyond. Data in the documentation reflect the designers' intent, but they do not make explicit the rationale behind design choices, whose documentation typically requires tacit knowledge to be externalized and formalized as information that complements data. On the other hand, every design activity strictly requires to be informed so that designers can make adequate decisions and develop solutions with effectiveness (make the right thing) and efficiency (make the thing right).
So far, most of the design activities have been based on the designers' or product planners' (e.g. professionals working in marketing departments) perception and interpretation of what the arena of potential customer wants (Becattini et al., 2017). These requests, often based on factual evidence emerged from market searches, are expressed in the form of needs, goals, targets and even requirements that define objectives to achieve. Still, most of the responsibility of "doing the right thing" depends on the talent of these professionals and their proper perception of the world and its needs. The increasing availability of data has nowadays given rise to a radically different way of informing the design activity so that data can more pervasively be used across the design process to inform the choices and support decision-making. This is to increase the chances of focusing on the right targets and releasing the designers and product planners from the responsibility of developing a successful solution or a commercial fiasco as the design simply meets the perceived customer expectations, not the real ones. Data-driven design is, therefore, a growing field of interest and the literature shows an increasing trend of contributions (Figure 1). It slowly started approximately 35 years ago and now becomes extremely promising and fast-growing because of the opportunities unleashed by the changes taking place in the field of Information and Communication Technologies (ICT). The comparison of the cumulative trend of papers with the S-curve function suggests that the topic of data-driven design could exponentially grow for the next 20 years.

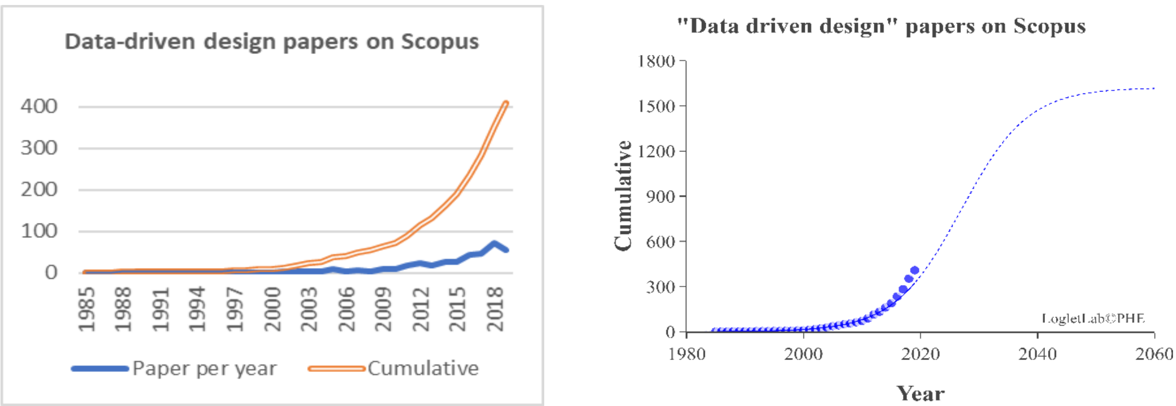

Figure 1. The number of papers reporting "data-driven design" in title, keywords, or abstract; Left: rate of growth (blue) and the cumulative number of papers; Right: forecast of the growth potential based on S-curve

Hicks et al. (2002), almost two decades ago, already highlighted the leverage that efficient and effective use of data, information and knowledge can bring to a company for keeping or increasing its competitiveness on the market. The identification of relevant sources, not just to manage what is

