Design Science

A meta-synthesis of the use of activity theory in design for sustainable behaviour

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Abstract

Over the past decade, the field of design for sustainable behaviour (DfSB) has gained a growing amount of research interest. However, as the field evolves, new challenges also arise. A suitable unit of analysis is needed to contextualize users' behaviour issues in a broader socio-cultural and long-term perspective. This paper explores the use of activity theory (AT) as a potential lens for guiding empirical analysis and design exploration in DfSB. By employing a meta-synthesis approach, we systematically search and synthesize existing studies that adopted AT in design for sustainability. Key findings show that AT's principles and theoretical implications are especially useful for helping design researchers frame and address DfSB challenges. We argue that by taking activity as the unit of analysis, the AT lens can enable researchers to incorporate users' dynamic, multi-level and complex activity systems into DfSB considerations.

Key words: sustainable development, design for sustainability, design for sustainable behaviour, activity theory, activity-centered design

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1. Introduction

Design for sustainability is a design process and resulting product that incorporates the environmental, social and economic sustainability concerns into product design and development (Crul, Diehl & Ryan 2009). It is an umbrella concept that comprises a variety of sub-fields, including sustainable design at the product level (e.g., green design and EcoDesign), product-service system level (e.g., sustainable product and service system design), spatial-social innovation level (e.g., design for social innovation) and socio-technical innovation system level (e.g., design for system innovations and transitions) (Ceschin & Gaziulusoy 2016). All these sub-fields are established on the transformative nature that design has on human doings. Nowadays, as many socio-ecological issues are caused by individuals' undesired consumption patterns, the need to guide people to adopt a sustainable lifestyle has become prominent in design (Thorpe 2010).

Over the past decade, the field of design for sustainability has witnessed a significant shift of research focus from technical-centric and product-oriented design to socio-technical centric and people-oriented design (Ceschin & Gaziulusoy 2016). Under this trend, design for sustainable behaviour (DfSB), which specifically

aims to reduce the negative environmental and social impacts of products and services by influencing users' behaviour, has gained a growing amount of research interest (Wever & Vogtländer 2015). Theoretical knowledge and practice-relevant contributions in the form of design strategies and techniques (see, e.g., Bhamra, Lilley & Tang 2011; Tromp, Hekkert & Verbeek 2011; Daae, Chamberlin & Boks 2018; Maccioni, Borgianni & Pigosso 2019; Kim *et al.* 2020) and toolkits (see, e.g., Lockton, Harrison & Stanton 2010; Daae & Boks 2014; Colusso, Do & Hsieh 2018; Hoolohan & Browne 2020) have been developed to guide design researchers and practitioners to make more informed decisions in sustainable behaviour design. Various conceptual models derived from behaviour change theories have been applied to investigate empirical phenomena and guide sustainable design explorations (see, e.g., Wever, van Kuijk & Boks 2008; Lilley 2009; Bhamra *et al.* 2011; Daae *et al.* 2018). To a large extent, these models are established on the view that the undesired interaction between users and designed artefacts may lead to underlying socio-ecological sustainability issues. Consequently, a better modelling and understanding of user-product/service interaction can be applied to solve these potential issues (Boks 2012).

However, design for sustainability research is currently evolving from perceiving sustainability as a static goal towards a dynamic target (Faber, Jorna & Van Engelen 2005; Joore & Brezet 2015), from focusing on single products and services towards making changes at a complex socio-technical system level (Adams *et al.* 2016). Facing this trend, two critical challenges have emerged in the sub-field of DfSB: first, existing studies appear to focus on addressing sustainable behaviour change problems from a short-term perspective (Brynjarsdottir *et al.* 2012). For example, some behaviour change strategies such as feedback can only draw people's attention to the environmental impacts of their behaviour for a limited time. The long-term dynamic perspective regarding how people might transform their behaviour over time has seldom been taken into account in empirical analysis and design explorations (van Dam, Bakker & van Hal 2010; Coskun, Zimmerman & Erbug 2015). Second, most of the commonly used sustainable behaviour change design models tend to narrowly focus on applying design techniques to influence the way how individuals interact with a specific product, thus neglecting the importance of understanding the complexity of why and how a specific behaviour is performed in the broader context of people's everyday life. Such complexity is not only determined by the usability problems situated within the interaction between a user and a designed artefact but also shaped by the interdependency between individuals and macro socio-technical systems, in which products function with other products and other people, forming an interconnected network (Mankoff *et al.* 2007; Wever *et al.* 2008). Consequently, due to its primary focus on how design can be used to influence people's behaviour, the current behaviour-based theoretical perspective might not always be sufficient to deal with these challenges.

As a response, many literature review studies suggested that future DfSB research needs to expand from solely focusing on users' specific behaviour to incorporating the long-term dynamic, multi-level, and complex features of people's everyday doings into consideration (Ceschin & Gaziulusoy 2016; Costa *et al.* 2019). Such expansion would require support from a theoretical lens that systemically contextualizes the interplay between users and designed artefacts in a real-life setting (Boon *et al.* 2015). Among a variety of theoretical perspectives such as

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practice theory (see, e.g., Shove 2007; Pettersen 2013; Kuijer 2014) and the theories of transitions and system innovations (see, e.g., Ceschin 2014; Gaziulusoy & Brezet 2015), activity theory (AT), with its focuses on understanding the role of artefacts (and design of artefacts) in purposeful need-based human activity, is regarded as one of the leading candidates to solve the challenges faced by DfSB identified above. Three theoretical features of AT: historical and developmental sensitivity, attention to complex systems, and reality-based solutions can be especially useful to understand the context of sustainability issues from a design perspective (Kaptelinin & Nardi 2006). Some recent works also pointed out that AT is a promising theoretical lens in DfSB research (Selvefors 2017; Renström 2019). However, despite the application of AT as a theoretical lens in the design field, especially in human–computer interaction design (see, e.g., Bødker 1989), how the theoretical features of AT can be employed to support design researchers in understanding and addressing complex sustainability issues remain ill-addressed.

To bridge this gap, the present study aims to systematically explore the potential use of AT as a theoretical lens for guiding empirical analysis and design explorations in DfSB. Two overarching research questions guide our research investigation: (1) *how have AT and its theoretical principles been applied in existing studies to guide the empirical analysis and design explorations for tackling design-related sustainability challenges?* (2) *how might the findings be translated to theoretical and practice-relevant implications for design researchers in the DfSB field to apply?* To achieve this goal, a theory-generating qualitative meta-synthesis approach (Finfgeld-Connett 2018) is adopted to synthesize results from the existing relevant studies. An overview of the research process and paper structure is illustrated in Figure 1.

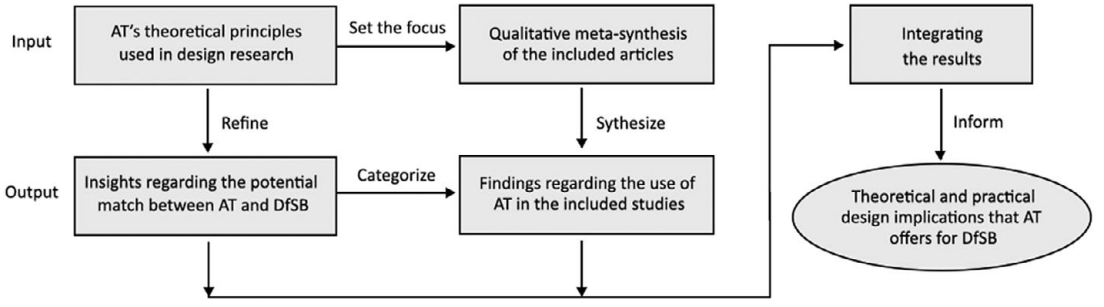

Figure 1. An overview of the research process in the present study.

2. AT theoretical background and applications in design

The conceptual origins of AT can be traced back to the work conducted by psychologist Lev Vygotsky and Sergei Rubinshtein in the 1920s and 1930s when they were in search of an understanding of how the complex relationship between human mind and society manifests itself in human activities (Kaptelinin & Nardi 2006). According to Vygotsky (1978), human activities are purposeful need-based relationships between the subject and the object mediated by the use of artefacts. Established on Vygotsky's AT model, a variety of models have been developed in different research fields. As illustrated in Figure 2, Leontiev's hierarchical structure

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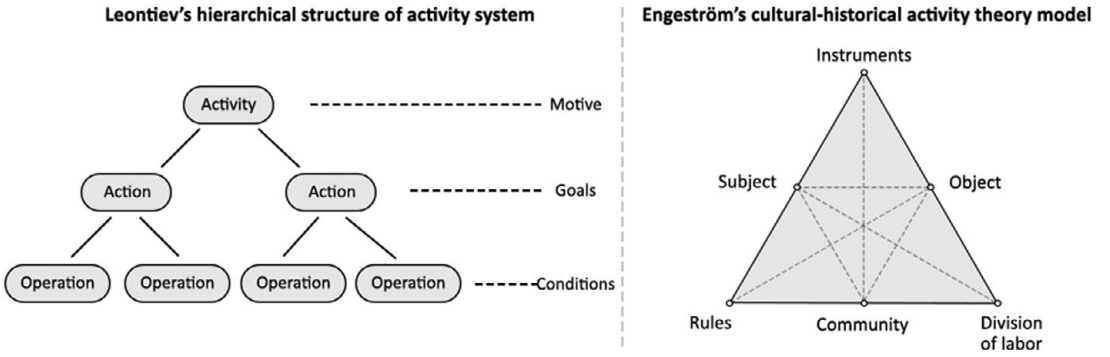

Figure 2. Leontiev's hierarchical structure model (adopted from Leont'ev 1978) and Engeström's cultural–historical AT model (adopted from Engestrom 1987).

model (Leont'ev 1974, 1978) (also referred as the second generation of AT model) and Engeström's cultural–historical AT model (Engestrom 1987) (also referred as the third-generation AT model) have been widely accepted and applied in the current research.

