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Theory as a Source of Software Requirements

Ruzanna Chitchyan
Woodland Road
Bristol,UK, BS81UB
email:r.chitchyan@bristol.ac.uk
orcid0000-0001-6293-3445

Caroline Bird
Woodland Road
Bristol,UK, BS81UB
email:caroline.bird@bristol.ac.uk
orcid 0000-0003-4318-7488

Abstract—Today, when undertaking requirements elicitation, engineers attend to the needs and wants of the user groups considered relevant for the software system. However, answers to some relevant question (e.g., how to improve adoption of the intended system) cannot always be addressed through direct need and want elicitation. Using an example of energy demand-response systems, this paper demonstrates that use of grounded theory analysis can help address such questions. The theory emerging from such analysis produces a set of additional requirements which cannot be directly elicited from individuals/groups, and would otherwise be missed out. Thus, we demonstrate that the theory generated through grounded theory analysis can serve as an additional valuable source of software system requirements.

I. INTRODUCTION

Requirements engineers are charged with the task of elicitation and specification of the needs and wants of the prospective software system users. The current predominant requirements elicitation methods are those based on agile methodology [1], [2], centred on the practical, incremental delivery of useful functionality, whereby the intended users actively participate in the formulation of roles and functions that the software system should support. This method ensures that the intended users are engaged with helping to define and test what the intended software will do.

The opposite side of active user engagement into the requirements elicitation process is comprised of ethnographic and observational methods [3], [4], [5], [6]. These methods underline a need for third party analysis for elicitation of tacit knowledge (i.e., knowledge that cannot be easily identified, conceptualised, or verbalised by those who possess it [7], [8]). While immensely rich in detail and context provision, these methods require prolonged situating of the researchers into the context of study, and often result in too large volumes of data which could be difficult to analyse and utilise within the constraints of a single software system development project.

As agile practice has taken root in software engineering, reliance on closer interaction with intended users, and their direct input for software system requirements elicitation has grown. The ethnographic and observational practices in SE have focused instead on explanation of processes and practices within development teams and ecosystems [9], [10], leaving it to the social scientists to engage with questions of societal practices and operation. Yet, given that the software systems are to be situated and operated within the societal fabric, requirements engineers are aware that societal concerns, norms,

and believes will drive additional requirements for the software system to be [11].

This paper presents the process which *accommodates elicitation of some of such societal requirements alongside the use case elicitation process*. The process emerged as we worked to elicit requirements for a new household energy management system, while also thinking about fostering wider adoption of this intended system.

To understand how to foster adoption, we drew on the Grounded Theory (GT) Analysis technique which helped us unveil how prospective users of a software system perceive their role within the socio-technical system facilitated by this software. We then observed that the Adoption theory that emerged from the Grounded Theory analysis motivates a set of additional socio-technical requirements which cannot be directly elicited from individuals/groups, and would otherwise be missed out. *Thus, this paper illustrates that a theory generated through grounded theory analysis can serve as an additional valuable source of software system requirements.*

Thus, based on the experience of the demand-side response (DSR) energy management system's study:

- We suggest that the theory building practice (through the Grounded Theory (GT) method) can be integrated into the requirements elicitation practice, and carried out alongside such established RE methods as use case elicitation. The Grounded Theory method provides a tool for theorising on the research question at hand, particularly when that question relates to systemic concerns. The validated theory (which explains the set question) can then serve as a source of new socio-technical requirements for the system-to-be.
- Our approach is not restricted to addressing one specific question. Instead, it provides a process for setting pertinent questions relevant to a given system. Nevertheless, as each question may require new data collection, the value of the answers must compensate the committed effort.
- We demonstrate the use of this process through a case study for an energy demand-side response management system. A number of such systems for business users are already in operation around the world [12], [13], [14].

The background concepts and related work for this paper are presented in Section 2. Section 3 reports on the study design and analysis. The study findings are presented in section 4. Section 5 discusses implications of the theory constructed

as part of this study to requirement elicitation. The lessons learned through this study are summarised in section 6, and section 7 concludes the paper.

II. BACKGROUND AND RELATED WORK

Our contribution to the research in RE is, thus, in using the GT analysis to form an inter-subjective theory that is of central interest to a software system-to-be, and *deriving new requirements due to this theory*.