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already owned and mastered, but also to retrieve what is not yet exploited and that can become relevant was already paramount at that time. Nowadays, the situation has radically changed as there is more general availability of data. Data protection is still an issue for a lot of companies in a wide variety of industrial contexts, but at the same time, the number of sources that provide data has also significantly increased. This wide availability is also fostered by a growing trend to release scientific data in an open format that makes them FAIR: Findable, Accessible, Interoperable and Reusable (Wilkinson et al., 2016). Not surprisingly, the opportunities of using open data have been also recently considered in the design field by Parraguez Ruiz and Maier (2017), which highlighted implications related to their identification in appointed repositories, their acquisition, analysis and interpretation for proficient use. Beyond the identification of opportunities for reusing data, a relatively recent special issue of the Journal of Mechanical Design (Kim et al., 2017) presented 20 papers on the topic, which further witness a fertile situation on the topic, especially in consideration of the variety of the contribution. They ranged from different methods to deal with data and use them to support designers in carrying out the design activities to applications where design could be also automated according to the contents emerging from processed data. Despite the largest majority of contribution in the literature deals with the retrieval of data for specific applications in the industrial domain (i.e. development of solutions for the industry), some of these also present examples of data-driven design based on data which are related to the use, of products and solutions by consumers/customers (e.g.: Zhang et al., 2017) as well as by their opinion (Jiang et al., 2017). The capability to capture user-related data that reflect both the conscious expression of viewpoints and unconscious behaviour during the use of solution represents a clear opportunity to better inform the design process also with reference to the targets set by the Sustainable Development Goals. The next sections will show how data can be more effective and efficient than the current practice to inform the design process.

3. Methodological gaps of Design for Sustainable Behaviour

This section proposes a critical analysis of the main findings emerged in four review studies related to DfSB topic and published between 2012 and 2015 (Coskun et al., 2015; Daae and Boks, 2015a; Brynjarsdottir et al., 2012; Boks, 2012). The search for these reviews has been carried out on relevant sources, such as the Journal of Cleaner Production and Design Studies, then refined according to the results emerging by means of the citation search (backward and forward citations). This analysis allows spotting the main methodological gaps of DfSB, which are organized (consistently with Coskun et al., 2015) according to the three design phases of exploration, generation and evaluation, as for Cross (2008).

3.1. Gaps related to the exploration phase

Gaps related to the definition of target SDGs: Most of DfSB contributions exclusively focus on environmental SDGs, to slash energy and resources consumption. While very few studies addressed social and economic sustainability, e.g. mobile phone use in a social context (Lilley, 2009) and littering behaviour in a public context (Wever et al., 2010).

Definition of the case/design task, the behaviour to modify and the appropriate behaviour: Very few of the reviewed contributions mention the criteria for selecting the case and the behaviours to change. Typically, previous studies that estimate the environmental impact of products drive the selection of the task, others rely on empirical data from the observation of product users in context. To define the case and behaviours to correct, designers observe users and determine their habits, beliefs, attitudes, intentions, constraints, etc. (Daae and Boks, 2015b). The latter is done by video observations whose data processing and analysis require high human efforts and time. As a consequence, observations tend to be poorly representative because conducted on very small samples of users, for a short time and over a reduced number of context scenarios (Brynjarsdottir et al., 2012). This implies a less informed design, thus the decision-making of this phase mainly relies on designers' experience and intuitions, bringing to the assumption that designers are expert of sustainability and more knowledgeable than users in defining the most appropriate behaviour.

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3.2. Gaps related to the generation phase

Definition of the strategies to change user behaviours: The set of strategies selected by designers to shape the user behaviours is very limited. Beyond differences in name, Lilley (2007) identified three main strategies to trigger behaviour change: eco-feedback (the change depends on the user), which is also the most common, behaviour steering (partially left to the user) and persuasive technology (it depends on an intelligent product). Strategies of reward, gamification (Scurati et al., 2019), positive and negative reinforcements are also very popular to encourage users to modify behaviours.

Creation of heuristics for DfSB: Most of the papers present applications instead of proposing methodologies. Except for few studies (Lockton et al., 2009; Lockton et al., 2013), the lack of problem characterization and the missing logic to consequently apply strategies for solving them (heuristics) results into poorly effective and efficient design processes. Designers should propose and use methodologies to model and classify problems to systematically guide the solution generation phase.