Originating from a socio-cultural tradition in psychology, two distinguishing features make AT applicable for design research: First, unlike most of the behavioural and psychological theories that provide researchers with models to predict people's behaviour, AT aims at supporting design researchers in formulating sensible inquiries based on the descriptive accounts of why and how people carry out a specific activity in a specific context to achieve a specific goal (Li & Landay 2008; Bødker & Klokmose 2011; Kaptelinin 2014). In this respect, AT works as a theory-based conceptual framework for structuring design research inquiries rather than a theory in the traditional sense (Karanasios 2014). Second, as Engeström (1999, p. 29) noted that 'AT has the conceptual and methodological potential to be a pathbreaker in studies that help humans gain control over their own artifacts and thus over their future'. AT's particular focus on the role that artefacts play in people's activity system is in accordance with the design tradition of product and service design in understanding and shaping human–artefact relationships (Duignan, Noble & Biddle 2006; Kuutti 2011). To narrow the scope down, in the present study, we mainly focused on the use of AT for guiding empirical analysis and design explorations.

Five key theoretical principles of AT have become the cornerstones that underpin the application of AT in design research (Kaptelinin, Nardi & Macaulay 1999). In the following part of this section, we briefly introduce each theoretical principle with a special focus on its specific implications for addressing design for sustainability challenges.

2.1. Mediating effects of artefacts

The theoretical principle of artefact mediation plays a central role in AT. According to Vygotsky (1978), all purposeful interaction between the subject and the world is mediated by the use of artefacts. The mediating artefacts used in activities include both external material tools (e.g., hammers, computers and digital interface) and internal immaterial tools (e.g., language, symbols and models) (Kaptelinin 2014).

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This conceptualization of artefact aligns with the classic definition that Herbert Simon made that an artefact can take any form on the continuum between abstract and concrete and act as a bridge between an internal and external environment (Simon 1969). From a design for sustainability perspective, we are interested in how the concept of mediating artefacts may guide the design of sustainable products and services in people's activity systems (hereinafter referred to as M-1).

2.2. Subject–object relationships

The theoretical principle of subject–object relationships is regarded by many theorists as the most fundamental notion that underpins AT. In the view of AT, subjects can be both individual (e.g., individual users) and collective (e.g., different stakeholders, organizations and communities). Correspondingly, the object involves both tangible biological (e.g., eat food) and intangible psychological (e.g., comfortable living) aspects of human life. When a specific need of a subject is coupled with a specific object, a motive is formed, and at the same time, an activity emerges. AT argues that it is the subject–object relationship, rather than the individual component of subject or the object, that determines how an activity is carried out (Gay & Hembrooke 2004). As Kaptelinin & Nardi (2006) indicated, when used in product and service design, this principle can enable designers to expand the scope of analysis from users' interaction with a specific product or service to how subjects carry out a meaningful motive-oriented activity (hereinafter referred to as SO-1).

2.3. Tensions and contradictions

Tensions and contradictions are broadly defined as misfits, problems, incoherencies and inconsistencies that subjects encounter in the targeted activity systems (Kuutti 1996). When this theoretical principle was applied in design research, in some cases, it was only used to identify product usability problems. However, that is an oversimplification as tensions and contradictions do not only exist in the interaction between users and artefacts but also can be found within and between different components of an activity system. It is due to this reason that understanding tensions and contradictions might provide design researchers with a systemic perspective of how sustainability problems take place at different levels of an activity system (hereinafter referred to as T&C-1).

2.4. History and development

When the subject begins to cope with the tensions and contradictions within and between activity systems, the activity system may undergo a development process (Engeström 1999). This development process does not just last for a certain time. On the contrary, in the view of AT, activities are under constant development and evolution (Kuutti 1996). Two features of this theoretical principle are relevant to be used for design for sustainability studies: First, when certain tensions and contradictions become materialized at a given point of time, the subject of the activity system may attempt to find temporary solutions to address the contradictions, it is under these moments that the activity undergoes a transformation process (Blackler, Crump & McDonald 1999; Boer, van Baalen & Kumar 2002) (hereinafter

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referred to as H&D-1). Second, AT postulates in its theoretical nature that a typical way to induce intentional changes is through re-mediation, that is, redesigning artefacts (such as products and services) to influence the way how subjects achieve the original object (Nardi 1996; Bødker & Andersen 2005) (hereinafter referred to as H&D-2).

2.5. Socio-cultural contexts

Gay & Hembrooke (2004) connects AT to an ecological perspective and posit a human activity at three levels: the micro-level represents independent activities carried out by each individual, the meso-level represents collective activities carried out by a group of individuals or a community, the macro-level represents large social contexts. They went on and argued that when an activity system is analysed at one particular level or context, its relations with activities at other contextual should also be taken into account. From a design for sustainability perspective, the sustainability effects of a product and service should not be limited to its environmental performance or its influence on individual user behaviour. Instead, it is vital for design researchers to analyse or envisage the potential impacts of a particular sustainable design intervention on different socio-cultural levels, covering individual to larger social contexts (hereinafter referred to as SC-1). Moreover, the theoretical principle of socio-cultural contexts also highlights the importance of understanding people's behaviour in real-life settings rather than task-based laboratory settings (Kaptelinin & Nardi 2006, p. 35) (hereinafter referred to as SC-2). A summary of the design for sustainability related insights extracted from AT's five key theoretical principles is shown in Table 1.

3. Methods and methodology

3.1. Theory-generating qualitative meta-synthesis

In order to synthesize findings from each independent primary study into generalizable theoretical understandings that can be applied beyond the original study sample, a qualitative meta-synthesis approach was adopted in this study (Stern & Harris 1985; Sandelowski, Docherty & Emden 1997). Qualitative meta-synthesis is a hermeneutic approach seeking to generate understanding about phenomena by integrating, comparing and translating original findings from a number of interrelated qualitative studies into coherent ones (Walsh & Downe 2005). Previously, this approach has been applied in the studies conducted by Stewart *et al.* (2012) and Clemmensen, Kaptelinin & Nardi (2016) to investigate the use of AT in the field of human–computer interaction. Integrating their methodological reflections with the research aim of this study, we adopted and adapted the theory-generating qualitative meta-synthesis methodological guidelines developed by Finfgeld-Connett (2018) to guide the qualitative data collection, extraction, analysis and synthesis process. This guideline was chosen due to its clear methodological procedures on theory development and higher level abstraction.

3.2. Identification of literature

To identify the relevant primary studies, we set the meta-synthesis scope to the existing studies that applied AT models (the first-, second- and third-

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Table 1. Activity theory's key theoretical principles and insights related to design for sustainable behaviour

Activity theory's theoretical principles	Theoretical insights that are useful for design for sustainability	Examples presented in the result section
Mediating effects of artefacts	M-1: The concept of mediating artefacts can guide design interventions to facilitate the transformation of users' entire activity system towards sustainability	Section 4.1
Subject–object relationships	SO-1: Expand the scope of analysis from users' interaction with products or services to how users carry out meaningful motive-oriented activities	Section 4.2
Tensions and contradictions	T&C-1: Provide design researchers with a holistic view of how tensions and contradictions within and between users' activity systems may lead to potential sustainability problems	Section 4.3
History and development	H&D-1: Behaviour transformation may occur due to users attempting to find temporary solutions to address tensions and contradictions in the activity system H&D-2: Re-mediation can be a way to achieve the intended sustainable behaviour change in the activity system	Section 4.4
Socio-cultural contexts	SC-1: Help design researchers analyse and envisage the potential impacts of sustainable design intervention at different levels: individual, collective and societal SC-2: Help design researchers understand people's behaviour in real-life contextual settings rather than task-based laboratory settings	Section 4.5

generation model) and its key theoretical principles (as indicated in Section 2) to understand or address socio-ecological challenges from a design for sustainability perspective. Following the qualitative meta-synthesis guideline suggested by Finfgeld-Connett (2018), we systematically searched relevant literature in Scopus and Web of Science Core Collection. Building upon a non-exhausted literature review that we conducted in a pilot study (see Chu, Glad & Wever 2021), two groups of search terms were adopted in the literature identification process (as presented in Table 2). Peer-reviewed conference papers, journal articles and book chapters were included in the literature search. The literature search was conducted in May 2020. After removing duplicated search records, the literature search resulted in 621 articles.

3.3. Study selection and quality assessment

Following qualitative meta-synthesis literature screening procedures proposed by Barroso *et al.* (2003), the selection process in the present study is divided into four stages (see Figure 3). By assessing all the identified articles against the criteria listed in Table 3, 18 articles were included in the final review stage while 603 articles were excluded.