A. Grounded Theory Method

Grounded Theory (GT) [6], [15], [5] is a method for qualitative analysis of data aimed at providing a systematised approach for constructing a theory about phenomena or a question of interest firmly grounded in (i.e., linked to) the collected data (e.g., via observations, interviews, reports, etc.). Here a theory "states relationships between abstract concepts and may aim for either explanation or understanding" [5] (p. 228). Briefly stated, the key notions of GT [6], [15], [5] relate to:

- Theoretical sampling: purposeful selection of sources and collection (i.e., sampling) of additional data for analysis which is expected to be relevant to the notions under analysis.
- Coding: the process of examining the data, breaking it down into small portions (e.g., from individual text lines to a few sentences) and assigning labels (called codes) to each portion.
- Constant comparative analysis: the codes are continuously compared/contrasted with each other, as they emerge when data is examined. As a result of this process, data is collated into conceptual categories, and links/relationships between the categories are identified. Unlike many other qualitative analysis approaches, there is no restriction on what themes/categories are considered relevant, so all emerging categories are acknowledged and considered. Throughout the analysis process, the reflections of the analysts are recorded into memos.
- Conceptualisation and abstraction: development of theories that emerge from the abstraction and review of the coding results and memos.

Presently there are three main strands of GT in practice, which differ substantially in philosophical worldview (e.g., objectivist [6] vs. constructivist [5]) and processes (e.g., could the researcher study the relevant literature prior to data analysis). A recent study by Stol and colleagues has proposed a set of good practice guidelines for GT in Software Engineering [16], suggesting that each study that uses GT should detail which specific strand it draws on and how it carries out data collection and analysis, as well as theory building and evaluation.

B. Use of Grounded Theory in Requirements Engineering

GT has already been applied in various areas of RE, but primarily as a tool for an abductive data categorisation. For instance, Sharma et al. [17] use GT to group functional requirements into categories, while Dupree et al. [18] use it to group stakeholders into categories to be represented as personas in privacy and security profile designs. Others directly utilise the categories that arise through GT analysis for software modelling. For instance, Wurfel et al. [19] first categorise the requirements data then map GT conceptual categories directly onto use case specifications, while Halaweh [20] builds an information model and a class diagram from GT conceptual analysis. Rashid et al. [21] use GT to integrate the reports of multiple similar security incidents into a single analysis and categorisation process, and (by learning from past incidents and constructing incident fault trees as part of the GT analysis) theorise as to how these security threats can be neutralised.

The above efforts demonstrate that GT analysis could be helpful for a number of RE activities: from structured stakeholder categorisation, to grounding use cases in interview data, and helping to model the information content. Yet, the key power of the Grounded Theory approach is in supporting *theory building* for explaining/understanding "relationships between abstract concepts" of interest. In requirements engineering the concepts and relationships of interest are, unavoidably, the socio-technical system and the in-situ interactions with the software system. Thus, where a *systemic question of interest* (i.e., a question that relates to a broad set of actors and their interactions within the given socio-technical system) is to be considered, we advocate use of GT to *theorise* about this question of interest and to *inform the system requirements through such theories*.

This differs from the widely used RE techniques in that a theory is constructed by the analyst (underpinned by the evidence from the empirical data): a) alongside the more established RE activities (such as use case elicitation), and b) with the explicit intention to use the theory to derive additional requirements for the system-to-be. This theory would aim at *elicitation of inter-subjective[1] tacit knowledge*, i.e., knowledge that the majority of the intended system users would tend to agree upon, if it were verbalised.

C. Energy Demand-side Response Management

Related work on energy demand management has observed that the "public wants and expects change with regard to how energy is supplied, used and governed." [22] Yet, while some scenarios of automated appliance government are acceptable (e.g., 78% of respondents accepted automatically turning off a TV from standby), the others are less so (e.g., only 30% of respondents accepted the idea of automatically turning off a fridge/freezer for short periods during the peak demand). Overall, the scenarios that allow householders some control are preferable and interventions that assist people in shifting their own energy use patterns are viewed positively. Yet, most

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[1]A valid theory can be derived for a small sub-set of the respondents as well. However, such a theory is unlikely to have good *resonance and usefulness* [5], i.e., have a significant impact on the overall socio-technical system requirements, as discussed in section VII.

elements of demand management are unfamiliar to the public and need explaining [23], [22].

Several studies have focused on understanding the factors that affect energy consumption at home. For instance, Jones et al. [24] identified 62 factors that affect energy consumption in households from an extensive literature review. These factors were related to 3 key areas, those most often repeated in (several) studies are:

- Socio-economic factors: e.g., more occupants, teenagers and higher income and disposable income all contribute to significant increases in electricity consumption. The presence of children or elderly people and education levels show no conclusive effect.
- Property factors: e.g., age and size (number of rooms, bedrooms and floor area) all contribute to increased consumption as does electric heating, electric water heating and air conditioning.
- Appliance-related factors show a clear effect in increasing consumption: e.g., the more appliances a household has, the higher is its energy consumption.