3.3. Gaps related to the evaluation phase

Measurement of the acceptability and durability of the behavioural change: The real impact of the changed sustainable behaviour over the SDG requires quantification of results to compare with the objectives set during the exploration phase. Behaviour change by user adoption of solutions is seldom monitored and often presented as anecdotes, not supported by metrics and statistics. As for exploration, very few studies monitoring activities of user behaviours have been conducted on very narrow spatial and temporal scales (ten subjects or less over one month) (Brynjarsdottir et al., 2012). In the authors' knowledge, there are no truly longitudinal studies with annual duration. The fact that these evaluations cannot be considered representative on a global scale perspective is a significant problem for sustainability, as SDGs are global challenges, whose target is not an isolated user, but an entire community and the impact of the solution has to be assessed along years. Additionally, designers have no support to check the compatibility of their proposals with other different SDGs.

Assessment of the effectiveness of the behaviour change strategies: The effectiveness of behaviour change strategies has been rarely discussed. In this phase, designers should evaluate how the adopted design strategy can promote the behavioural change stated and eventually compare it with alternative strategies. This is a critical task to improve the effectiveness and efficiency of the overall design process.

4. Driving Design for Sustainable Behaviour by quantitative data

The analysis of gaps points out the paramount role of information during the design process and the limitation of current DfSB studies based on knowledge-driven approach. DfSB needs to be informed to shift the responsibility of decision making from designers' intuition to fact-based information. Figure 2 shows a framework for a data-driven approach to inform designers (Data to Information: D2I) that complements a more traditional approach (Knowledge to Information: K2I). The figure presents a scheme of the design process (Cross, 2008) contextualized to the DfSB and substantially based on two DIKW pyramids. The one on the right describes what comes from the external world, (that here takes the same meaning proposed for the situated FBS) and that is required to "inform" the designers. The one on the centre is for the designer's mind that needs to "interpret" the external world, and that "explores" the task, "generates" the solution and "evaluates" the behaviour changed on the basis of its own set of beliefs and values (wisdom), its knowledge (tacit and explicit) and information and data stored in memory. The designer relies on all the DIKW levels of its own and that are part of his memory. In addition, these design activities are also informed by the external world through the information that can be generated as an "externalization" of the users' tacit knowledge or a "processing" of data.

4.1. Knowledge-driven approach (K2I)

Most of DfSB studies are based on approaches that exploit information externalized from tacit knowledge ("externalization" Figure 2). Externalization methods used in DfSB applications are various, e.g. interview, focus group, survey, questionnaire, etc., and a more exhaustive list can be found in the article of Daae and Boks (2015b). These methods are used to make explicit the knowledge that comes from users' memory and self-awareness of their behaviours ("retrieve" Figure

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2), thus the information, that designers collect, come from self-conscious knowledge. As a consequence, these methods are affected from bias and can only be used to extract conscious behavioural factors (e.g. beliefs, attitudes, intentions, personal norms, values, etc.) that users are aware of. On the contrary, unconscious behaviours cannot be made explicit, thus cannot be retrieved by designers.