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Table 2. Search scope, search string and the corresponding search records

Databases and search criteria	Scopus	Web of science core collection
Document type	Article, conference paper, book chapter	Article, conference paper, book chapter
Language	English	English
Publication year	From 1990 to May 2020	From 1975 to May 2020
Search strings applied to	TITLE-ABS-KEY	TITLE-ABS-KEY
'activity theory' AND 'sustainab*'	98 records	67 records
'activity theory' AND 'behavior* change'	8 records	3 records
'activity theory' AND 'environment*' AND 'design'	243 records	148 records
'activity theory' AND 'social*' AND 'design'	294 records	156 records

3.4. Data extraction and synthesis

Two types of data were extracted from the included primary studies: (a) basic study characteristics and (b) findings related to the use of AT. Basic study characteristics include research aims and questions, specific goals concerning sustainability and design, data collection and analysis methods and main study outcomes. Findings related to the use of AT were extracted based on the following themes:

(i) Purposes or rationales for adopting AT.
(ii) Engagement with AT models and theoretical principles.
(iii) Author(s)' reflections on the use of AT.
(iv) The specific unit of analysis in the study.
(v) The specific usage of AT concerning the investigation of sustainability problems.
(vi) Implications to design.

The data synthesis method memoing was used to explicate the relationships among different studies while avoiding decontextualizing the data. First, the extracted data were distilled into descriptive statements in the form of within-study memos. Following that, the within-study memos were grouped and reconstructed into cohesive cross-study memos (as illustrated in Figure 4). These within-study and cross-study memos were then synthesized into different themes from a bottom-up (based on their emergent characteristics) and a top-down manner (based on their coherence with the five key AT theoretical principles). The data synthesis process was conducted in a test–retest iterative manner. Moreover, to a better synthesis of the results, we first sorted the included articles according to two characteristics: the main study outcomes and the overall engagement with AT. The included primary studies were divided into two sub-categories based on their main study outcomes: (a) studies that focus on analyzing empirical findings of a sustainability-related phenomenon and (b) studies that focus on formulating AT-based analytical frameworks or models to guide the investigation of a specific empirical phenomenon.

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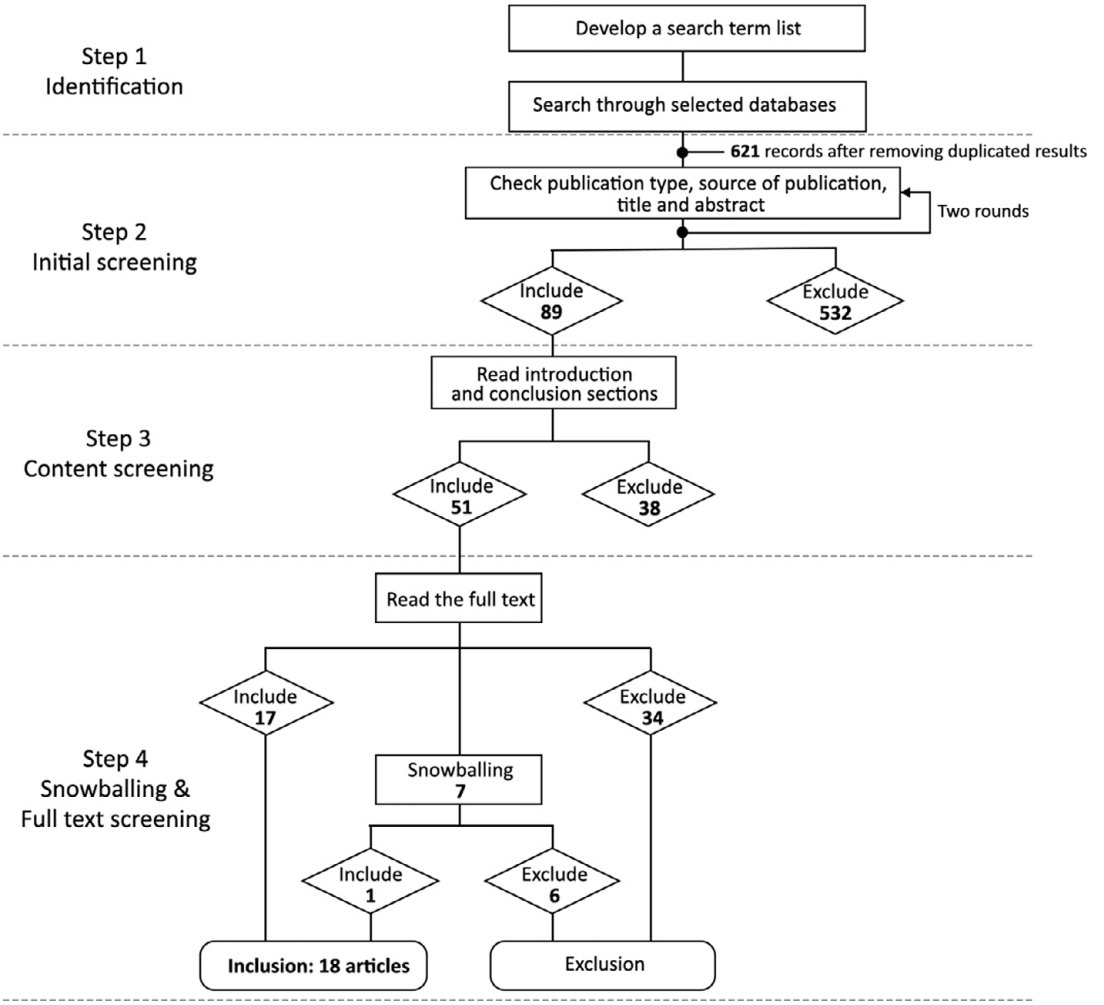

Figure 3. Literature identification and screening process implemented in this study.

4. Results

Table 4 presents an overview of the articles mapped into different subgroups. Two themes emerged from the results. Theme 1 comprises eight articles that used AT to analyse the causes of sustainability issues and inform sustainable design interventions. Theme 2 comprises ten articles that used AT to evaluate the sustainability or unsustainability effects of the proposed design interventions implemented in the studies.

Although the specific use of AT in each study varies across different research contexts, they can generally be summarized as (1) Investigating sustainable effects of mediating artefacts, (2) Directing sustainable subject–object relationships, (3) Uncovering tensions and contradictions within and between activity systems, (4) Understanding the dynamism of activities from a history and development perspective and (5) Incorporating socio-cultural sustainability into design consideration. Table 5 gives an overview of AT's theoretical principles applied in the included studies. A detailed summary can be found in Appendix Table S1.

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Table 3. Literature screening steps and criteria

Procedures	Inclusion and exclusion criteria (S, step number; I, inclusion; E, exclusion)
Step 2	S2-I1: The article presents both design and sustainability components in its title, abstract or keywords
	S2-I2: The article is published in a journal or conference or as a book chapter related to the design research field
	S2-E1: The article does not present any design or sustainability components in title, abstract, keywords and source of publication
Step 3	S3-I1: The content of the study is related to one or multiple design research topics such as interaction design, information system design, architecture design, behaviour design, information and communication technology and participatory design
	S3-I2: The goal of the study involves understanding the nature of design-related phenomena or developing design-related knowledge, artefacts, interventions, principles and guidelines
	S3-I3: The article employs a research methodology that is relevant to design research
	S3-I4: Adding on the above design-related selection criteria, addressing environmental or social sustainability challenges is a major goal that the study aims to achieve
	S3-E1: The article either lacks a clear indication of the meaning of sustainability, or the sustainability aspect of the study is only mentioned without further elaboration
	S3-E2: The article does not focus on environmental or social sustainability challenges. For example, articles that aim to sustain organizational development were excluded
	S3-E3: The article only touches upon the design perspective in a general way. For example, in some studies, the term design is only used to represent the general process of project planning and development
Step 4	S4-I1: The article explicitly indicates that AT is used to understand design-related or user activity-related phenomena
	S4-I2: The article clearly presents how an AT perspective was employed in the research
	S4-I3: The article cites classic AT literature that focuses on presenting theoretical models, concepts and principles
	S4-E1: The article only mentions the concept of AT without notable use of it in the research process. For example, AT was only mentioned in the introduction, background or literature review section without further application or discussions
	S4-E2: Although the article states that an AT perspective was applied in the research process, it does not provide a detailed description of how AT was employed. Therefore, it is impossible to evaluate how the use of AT is connected to the study results
	S4-E3: Although the article employs AT in data analysis or design exploration process, the use of AT is not related to the sustainability challenges that the study aims to address

4.1. Investigating sustainable effects of mediating artefacts

The primary theoretical understanding we used for structuring the results in this sub-category revolves around how the concept of mediating artefact may guide the design of products and services to facilitate the transformation of users' whole activity system towards sustainability (see M-1 in Section 2.1). The results showed that all the included articles applied the theoretical principle of mediating artefact

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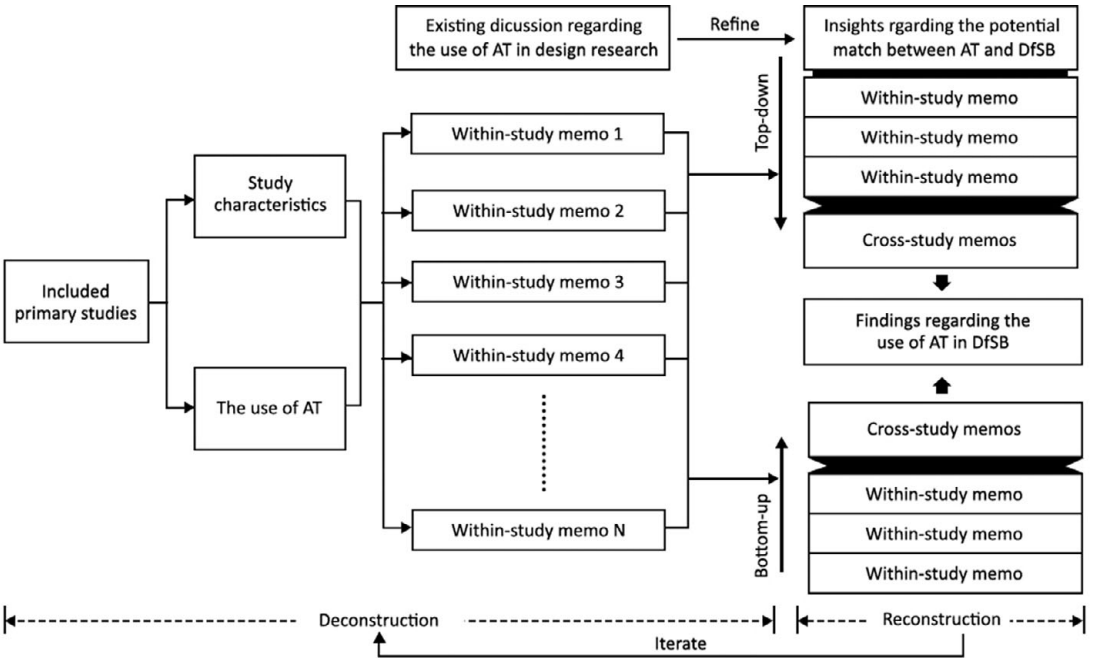

Figure 4. The analysis and synthesis of the insights extracted from the included primary studies.