Boomsma et al. [25] categorised consumption by contexts: morning, evening, regular, important, most energy consuming, summer or winter.

Kavousian and colleagues [26] suggest that the daily minima of consumption is explained by constant factors (e.g., house size, numbers and type of devices), whilst daily maxima relate to the number of occupants and high-consumption intermittent-use appliances. It is suggested that there are four groups of factors affecting energy use: (i) external conditions (weather, location), (ii) physical characteristics of the building, (iii) appliance and (iv) occupant behaviour.

Others have studied the effectiveness of information provision to households on their energy consumption either through smart meters, or via in-house displays [27], [28], concluding that, by themselves, these are insufficient for motivating any action or change in energy consumption behaviours.

A study by Whitmarsh et al. [29] notes that the ability of households to change their behaviour in support of carbon reduction is limited, because carbon footprint (and hence, energy consumption) is not a driving force in everyday behaviours even when individuals are knowledgeable and motivated to act. Gabe-Thomas et al. [28] concur that the fact as to how much energy an appliance consumes is not at the forefront of householder's consideration when utilising an appliance; instead the domestic practices take priority. As noted by Shove and Walker [30], energy consumption is a by-product of the activities of society; "demand and the means to consume constitute each other", where means to consume include such things as grids, power stations, networks, and devices with which end-users engage.

In summary, it is evident that energy consumption is intertwined with the habits and preferences of households, the stock and capability of their appliances, the physical properties of their dwellings, and the social and personal values and norms. Given that the problem is inherently multi-faceted [31], it is necessary to provide a solution that tackles as many facets of this problem as possible.

III. DSR STUDY

A. Case study and Research Questions

This research was formulated through work on a case study of an energy demand-side response (DSR) management system. The study to design this system was commissioned for a DSR service trial by the Anonymous City Council (ACC), in Anonymous City and Country. The **overall brief** is that: to use this system users register their energy generation (e.g., roof-top solar PV) and consumption (e.g., washing machines, dishwashers, water heaters, etc.) assets with the DSR service provider. The service provider monitors the supply & demand conditions on the energy market and schedules the device runs when energy prices are most suited (e.g., run dishwasher at midday when renewable generation is in excess, and so energy prices are low). This system would be used by households to help reduce pressure of the peak time energy consumption (i.e., when consumption threatens to overrun available generation) and foster better use of the local renewable energy.

The system owners wanted to know: **RQ1: what did the households wish the system to do**. Moreover, they were concerned about reports of poor adoption of similar systems elsewhere [32]. Thus, they also asked us to consider **RQ2: what could foster better adoption of the intended system by the households?**

B. Study Design

As the present study required both understanding of the key functional requirements of the system (i.e., RQ1), as well as of the adoption considerations (i.e., RQ2), we opted for data collection via semi-structured interviews and co-design workshops which would allow for exploration of the both expected functionality (through use cases) and the contextual issues (through study of householders' routines and perceptions) of the intended system through the same data collection activities.

The study was structured into two cycles. In the *first cycle* an interview study was set up to collect requirements for use cases as well as build an initial theory [5] that would address the question on system adoption.

The grounded theory approach used in this study draws on work of Charmus [5] and guidelines by Stol et. al [16], whereby the *initial research question* for the study is set, but can evolve throughout the study. Although this research did not commence with a full *literature review*, the authors had previous familiarity with the literature of the DSR domain, most of which had focused on reporting how prospective users (or pilot study participants) responded to specific stimuli for DSR (such as time-of-use energy pricing, i.e., pricing based on time of energy consumption as opposed to the flat rate which is commonplace today; notifications of price change/high demand periods, etc.).

The interview was first piloted, then carried out as a full study. The results of the interviews were analysed and a set

of use cases as well as an initial theory to address adoption question were derived.

In the *second cycle* two co-design workshops were planned and executed to validate both the use cases elicited from the interview study and the *resonance* [5] of the developed theory (i.e., checking if the theory makes sense to the study participants).

The set of all data collection activities is detailed below:

1) Interview: Pilot Study: The interview study was piloted by two requirements analysts (see [33] for details). The interview questions were pre-piloted with 2 individuals, to check the clarify and utility of the set questions. The updated questions were then used for a pilot. Using *convenience sampling* [34], 7 interview participants (4 male and 3 female) were recruited from non-single occupancy households, as these households have a richer context of interactions around use of shared devices. The pilot study interviewees presented a mix of professionals (a lecturer, a researcher, an investment banker, a medical practice manager) and students. The number of interviews was limited to 7 due to the time constraint of the pilot study and available researcher time (4 weeks altogether).