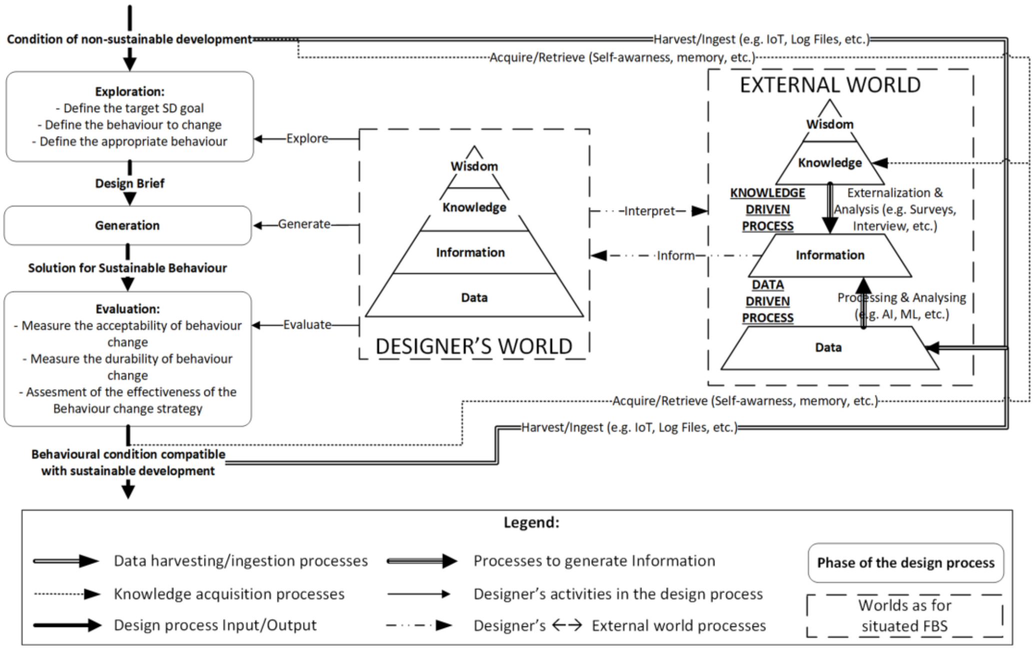

Figure 2. Data-driven approach to inform DfSB; Model representation and comparison with knowledge-driven approach

4.2. Data-driven approach (D2I)

The proposed data-driven approach generates information by processing data that are explicit elements ("processing" Figure 2). Currently, as emerged from the gaps presented in sub-sections 3.1 and 3.3, very few DfSB contributions adopt approaches that collect data, e.g. observations, video ethnography, shadowing, contextual inquiry, etc. These data are qualitative and their interpretation of and transformation in quantitative data (e.g. by using coding schemes and multiple analysts) is not bias-free and very consuming in terms of time and resources. This activity is so demanding that some designers even skip it and assume the responsibility of their decisions based on other information coming from previous studies. Otherwise, observations have been conducted on very limited spatial and time scales, with unpredictable consequences, as the information gathered may be not representative or incorrect.

A data-driven approach based on quantitative data overcomes the limitations of the current approaches based on both knowledge externalization and processing of qualitative data. The suggested data-driven approach consists of two phases (shown in Figure 2): the acquisition of quantitative data (e.g. through ICT devices, IoT, etc.) and the processing of quantitative data to generate information (e.g. on techniques typical of computational science).

Data acquisition (Figure 2) depends on the availability of data and the capability of managing it. As discussed in section 2, the ICT is growing fast, consequently, the capability of collecting and storing is also developing. The most evident opportunities come from the integration of devices within communication networks (from domestic through industrial, to world-scale ones), consistently with the trend of the IoT. This enables systems to share data with others into an ecosystem that allows them to become "smart" and, therefore, active. Nevertheless, all the systems that already embed some form of data processing logic typically store a record of the action performed into log files, which should be considered a goldmine to dig in order to learn more about user behaviour and also to leverage in order to evaluate the conditions in which they use solutions (Becattini et al., 2019).

Data processing (Figure 2), the transformation of quantitative data into information depends on data retrieval and interpretation. This D2I transformation can benefit from a still-growing body of tech-

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nologies and approaches that enables the processing of data of extremely different nature. Growing computational capabilities make possible to process a larger and larger quantity of data and highlight hidden relationships to show emergent behaviours (e.g. through Artificial Intelligence) and learn, at the same time, how to process and analyse them better and better (e.g. by Machine Learning). Qualitative data can be also processed by means of appropriate techniques (e.g. image processing). On a similar wavelength, techniques for Natural Language Processing allow the exploration of semantics for disclosing meanings from information which are otherwise not immediately evident (Montecchi et al., 2013). Differently from the former, NLP directly works on information by turning them into data, which are then re-organized to focus on the informative targets which are otherwise diluted or implicit. Undoubtedly, computing science can contribute to achieving SDGs, and the growing recent contributions on the computational sustainability point out the opportunities that derive from the synergy of these two disciplines (Fisher, 2011). An example is provided by the Association for the Advancement of Artificial Intelligence (AAAI), which in 2011 published several papers on the role that AI plays in supporting sustainable design through technological change, although the topic of DfSB had not yet been addressed.