Table 4. Included articles mapped according to the study outcomes and engagement with AT

Overall engagement with AT	Theme 1: analyse the causes of sustainability issues and inform sustainable design interventions	Theme 2: evaluate the effects of design interventions on addressing the targeted sustainability challenges
Analyse empirical data/findings	Hasan & Meloche 2013	Hasan & Ionescu 2017
		Lin & Hsieh 2014
	Hasan, Smith & Finnegan 2017	Sclater 2016
	Perold, Donaldson & Devisch 2019	Lally & Sclater 2012
	Selvefors, Karlsson & Rahe 2015	Ssozi-Mugarura, Rivett & Blake 2016
	Chen *et al.* 2009	Svensson 2020
		Viktorelius & Lundh 2019
Formulate analytical framework	Bai & Guo 2011	Aguayo 2016
	Chu *et al.* 2020	Aguayo & Eames 2017
	Khan, Lodhi & Akhtar 2015	Smith & Turpin 2017

in their studies. However, the way how this principle was used varied across each study (as presented in Themes 1 and 2 in the following paragraphs). As shown in Table 6, most of the included studies propose and evaluate digital design interventions to address socio-ecological sustainability challenges, which is not surprising given that AT has already been widely applied in the research field of ICT and HCI.

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Table 5. An overview of the key AT theoretical principles employed in each included primary study

Themes	Articles	Mediating artefacts	Subject–object relationships	Tensions and contradictions	History and development	Socio-cultural contexts
Theme 1: analyse the causes for sustainability issues and inform sustainable design interventions	Hasan & Meloche 2013	√				
	Hasan *et al.* 2017	√	√	√		√
	Perold, Donaldson & Devisch 2019	√		√		
	Selvefors *et al.* 2015	√	√	√	√	
	Bai & Guo 2011	√	√			
	Chu *et al.* 2020	√	√	√		
	Khan *et al.* 2015	√				√
	Chen *et al.* 2009	√	√			√
Theme 2: evaluate the effects of design interventions on addressing the targeted sustainability challenges	Hasan & Ionescu 2017	√				
	Lin & Hsieh 2014	√		√		√
	Sclater 2016; Lally & Sclater 2012	√			√	
	Ssozi-Mugarura *et al.* 2016	√	√		√	√
	Svensson 2020	√	√	√		
	Viktorelius & Lundh 2019	√		√	√	
	Aguayo 2016; Aguayo & Eames 2017	√	√		√	√
	Smith & Turpin 2017	√		√		√

Theme 1. As presented in Section 2.1, the artefact mediation process consists of a network of interconnected mediators involving both internal and external artefacts. This concept of internal and external artefacts is applied in the identified study to inform sustainable design interventions that facilitate more fundamental behaviour transformation of users' activity system. For example, Hasan *et al.* (2017) pointed out that artefacts can influence activities in two dimensions. External tools such as computers and machines can produce changes in material dimensions, while internal tools such as signs and models can produce changes in user behaviour. Based on this understanding, they proposed a series of design interventions that involved both material and behavioural dimensions (e.g., web-based user-oriented applications with social media campaigns) for exploring potential information system design opportunities to tackle climate change adaptation challenges (Hasan & Meloche 2013; Hasan *et al.* 2017). Moreover, with the goal to reduce date labelling-related household food waste, Chu *et al.* (2020) applied the concept of internal and external mediating artefacts for identifying potential opportunities for design to intervene in the interaction between

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Table 6. The research field and intended artefacts analysed in the included primary studies

Research field	Included articles	Intended artefacts
Information and communication technology (ICT)	Aguayo 2016; Aguayo & Eames 2017	An online learning platform that promotes socio-ecological sustainability
	Smith & Turpin 2017	A socially relevant ICT platform for rural elderly women
	Ssozi-Mugarura *et al.* 2016	An ICT tool for rural community water management
	Sclater 2016; Lally & Sclater 2012	A virtual platform for learning socio-ecological sustainability issues
	Hasan & Meloche 2013	ICT solutions to tackle environmental problems
Information system (IS)	Hasan *et al.* 2017	An information system tool for climate change adaptation
	Hasan & Ionescu 2017	An online system for tracking the environmental footprint of business
	Chen *et al.* 2009	Sustainable information system for emergency disaster communication
eHealth services	Svensson 2020	Sustainable eHealth services introduced at a municipal level
	Bai & Guo 2011	A sustainable elderly care eHealth system
	Lin & Hsieh 2014	Sustainable eHealth services
Energy consumption and conservation	Selvefors *et al.* 2015	Household energy conservation appliances
	Viktorelius & Lundh 2019	Energy monitoring system in shipping
Sustainable architecture and urbanism	Perold, Donaldson & Devisch 2019	A conceptual framework for transitions towards sustainable urbanism
Household food waste	Chu *et al.* 2020	A conceptual framework for reducing food waste caused by date labelling design
Electronic waste	Khan *et al.* 2015	A conceptual framework for electric and electronic waste management

consumers and on-pack date labelling. The findings showed that although date labels (such as 'Best-before' date and 'Use-by' date) are used as external tools that assist consumers in judging food quality and safety, the lack of the corresponding internal mediation tool on the consumer side, such as confusion on the meaning of different types of labels, conflicts between the usage of labels and consumers' sensory perceptions in food edibility assessment activities, can still lead to potential problems associated with household food waste in consumers' food edibility assessment systems.

Theme 2. Studies categorized in Theme 2 also highlighted that to achieve the intended sustainable behaviour transformation, solely focusing on improving the sustainability aspects of external artefacts or interventions is likely to be

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insufficient, the question of how users might perceive and incorporate the introduced sustainable design intervention into their existing activity systems should also be considered. For example, Viktorelius & Lundh (2019) used AT to investigate the effects of a newly installed energy monitoring system on improving crew members' shipping energy operation efficiency. The original design intention is to replace crew members' experience-based intuitive understanding of energy efficiency with data-informed decisions. However, since the crew lacked the necessary knowledge and skills as internal mediating tools to interpret and transform the massive amount of data provided by the system into their actual work practices. As a result, the system ended up not being used by any crew members after installation. Similarly, in her investigation of the effects of a newly introduced eHealth service system, Svensson (2020) also noted that users' lack of knowledge and skills of how to apply the new eHealth service in their existing healthcare activity systems is one of the main reasons that affect the intended sustainability effects of the design.

4.2. Directing sustainable subject–object relationships

As mentioned in Section 2.2, AT's theoretical principle of subject–object relationships suggests that rather than taking subjects (users) and objects (motives and goals) as independent and separate components in a design process, studying the relationships between these two components within an activity system might be able to provide design researchers with a holistic lens to direct the subject to fulfill the intended objects in a sustainable way (S&O-1). In general, the review results of our study provided detailed suggestions to make this theoretical insight more specific.

Theme 1. First, to outline the causes of sustainability issues and inform sustainable design implications, the principle of subject–object relationships was used to reveal connections between subjects' primary motives in an activity system and the corresponding sustainable or unsustainable actions that the subject performed. The most representative case of how this theoretical principle was used can be found in the study conducted by Selvefors *et al.* (2015). By looking at household energy consumption from a goal-oriented perspective, Selvefors *et al.* (2015) investigated why people do, or do not, prioritize energy conservation in household contexts. They indicated that people's motives and goals in everyday life contexts can influence which activities and energy-consuming artefacts they would use. Based on this insight, they suggested that to effectively support energy conservation, only focusing on improving the energy efficiency attributes of artefacts is not enough, artefacts should also be designed to better support users in attaining their primary motives and goals in everyday life contexts.

Theme 2. When the principle of subject–object relationships was used to evaluate the sustainability effects of design interventions, findings from the meta-synthesis suggest that, in some cases, the introduced sustainable design intervention failed to achieve its anticipated outcomes as the subject lacked certain motives to adopt the design into their existing activity systems. For instance, Svensson (2020) used AT to evaluate the effects of a newly implemented eHealth service on the existing healthcare practices at a municipality level. The original object of the eHealth service was to bring economic, social and ecological sustainability to the local society. However, some healthcare workers reported that they

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lacked motivations to use the system in their work practices, thus leading to unwanted waste of resources. In contrast, a successful design case was reported by Aguayo (2016) and Aguayo & Eames (2017), in which an ICT platform was developed to facilitate socio-ecological behaviour transformation at a community level. In their pre-design phase, AT's subject–object relationships enabled them to develop an in-depth understanding of the conditions of the local community and the needs of community members. Based on this understanding, the ICT platform was designed to incorporate the local socio-ecological sustainability goals into the needs of each individual in the local community. This design strategy was proven successful as participants reported that the platform prompted new motivations, which later made them take direct or indirect actions to solve the local socio-ecological issues in the community. In a similar vein, in Ssozi-Mugarura *et al.* (2016)'s study, AT was adopted to evaluate the effects of an ICT-based mobile water management application in the context of rural communities in Uganda. The principle of subject–object relationships was used as a dimension to develop an understanding of what motivates and demotivates people in rural communities to use the application. The results showed that a close match between users' needs and the functionality of the application created motivations for users to adopt the application and thus change their existing water management practices. In summary, the principle of subject–object relationships highlighted the importance for design researchers to understand subjects' existing motives and goals embedded in the targeted activity system and carefully consider how sustainable design interventions can be compatible with these existing motives and goals, especially in the early-stage design process.

4.3. Uncovering tensions and contradictions of the user activity system

Theme 1. Most of the included studies categorized in Theme 1 used the theoretical principle of tensions and contradictions to reveal the existing conflicts and mismatches within and between different components of a targeted activity system. For example, as mentioned in the preceding section, Selvefors *et al.* (2015) concluded that a variety of conflicting motives in people's daily life contexts, such as conflicts between ensuring well-being or reducing effort, on the one hand, and reducing energy consumption, on the other hand, can hinder people from prioritizing energy conservation. In a similar vein, to understand the connection between consumers' usage of on-pack date labels and household food waste issues, Chu *et al.* (2020) investigated tensions and contradictions that consumers encounter when using date labels and sensory perceptions to assess food quality and safety.

Theme 2. When the principle of tensions and contradictions was used to evaluate the sustainability effects of design interventions, all the studies included in this category focused on investigating why interventions particularly designed to promote people's sustainable behaviour failed to achieve the intended sustainability outcomes. For example, in Viktorelius & Lundh (2019)'s study about how a newly installed energy monitoring system onboard ships may affect the energy efficiency of crew members' work practice operations, it was reported that although the energy monitoring system was designed to help crew members to better understand their daily work energy consumption, several existing tensions and contradictions, such as the ambiguity related to energy efficiency (tension between

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crew members and the newly introduced system) and lack of technical support from shore (tension between the object of saving energy and division of labour) remained unsolved. At the same time, new tensions, such as the lack of energy data analysis skills (tension between crew members and the newly introduced system) and information overload (tensions between the newly introduced system and the object of saving energy), emerged due to the implementation of the system. Similarly, in Svensson (2020)'s study about the sustainability effects of a newly developed eHealth service, it was found that although the implementation of the new service had radically changed the existing work practices conducted by health workers, however, several problems, such as the lack of proper knowledge to use the eHealth service and the concerns about healthcare resource efficiency at the municipality level, emerged when the new services were introduced to the existing healthcare activity systems. Furthermore, from an information system design perspective, Hasan *et al.* (2017) used contradictions as a dimension to explore the design opportunities for tackling climate change adaptation challenges. They noted that the theoretical principle of tensions and contradictions is particularly useful for understanding the evolving nature of the human activity and how it is influenced by the evolution of technology. Furthermore, Lin & Hsieh (2014) used tensions and contractions for understanding the factors that affect the sustainability outcomes of three newly deployed telehealth service systems. Reflecting on the use of AT, they noted that the theoretical principle of tensions and contractions 'helps to reflect on design strategies that can accommodate all interests and thus fulfill the stakeholders' objectives and satisfy their needs' (p. 116). Smith & Turpin (2017) also pointed out that tensions and contradictions can allow researchers to identify the mismatches between the goal of the sustainable design intervention and the needs of different stakeholders in the context of an activity system.

4.4. Understanding the dynamism of user activities from a history and development perspective

As tensions and contradictions reveal how different types of conflicts manifest in the targeted activity system, the theoretical principle of history and development uncovers how subjects cope with the tensions and contradictions and how this can lead to changes in the existing activity system (see H&D-1 in Section 2.4). Findings from the reviewed study showed that this theoretical concept was used to illustrate how activity develops over time and what sustainability challenges, along with potential design opportunities, may emerge in the development process. For instance, Selvefors *et al.* (2015) found that as participants encountered contradictions between energy conservation and other competing goals in everyday life, they had searched various strategies, ranging from increasing family members' energy consumption awareness to investing in new household energy efficiency technologies, to better resolve the contradictions. Putting this developmental view of people's energy consumption behaviour in longer time spam, they noted that 'people's energy use rarely has a purpose of its own; it is embedded in the actions and activities that form everyday life. People's energy demanding activities thus co-evolve over time with, for instance, people's preconditions, available technologies, the socio-cultural setting, and the goals people find relevant to pursue' (p. 5974). In addition, the principle of history and development was also used to conceptualize people's life event transition process. Sclater (2016) designed and evaluated a

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virtual platform for young people to better cope with social and emotional challenges in life event transitions. In their study, the development perspective of AT was directly used to understand how the virtual platform may work as a mediating artefact for participants to form new motivations with a range of problem-solving skills, including potential skills to deal with socio-ecological sustainability challenges that they are going to face in the future.

Some of the included studies also used the principle of history and development to unfold how desired or undesired changes take place in the targeted activity system due to re-mediation (see H&D-2 in Section 2.4). Aguayo & Eames (2017), for example, noted that the implementation of an ICT platform in a community resulted in the development of a network of subsequent activities for the community members to solve the local sustainability challenges, such as adopting sustainable lifestyle at home or workplace, taking direct measures to help improve the community's environment and educating kids about local sustainability problems (Aguayo & Eames 2017). The desired sustainable behaviour changes described above were enabled by incorporating the long-term developmental perspective into the early-stage design phase of the ICT platform as Aguayo indicated 'The EfS website was regarded then as being part of a dynamic and expansive activity system nurtured by the EfS website itself, this being one of the expected goals from the design process' (p. 7). The importance of taking the development perspective in sustainable behaviour design explorations was also highlighted in the study conducted by Ssozi-Mugarura *et al.* (2016), in which this theoretical principle was used to assess whether and how behaviour changes in terms of water management took place at both individual level and community level after the deployment of an ICT-based design intervention.

However, the re-mediation of activity systems does not always necessarily lead to intended sustainable behaviour changes in people's activity systems. As mentioned previously, in Viktorelius & Lundh (2019)'s study, an energy monitoring system was introduced to re-mediate the relationships between crew members' shipping operation practices and the object of improving energy efficiency. However, the system ended up not being used by any crew members and thus had no effects on crew members' existing energy consumption behaviour. By employing the theoretical principle of tensions and contradictions with the development perspective, they found that caused by the lack of systemic understanding of crew members' energy consumption activities in the design process, the fundamental reason for the unsuccessful behaviour transformation lies in the fact that the energy monitoring system was not designed to fit into crew members' existing working routines in the first place.

4.5. Incorporating user activities' socio-cultural context into sustainable design considerations

Theme 1. Results from the meta-synthesis show that when AT is used to analyse the causes for sustainability issues and inform sustainable design interventions, it can help design researchers to interpret and connect individuals' needs in relation to the context of the targeted activity system (see SC-1 in Section 2.3). For example, in his sustainable community-based ICT platform design project, Aguayo (2016) found that individuals' motivations for performing sustainability actions are directly related to the surrounding socio-cultural contexts. Such motivations can

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be more meaningful to users when they are linked with users' socio-cultural reality. Based on this finding, he emphasized that individual users' characteristics and needs cannot be fully understood if they were analysed separately from the social, cultural and historical context of the activity system. Khan *et al.* (2015) employed AT as a theoretical framework to solve the environmental management issues of electric and electronic waste based on AT's particular attention on connecting individual actions to socio-cultural factors. The study results indicated that addressing complex sustainability issues requires all the relevant actors, including administrations, government agencies, business partners and individuals, to be taken into account in the problem-solving process. Moreover, they pointed out that in such problem-solving process, AT's socio-cultural dimension can provide a theoretical basis for guiding not only the changes at the individual behaviour level but also transformation at the societal level. Furthermore, in Hasan *et al.* (2017)'s study, AT was used as an analytical lens to investigate problems that existed in climate change adaptation activities. The identified problems were analysed at three levels, from global concerns to local governments' measures to individual behaviour change. They argued that taking an activity theoretical perspective helps find the analytical balance to investigate sustainability issues between individual behaviour and the broader socio-cultural context.