4.3. Opportunities of the approach: discussion on examples from literature

Two case studies of DfSB literature (Bhamra et al., 2011; Elias, 2011) are discussed in Table 1, as examples to highlight the opportunities offered by the proposed data-driven approach and show the overcoming of the main limitations of current applications. The step of SDG definition has been omitted from Table 1 because it has been assumed by definition from the two applications considered. Both aim at reducing the energy consumption of fridges, thus address the SDG number 12 (Responsible consumption and production) defined by the United Nations.

Table 1. DfSB based on data-driven: opportunities to overcome the main limitations of literature applications

Step	Literature examples of fridge usage	Gaps: current approaches	Opportunities: data ingestion examples to foster a data-driven design approach
Select the case/ define the tasks	Tasks: Reducing fridge energy consumption. Selection of fridge case based on previous studies: fridges are in use 24/7 thus their environmental impact is higher than other domestic appliances	The case and user behaviours are interrelated and need to be considered together to select a case where a behaviour change produces a high impact	Energy usage data of the fridge could be used to measure the environmental impact together with data related to user habits (e.g. if the energy consumption depends only minimally on how families use fridges, the behaviour change will produce a very small impact and the target case will be irrelevant). Additionally, energy usage data and family habits are fundamental to identify the second most impacting domestic appliance
Define the behaviour to modify and the appropriate behaviour	Behaviour to modify: Keeping the fridge door opened too long Appropriate behaviour: Reducing the opening/closing time of fridge doors (Bhamra et al., 2011) Study set-up: 3 families; survey, 24h video recording, post-survey, interview (Elias, 2011) Study set-up: 2 families; motion-triggered camera for 9 and 18 days	K2I (surveys, interview) and D2I approach based on qualitative data (videorecording) are affected by biases. Very limited participants and study duration. Appropriate behaviours need to be estimated according to the impact on energy consumption	Data allow to avoid biases, profile users, define conscious behaviours and unconscious habits on a large spatial and temporal scale. Example of data useful to define fridges user behaviours: Usage: the frequency, time and duration of door opening, % of the volume occupied by items, set temperature, most used compartments, etc. User: age, sex, profession, culture, country, diet, allergies, food and drinks preferences, favourite recipes, cooking skills, type-quantity of food, etc. Context: family composition, cooking process, kitchen layout, proximity to heat sources, house temperature, the temperature of food inserted, etc. Data are necessary to rank the inappropriate behaviours according to their real user behaviour

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			impact on energy consumption, e.g. we should measure the impact of a) time/frequency of opening/closing the door, b) food temperature. To define if the appropriate behaviour should be inserting food with a lower temperature or closing the door faster/opening it less
Assess the solution acceptability, durability and the effectiveness of change behaviour strategies	(Bhamra et al., 2011) Testing and results: not available (Elias, 2011) Testing: prototype in 1 family for 10 days Results: - 43% of user-related losses, potential saving of 25–50kWh/year measured by video analysis	Current approaches are affected by biases and time/resources consuming, thus spatial and temporal scales are very limited. The change strategies effectiveness is not assessed	Data allow quantifying the real impact on energy consumption thus on environmental sustainability. The new behaviour learned can be measured on large spatial (cities, countries, worldwide) and temporal (annual duration and with repeated monitoring activity) scale and avoiding evaluation biases.

4.4. Summary of the main advantages

A well-structured data acquisition and effective data processing/analysis are basic ingredients to extract information about both conscious and unconscious behavioural factors, reducing biases due to self-conscious externalization or the interpretation of qualitative data. In particular, this approach can be exploited to identify unconscious habits, automated process that users are not aware of (Klöckner et al., 2003), which play a central role among the entire process of design for sustainable behaviour, as pointed out from Daae and Boks (2015b).