Theme 2. Most of the studies in this category pointed out that the main reason for adopting AT in the design evaluation process lies in its capacity to analyse the sustainability effects of design interventions in reality-based socio-cultural contexts rather than lab settings (see SC-2 in Section 2.3). These studies indicated that the multi-level analysis informed by AT can help design researchers not only understand the effects of sustainable design interventions on individuals but also inform design opportunities regarding how the interventions might be potentially incorporated into the targeted activity system on a larger scale. For example, in their study about co-designing an ICT design intervention to empower the status of elderly women of a rural community in South Africa, Smith & Turpin (2017) used AT to take the social and political dynamics of the local community into the design considerations. Their reflections showed that the theoretical principle of socio-cultural contexts helped them identify the potential impacts that unvoiced social and political issues may have on the sustainability effects of the design interventions. Lin & Hsieh (2014) adopted AT to assess the use of sustainable eHealth services in healthcare practices. They mapped the socio-cultural contexts and identified contradictions between different components of the healthcare activity system at three levels of analysis: micro-individual level, meso-group(community) level and macro-institutional level. They stressed that 'AT helps to adequately maintain the relationship between the individual and social levels in the objects to be studied, particularly to understand emergent features in individual and social transformation' (p. 116). Similarly, the same socio-cultural contextual mapping appeared in Ssozi-Mugarura *et al.* (2016)'s study about evaluating an ICT-based design intervention for sustainable water management in rural communities. Drawing on their results, they noted that this mapping of socio-cultural levels provided them with the flexibility to look at different aspects of the design intervention, such as the purpose that the design intervention serves, the users, the context that the user situates in and the relationship between the above three aspects.

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5. Discussion

Building upon the meta-synthesis results presented above, in the discussion part, first, we summarize the key insights extracted from the results to answer the RQ1: *how have AT and its theoretical principles been applied in existing studies to guide the empirical analysis and design explorations for tackling design-related sustainability challenges?* After that, we focus on synthesizing AT-based theoretical and practice-relevant design implications to address the RQ2: *how might the findings be translated to theoretical and practice-relevant implications for design researchers in the DfSB field to apply?*

5.1. AT as a systemic approach for guiding empirical analysis and design explorations to cope with complex sustainability challenges

As presented in the result section, many included studies pointed out that the AT lens can guide the development and evaluation of design interventions to accommodate the complexity of sustainability challenges. This capacity of coping with complex sustainability phenomena is one of the main reasons for authors in some of the included studies to select AT as the overarching theoretical perspective in the design research process. For instance, Hasan & Meloche (2013) noted that 'AT supports a holistic perspective which can be used to address wicked problems such as climate change and other complex environmental challenges so that more innovative solutions can be found' (p. 336). The complexity of sustainability challenges comprises not only the technical aspect, such as the usability and applicability of the design intervention for enabling subjects to fulfill a specific object, but also the social aspects of design, such as the relationships between different actors involved in an activity system and the actual implementation of the introduced design intervention in real socio-cultural environments. For instance, Lin & Hsieh (2014) and Svensson (2020) adopted AT to model how coordination between different stakeholders, objectives, environments, tools and outcomes form a complex activity system that may affect the sustainability of the newly implemented eHealth system. Aguayo (2016) and Smith & Turpin (2017) evaluated how local community members used ICT platforms to solve sustainability issues in their real social-cultural contexts.

Reflections from the included studies showed that, when being used in design, AT can provide design researchers with a systemic approach for understanding the complex socio-technical sustainability challenges. Aguayo (2016), for example, pointed out in their design process that 'a dilemma arose in how to make sense of data comprising social, cultural, educational, ecological and technological components, while embracing a systems thinking approach. It is in this context that AT provided conceptual elements in the form of a meta framework that informed and guided data analysis and sense-making' (p. 4). Khan *et al.* (2015) also noted that when facing complex electric and electronic waste management issues, AT's particular strengths in problem modeling and solution modeling can guide design researchers to find a design solution at a system level to 'deal with broad spectrum instead of finding short-sighted technical solutions' (p. 87). Furthermore, in Aguayo (2016) and Hasan *et al.* (2017)'s study, AT was applied in combination with complexity theory to develop an in-depth understanding of how system

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behaviour emerges through the interaction of a number of interrelated components. They indicated that AT works as a useful theoretical lens to interpret sustainability phenomena in complex socio-technical contexts.

Moreover, we also found that AT's emphasis on higher level motive-oriented activities is particularly helpful for uncovering the interdependency of different components at an activity system level. For instance, Lin & Hsieh (2014) noted that 'AT is suitable for understanding the design and analysis of complex systems, such as service innovation, in which it strongly emphasizes the interactions between subjects with different environments to achieve their objects and result in different outcomes' (p. 116). Selvefors *et al.* (2015) also concluded that AT's particular focus on how people carry out their actions and activities can help researchers become more aware of the complexity embedded in people's everyday life energy consumption practices: 'Instead of exploring energy behaviours and their determinants in isolation from each other, it could be beneficial to study people's actions in relation to other actions and everyday priorities with which they coexist, interact, and compete' (p. 5965).

Furthermore, AT's theoretical principle of history and development is another feature that allows design researchers to view users' activity systems as a changing entity and develop sustainable interventions that keep evolving with users' activity systems. For example, Bai & Guo (2011) suggested that a key factor in achieving system sustainability in eHealth solutions is allowing eHealth services to continuously evolve to integrate new users and applications into the system. In a similar vein, Viktorelius & Lundh (2019) used AT to examine the situated complexities that emerged in crew members' shipping practices by investigating how the existing energy operation may undergo a transformation process when a new energy monitoring system was introduced. The reflection from both studies showed that AT can direct design researchers' attention towards the dynamism of the targeted activity system that changes over time rather than viewing activity as a static frame. A summary of how the key AT theoretical principles are employed for guiding empirical analysis and design explorations in the included primary studies can be found in Table 7.

5.2. Theoretical implications: design for sustainable activity

As indicated in the preceding section, AT focuses on understanding the interaction between users and artefacts in a broader context: users' activity systems. Building upon this theoretical nature of AT, findings from this study reveal that when AT was used to analyse the causes of sustainability issues or evaluate the effects of sustainable design interventions, its unique strength lies in its capability to incorporate the complex spatial and temporal context of users' activity systems into the design process. More precisely, all the reviewed articles take the entire activity system, which comprises three dimensions as an integrated unit of analysis.

(i) The fundamental constituents of the activity system including subjects, objects and mediating artefacts.
(ii) The dynamic development and transformation of the relations between subjects, objects and mediating artefacts over time.
(iii) The relations between these constituents in different levels of analysis, including individual, collective and socio-cultural levels.

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Table 7. Activity theory's key theoretical principles and their applications summarized from the results of the meta-synthesis

AT's theoretical principles	Theoretical insights	Outline the causes for sustainability issues or inform sustainable design interventions	Evaluate the effects of designed artefacts/interventions on sustainability challenges
Mediating effects of artefacts	M-1	To inform sustainable design interventions that take both the internal and external mediating effects of artefacts into considerations	To envisage whether and how users might incorporate the proposed sustainable design interventions into their existing activity systems
Subject–object relationships	SO-1	To uncover the relations between the user's primary motives in an activity system and the corresponding sustainable or unsustainable actions and operations that the user performs	To assess how the proposed design interventions might be compatible with the user's existing motives and goals embedded in the targeted activity system
Tensions and contradictions	T&C-1	To reveal tensions and contradictions within and between different constituents of the user activity system and how these tensions and contradictions may affect the sustainability outcome of the activity	To investigate why interventions specifically designed to promote users' sustainable behaviour failed to achieve the intended outcomes To identify the contradictive motives and needs of different actors involved in the user's activity system and the influences on the sustainability outcome of the activity To identify the potential conflicts between users' existing forms of the activity system and their preferred sustainable forms of the activity system promoted by the design interventions
History and development	H&D-1 and H&D-2	To analyse how users cope with existing tensions and contradictions in their activity systems and how this can lead to potential opportunities for introducing design interventions To illustrate how the user activity system develops over time and what sustainability challenges may naturally emerge in this development process	To envisage whether and how the proposed design interventions may lead to desired or undesired changes in users' activity systems
Socio-cultural context	SC-1 and SC-2	To interpret users' needs in relation to the social, cultural and historical context of the targeted activity system To find a balance between user behaviour and the socio-cultural context for investigating the cause of sustainability issues	To investigate the effects of the proposed design interventions at the individual level while assessing how the interventions might be incorporated into the targeted activity system on a broader scale

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These three dimensions also indicate that AT treats design for sustainability-related challenges as wicked problems that are complex and keep evolving. Solving these problems would require a network of interrelated design solutions (Bennett, Cassim & van der Merwe 2017). In response to the dimensions presented above, a key insight extracted from our results is that the AT theoretical lens can enable design researchers to navigate their sustainable design solutions based on the following analytical perspectives:

(i) Mediating subject–object relationships in a sustainable direction.
(ii) Moving from focusing on static behaviour to dynamic activities.
(iii) Analyzing individual behaviour at different socio-cultural levels.

Furthermore, to highlight the unique theoretical contribution of AT lens, it makes sense to compare and differentiate the theoretical features of AT from the other theoretical lenses used in the field. As indicated in the introduction section, the field of DfSB is evolving. The widely adopted behaviour-based theoretical lens might not be sufficient to deal with the challenges that recently emerged in the field. Therefore, revealing the differences and overlaps between the two theoretical perspectives can allow us to better discuss the potential strengths and limitations that the AT theoretical lens might be able to bring to the DfSB field.

The behaviour-based lens explicitly focuses on analyzing the interaction between users and artefacts and the corresponding sustainable or unsustainable behaviour generated from the interaction (Tromp 2013; Kuijer 2014). As illustrated in Figure 5, the analysis is often conducted by first deconstructing a system into different elements (e.g., user behaviour and attributes of artefact) and then making inferences about the relations between a specific user behaviour and a specific attribute of the designed artefact (Jackson *et al.* 2005). The goal for design thus is either to promote a specific desired user behaviour or to change an undesired and unsustainable behaviour of the user (Niedderer *et al.* 2014). To achieve this goal, behaviour change models are adopted and adapted in design to help researchers and practitioners identify how relevant behaviour determinants can influence the targeted behaviour. Consequently, in some cases, it can be argued

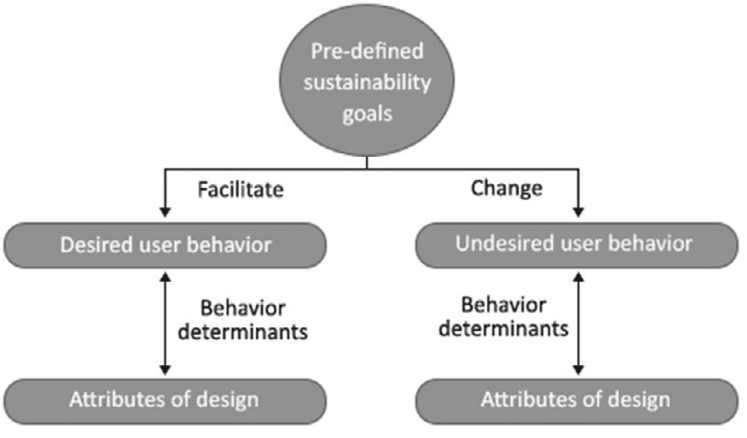

Figure 5. The focus of behaviour-based lens in DfSB.

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that it is these design strategies and techniques that are imposed on the artefact, rather than the design of the artefact itself, that creates sustainability effects on users' behaviour.

By contrast, according to Kaptelinin & Nardi (2006), when it comes to forming design solutions, an AT theoretical perspective often suggests that 'the attributes of individual components are of little consequence when the components are integrated within a higher-level unit' (p. 40). Building upon this argument, findings from this study also show that when AT is specifically applied to address design and sustainability issues, it views sustainability as a system property embedded in the complex socio-technical context of people's everyday life rather than an independent element or attribute added onto the designed artefact. It implies that the socio-ecological impacts of a product and service should not be oversimplified and interpreted as a sum of users' sustainable or un-sustainable behaviour. Rather, the human activity, that is, the need-based artefact-mediated interaction of users (subjects) with the world (objects), should be taken as the fundamental unit of analysis for design to understand and tackle the complex sustainability challenges. In other words, while the behaviour-based lens focuses on designing the attributes of an artefact in a way to adapt user behaviour to a set of specific pre-defined sustainability standards, the AT-based lens takes a bottom-up approach and asks: how the users' activity system can be improved by the design of artefacts towards achieving sustainability goals.

Note that despite the behaviour-based lens, the use of practice theory in Design for Sustainability studies has also gained increasing interest in the recent decade. A holistic comparison between the behaviour-based lens, the practice-based lens and the activity-based lens can be found in Daae (2014) and Selvefors (2017). However, given the primary scope of this study, we only intend to compare the AT lens with the behaviour-based lens. It is worth mentioning that the intention behind the comparison presented here is not to argue which theoretical lens is more applicable or useful. Instead, the goal of the comparison is to better discuss the potential strengths and limitations of AT. In this regard, Table 8 summarizes the differences and overlaps between the behaviour-based lens and the AT-based lens.

Table 8. Differences and overlaps between the behaviour-based lens and the AT-based lens

	Behaviour-based lens	AT-based lens
Unit of analysis	Sustainable/un-sustainable behaviour: Isolated and specific interaction between users and artefacts	Activity: Purposeful need-based interaction of users (subjects) with the world (objects) mediated by artefacts
Analytical approach	Deconstruct the user-artefact interaction into different elements, make inferences about the relations between specific user behaviour and specific attributes of the designed artefact	Understand why and how sustainability problems take place in the complex interplay between different components in an activity system
Artefacts' roles	Influence user behaviour	Mediating subject–object relationships in an activity system
Users' roles	Users of artefacts	Participants in activities

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5.3. Practice-relevant design implications regarding the use of AT theoretical lens in DfSB

Given the theoretical implications of AT for sustainable behaviour design presented above, in the following sections, we intend to translate the AT-based theoretical insights described in Tables 7 and 8 into practice-relevant design implications.

Mediating subject–object relationships towards a sustainable direction

In line with the theoretical nature of AT, results from this meta-synthesis confirmed that taking activity as the basic unit of analysis can help design researchers expand their analysis scope from users' behaviour generated in the interaction with single products or services to users' meaningful motive-oriented activities. Although users' interaction with specific artefact inevitably influences the sustainable or unsustainable behaviour of individual users, from the perspective of AT, such interaction is not the root cause of sustainability issues. Instead, many studies included in this meta-synthesis argued that the way how the subjects use different artefacts as mediating tools to fulfill their objects/goals is what lies behind the sustainability issues. To be more specific, as illustrated in Figure 6, how a user carries out an activity is governed by the needs and objects that the user has within the activity system. In most cases, multiple needs and objects may co-exist within the user's activity system (presented as need-a to need-c and object-1 to object-3 in Figure 6). A successful sustainable design intervention thus needs to aim to facilitate the user to couple a specific need with a desired sustainability-related object (see Figure 6). The study conducted by Selvefors *et al.* (2015) on people's energy consumption behaviour in household laundry activities can be used here as an example to better illustrate this argument. An individual may have different general needs such as wearing clean and dry clothes. At the same time, the individual also may have various context-specific objects such as limiting the time spent in laundry, reducing energy consumption during laundry, increasing comfort and reducing effort. A washing machine with a quick eco-draining mode thus may have a higher possibility to facilitate the user to effectively connect their needs of getting clean and dry clothes to the objects of reducing energy consumption and limiting the time and effort spent in laundry activities. Incorporating this insight with the theoretical implications on how to design for users' sustainable activity presented in the preceding section, we argue that if a sustainable design intervention does not fit into the needs and objects of the user's activity systems, it would only lead to limited desired sustainability effects on users' behaviour.

However, taking activity as the basic unit of analysis does not necessarily mean that users should be de-centralized in the design process. After all, the user-centered design (UCD) approach is what underpins the development of the DfSB field (Wever *et al.* 2008). In AT, Don Norman noted 'a deep understanding of people is still a part of activity-centered design. But activity-centered design is more: It also requires a deep understanding of the technology, of the tools, and of the reasons for the activities' (Norman 2005, p. 16). In other words, AT's theoretical principles of subject–object relationships and mediating artefacts suggest that a user is more than just an individual who use the designed artefacts, as illustrated in Figure 6, the user should be regarded as a participant in different activities which are socially constructed and developing over time (Williams 2009). Since products

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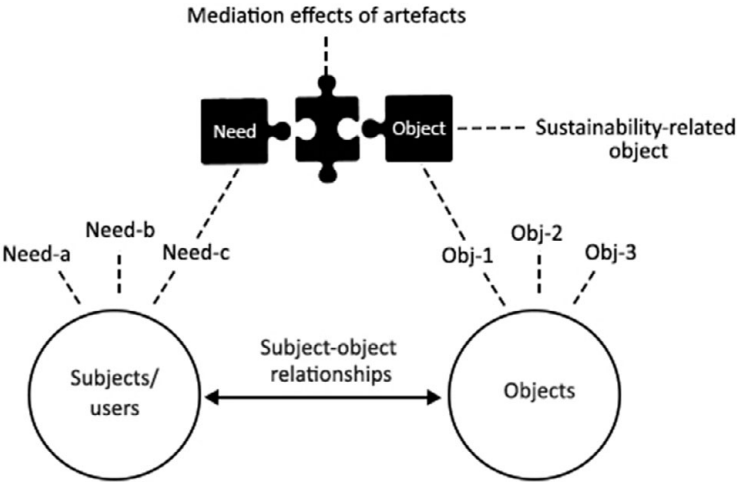

Figure 6. AT's view of mediating subject–object relationships towards a sustainable direction.

and services solely driven by user needs may end up in rapid obsolescence (Blevis 2006), AT's primary focus on activity might shed some light on balancing the relations between users' needs and sustainability aspects of the corresponding activity system. In summary, we suggest that AT can bring the analytical strength for design researchers and practitioners to:

Implication 1. Inform design interventions that take both the technological/functional aspects of design and the behaviour impacts on users into consideration, thus improving both the artefacts' performance and the user behaviour associated with the use of the artefact in users' activity system.

Implication 2. Incorporate design interventions into users' existing motives and goals in the targeted activity system, evaluate the extent to which the proposed design intervention might facilitate or constrain the users to attain their primary motives and goals in the targeted activity system.

Temporal lens: moving focus from users' static behaviour to dynamic activities

As mentioned in the preceding section, AT emphasizes the importance of understanding the dynamism of an activity system rather than viewing it as a static construct (Kaptelinin *et al.* 1999; Döweling, Schmidt & Göb 2012). In the view of AT, behaviour transformation often occurs when subjects attempt to find temporary solutions to address tensions and contradictions that emerged in the activity system. The transformation process does not follow a linear fashion; instead, it follows a cyclical pattern (Blackler *et al.* 1999). As tensions and contradictions manifest themselves in the activity system, subjects would then search for tentative solutions such as improvising the use of artefacts or adjusting the original objects and goals to solve these tensions and contradictions. The solutions that the subjects developed may also bring new tensions and contradictions to the activity system. Therefore, sustainability problems in an activity system cannot be fully understood without analyzing how the activity has developed into the present form. Since artefacts used in an activity system carry with them the socio-cultural knowledge of

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the past and also reflect the problems of the present (Kuutti 2011), insights generated from AT's temporal lens thus may help to inform design implications to address the long-term dynamic sustainability challenges embedded in people's activity system.