The increasing number of available sources and tools for data acquisition, processing and crossing, combined with Big Data management techniques can enable measurements on larger spatial and temporal scales. This both supports exploration and evaluation: e.g. for targeting SDG, behaviour to correct/re-educate the user as well as measuring the acceptability and durability of behavioural change.

Crossing behavioural data before and after the adoption of the solution generated for DfSB is the key to assess the effectiveness of the behaviour change strategy and start shaping heuristics that designers can use for the generation phase. The collection of a wide set of these data will also support the development of standard solutions, e.g. similarly to TRIZ 76 solution standards by Altshuller (1984), that enables to make a quick link between behaviour to correct and the strategy to make it.

The fact that data need to be acquired and interpreted offers a paramount advantage in the generation phase to develop solutions for changing behaviour where real-time data are integrated and part of the solution, i.e. intelligent products.

4.5. Challenges

Despite the proposed example provides preliminary evidence of how a data-driven approach can significantly widen the opportunities to meet the SDGs, the approach also brings several challenges to face in order to make it effective and potentially free from undesired consequences. The availability of data, despite growing, still represents an issue: some of the data presented in the example require inventiveness to be grabbed as they are not typically there and ready to be analysed. Designers, therefore, will also have to devise strategies to extract plainly not available data, become capable of structuring the data that come from unstructured sources as well as develop data crossing strategies when the amount of data is not compatible with machine-based approaches in order to extract and analyse meaningful information to drive their design activity. Obviously, this can be done by relying on existing devices for data acquisition, but their addition to existing systems to retrofit already existing solution does not seem to be a fully sustainable solution, as it will require more resources for which it is necessary a cautious use. Moreover, the harvesting of behavioural data presents the huge issue of personal data protection, as the recent cases leapt to the headlines (e.g. Cambridge Analytica and the case of US elections 2016 and the Brexit referendum in the UK). These are just the most

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evident litmus paper of how behavioural data on habits can be used for malicious purposes that nothing has to deal with goals of sustainable development. Data storage and processing will, therefore, become critical and adequate policies will be necessary to ensure privacy and allow the world to evolve for the better. Failing with data safety and transparency of policies for data processing/treatment will make users lose their trust, making the use of these data almost impossible, thus complicating the opportunities to meet Sustainable Development Goals. The storage of data, in itself, is also an environmental issue: for how long data should be stored? What is the environmental price of such storage? Where to set the trade-off for this?

5. Conclusions

The paper analyses the main gaps of Design for Sustainable Behaviour, as they emerged from the literature, from the perspective of the flows of data, information and knowledge that support the execution of design activities. Exploration, Generation and Evaluation are the three design activities the analysis focused on, in order to highlight the main informative lacks that they typically deal with. The informative lacks have been considered with reference to the DKIW hierarchy and to the processes that are currently capable of transforming Data into Information (D2I by processing) and Knowledge into Information (K2I by externalization). The limitations of the current approaches are critically discussed, especially in terms of the representativeness of the information flows they generate (e.g. the presence of bias) and the efforts required to produce them and inform the designers' activity. The largest majority of approaches to generate useful information for designing are currently gathering qualitative data, whose processing is still human-based and whose processing time grows exponentially with the size of data collection. The paper, therefore, underlines how quantitative data and already existing and emerging as well as consolidated ICT technologies for collecting, storing, processing and analysis (e.g. IoT, NLP, AI and ML) can trigger a significant shift in current practices. The literature already witnesses this trend with some recent applications of data-driven design which are, however, not yet considering targets of sustainable behaviour, nor Sustainable Development Goals. The paper spots the main challenges that future research steps of DfSB should address, including the limitations that personal data protection requires. Despite significant efforts focus on data retrieval and processing techniques through ICT technologies, the authors stress the need to address also complimentary research threads:

- How to exploit already available data and existing sources in order to limit the adoption of additional systems to retrofit existing technical solutions?
- How to reorganize already existing data to address the challenges of sustainable development in order to infer both subjective and collective behaviour, highlighting interrelations between goals and, thus, inform design?

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