Looking at sustainable behaviour design from the temporal lens that AT offers, we suggest that a successful sustainable design intervention needs to co-evolve with the activity system. We suggest that AT's temporal lens can bring the analytical strengths for design researchers and practitioners to:

Implication 3. Investigate what sustainability-related problems and design opportunities may emerge as users cope with the existing tensions and contradictions in their activity systems. This understanding can help locate the appropriate window of opportunity for design to intervene in the targeted activity system.

Implication 4. When facing the window of opportunity, new motivations, along with new tensions and contradictions, may emerge as the design intervention is introduced to the existing activity system. A successful sustainable design intervention thus needs to consider its potential influences on both the present and the subsequent activities the user may carry out.

Implication 5. Explore design inspirations by learning from how the activity was carried out in the past.

Implication 6. Identify the potential conflicts that the user may encounter in the existing form of the activity and the anticipated more sustainable version of the activity.

Spatial lens: analyzing individual behaviour at different socio-cultural levels

The meta-synthesis results show that when used for addressing design ad sustainability challenges, the spatial lens of AT can enable design researchers to understand people's sustainable or unsustainable doings in real-life contextual settings rather than task-based laboratory settings. This theoretical feature provides two strengths for analyzing complex DfSB issues.

First, it positions individuals' behaviour in the higher level meaningful contexts of an activity system and connects individual users with other artefacts and other people in their socio-cultural contexts. As Kaptelinin & Nardi (2012) highlighted that 'individual human person does not disappear in AT; rather, this person is defined – through the principles of mediation, development, and internalization–externalization – indivisibly in relation to culture and other people' (p. 74), our results also show that individuals' sustainability-related motivations behind an activity system are often directly related to their socio-cultural contexts, making such motivations meaningful to the individual thus might facilitate the transformation of the entire activity system towards sustainability.

Second, the causes of sustainability issues are always interconnected across different levels: product level, product-service system, spatio-social level and socio-technical system level (Ceschin & Gaziulusoy 2016). In this respect, AT's spatial lens can help design researchers and practitioners to zoom in and zoom out to find the most appropriate level of analysis that fits the particular goal of each specific design project. At the same time, it also allows design researchers and practitioners to envisage and evaluate the potential impacts of the proposed sustainable design intervention beyond individual users at a broader socio-cultural level. In summary, looking at sustainable behaviour design from the

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spatial lens of AT, we suggest that AT can provide design researchers and practitioners the analytical strength to:

Implication 7. Identify the contradictive motives of different actors involved in the targeted activity system and their impacts on the sustainability outcomes of the activity system. Formulate sustainable design strategies that accommodate the needs and objects of different actors involved in the targeted activity system.

Implication 8. Zoom in and zoom out to analyse the sustainability impacts of the targeted activity system at different levels ranging from individual behaviour to socio-cultural contexts. Uncover how different components of the targeted activity system such as motives and the use of mediating artefacts link to the broader socio-ecological sustainability concerns.

Implication 9. Analyse the effects of sustainable design interventions at an individual level, at the same time, considering how the interventions might be incorporated into the targeted activity system on a larger scale.

Implication 10. Envisage how the proposed design intervention might lead to desired or undesired changes associated with the sustainability challenges at the individual, collective and societal levels in the user activity system.

Figure 7 provides a visual presentation of the three analytical dimensions and the corresponding practice-relevant design implications inspired by the AT theoretical lens. These implications have the potential to be used in designers' early-stage ideation process to understand empirical phenomena and generate initial sustainable design concepts that take users' dynamic and complex activity systems into account. Following the conceptual framework for generating sustainable behaviour-based intervention design developed by Lambe *et al.* (2020), we believe the theoretical and practice-relevant implications developed in this study can be useful to be applied in the first three stages of the sustainable design intervention process – defining the sustainability problem area, identifying the underlying causes of the problem and mapping the entire system.

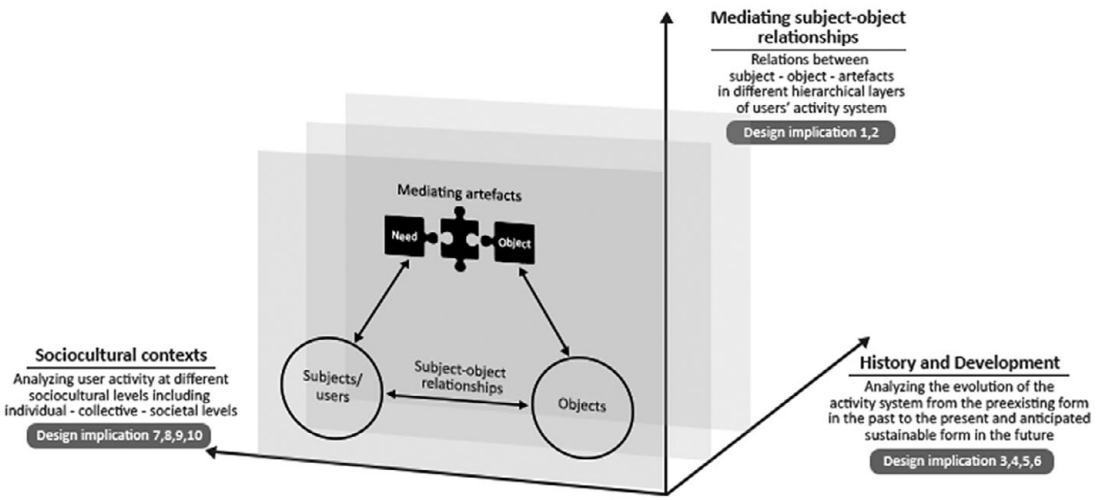

Figure 7. A visual presentation of activity theory's three analytical dimensions and the corresponding practice-relevant design implications.

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5.4. Limitations of the study

Some limitations of the study should be noted. First, in terms of the meta-synthesis results, 18 articles were included in the final synthesis stage. This sample size might be considered small; however, these articles were carefully screened and assessed based on a systematic selection process. Totally, 621 articles were identified in the initial literature search phase. They were later excluded in a rigorous literature selection process. The limited number of the included articles in a way reflects the rigidness of the study.

Second, in Section 5.2, when comparing an AT-based theoretical perspective with a behaviour model-based theoretical perspective, questions such as which theoretical perspectives are more effective when used for sustainable product and service design may arise. We hold the opinion that there is no universal answer to this question. Instead, it depends on the research scope and focuses of each design project. For example, if a project aims to improve the design of a specific artefact to change an un-sustainable behaviour, the behaviour model-based perspective would be more appropriate as it has a particular focus on identifying and addressing the sustainability problems caused by the interaction between the user and the specific attributes of the artefact. By contrast, if a project centres around how to shape or re-design the way that users carry out a specific doing in an everyday life context, for example, changing individual's unsustainable energy or food consumption doings or facilitating community's ecological actions, the AT-based theoretical perspective would be a more suitable candidate for guiding the empirical analysis and design explorations. Furthermore, the behaviour model-based perspective and AT-based perspective are not entirely incompatible with each other. Both theoretical perspectives originated from psychology and were later adopted and adapted in product and service design. More importantly, both theoretical perspectives are established on the user-centred design approach and emphasize the importance of understanding human-product interaction as the prerequisite for sustainable behaviour design. It may be interesting from a design research perceptive to explore the possibility of integrating these two theoretical lenses into one unified sustainable design strategy; however, it is out of the scope of this paper to discuss this point.

6. Conclusions and future work

This paper explores the use of AT as a potential lens for guiding empirical analysis and design explorations in DfSB studies. In doing so, we presented a meta-synthesis of design for sustainability relevant articles that draw on AT. We found that AT was employed in the included studies to (a) outline causes of sustainability issues and inform concepts of sustainable design interventions and (b) evaluate the effects of design interventions on solving the identified sustainability challenges. Furthermore, we found that a potential match between AT's key theoretical principles and their capabilities in solving current challenges that emerged in the field of DfSB do exist. Consequently, we proposed AT-based theoretical and practice-relevant implications based on our reflections on the analysis of the meta-synthesis results.

The present study contributes to the DfSB field by investigating the potential use of AT as a guiding theoretical perspective. The key message of the study is that shifting focus from user behaviour to user activity can enable design researchers to take activity as a unit of analysis and incorporate the long-term dynamic, multi-

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level and complex user behaviour phenomena into product and service design considerations. Furthermore, we find that three key theoretical dimensions of AT: mediating subject–object relationships, temporal lens and spatial lens are especially useful for supporting design researchers in better framing and addressing design challenges concerning users' sustainable behaviour in the context of users' activity systems. Finally, we summarized the abstract theoretical insights into ten practice-relevant design implications, which can be further developed into more concrete activity-centred sustainable design strategies in the future work.

Despite the rich theoretical nature and a potential match to solving the current challenges faced by the DfSB field, AT still provides little support for assisting designers in their real design practices. Therefore, we suggest that future work should investigate how to enable design practitioners with limited or no prior knowledge of AT to apply the theoretical lens in their design practices. More research is needed to better incorporate AT's theoretical concepts and principles into more descriptive design solutions. One option we are currently exploring is incorporating the AT theoretical and practice-relevant implications proposed in this study into a toolkit for designers to use in their early-stage ideation process. Following this option, the next step is to develop, test and validate a framework and a toolkit based on insights from some of our case studies which adopt AT as the main theoretical lens in DfSB.

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Competing interests

The authors declare none.

Supplementary Materials

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/dsj.2021.17.

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