All interviews were carried out in English and face-to-face, they were recorded, transcribed and analysed for both use case elicitation, and for grounded theory analysis.

The pilot validated the suitability of our data collection instrument and the process for both DSR requirements use case elicitation and for an adoption theory-building exercise. Most significantly, we trailed the objectivist [6] GT approach, and observed that our study constraints and context are best aligned with the constructivist [5] strand of GT. The pilot also helped us improve the structure of the questions by splitting them into a topic-specific sub-groups.

We noted that use of convenience sampling, threatened the relevance of the pilot study findings, as the stakeholder sample was too biased towards the university members, and not representative of the population at large. Yet, this is an acceptable trade-off, as the pilot was specifically aimed at the validation of the interview instrument as well as the refinement of the data analysis process.

Thereafter the full interview study was carried out.

2) Interview: Full Study: The full interview study was carried out with 28 households (with two interviews carried out with couples, the total of 11 male, 19 female) during November 2018-Feb 2019. The interview questions were split into 3 sections:

- Participant background details;
- Current practices of appliance and energy use;
- Responses to the idea of automation for energy management.

Interviewees were drawn from households that had received smart appliances from ACC as part of the smart city initiative (16 in total) and households with no direct relationship to ACC (12 in total). In the participant recruitment, an active effort was made to obtain a representative sample of participants, balancing for both demographic and owned/occupied property characteristics of the households. We stopped the interview process when no new significant use cases or code categories emerged from the last 3 interviewees (i.e., *theoretical saturation* was deemed achieved).

The participants' demographics are summarised in Table I (see column *Int*, short for Interview):

TABLE I
CHARACTERISTICS OF STUDY PARTICIPANTS

		Int	WS1	WS2
Gender	M	11	7	4
	F	19	4	8
	N/A			
Age	16-25	1		
	25-49	17	7	4
	50-65	10	1	3
	N/A		3	5
Income	< 25K	13	3	4
	25K-50K	10	1	1
	> 50K	5		1
	N/A		7	6
House Type	Semi/Detached	4		
	Terrace	20	7	3
	Flat	4	1	4
	N/A		3	5
Household Size	Single	4	2	3
	Couple	3		
	House-share	4	3	
	1 parent, adult kid	1	2	
	Couple, adult kids	3		1
	1 parent, young kids	4		2
	Couple, young kids	9	1	1
	N/A		3	5

Here too, as for the pilot study, interviews were carried out face-to-face in English; these were recorded, transcribed and analysed for both use case elicitation, and adoption related theory building (following the process validated through the pilot study). The collected data was analysed and a set of use cases and as well as adoption theory were formulated. These were further refined and validated through two co-design workshops and a questionnaire respectively.

3) Use Cases: Co-Design Workshops: Two, 2-hour long workshops were held in March and April 2019 with a total of 22 participants. Participant demographic details are shown in Table I (see columns WS1 adn WS2 for workshops 1 and 2 respectively). The workshops were used to validate the findings of the analysis from the interview-based data collection for the DSR requirements. Half of the workshop participants were also interviewees, others were recruited through the wider ACC smart city project or via a register of energy champions (a different pool of potential DSR system users from those recruited for the interview study).

The set of activities carried out at the workshops included:

- Co-designing a DSR automation system interface to accommodate the participants' personal routines and preferences (as previously elicited through interview study);
- Reflecting on how an energy management system might deliver maximum gains;
- Walking through the process of DSR sign-up and use;

- Discussing the use of rewards or savings for personal or community gain.

The activities were carried out in groups of 3-5 participants. Each group had an assigned scribe, responsible for taking notes of the discussions, although most activities also had accompanying forms to be filled in either individually or in pairs/groups. The notes from the workshop participants and the scribes were then collected and treated as supplementary materials to those of the interview transcripts, helping to validate/refute the suggested DSR requirements and design choices.

4) Theory Validation: Questionnaire: To validate/refute the resonance [5] of the proposed theory, a questionnaire was designed to seek agreement/disagreement with the premises of the theory, along with the justification for own opinions, from the intended users (see Appendix A).

The questionnaire was distributed for completion at the second (April) co-design workshop, as an additional activity. The demographics of the questionnaire respondents are presented in Table I (see column WS2).

Since the results of the GT analysis (as discussed in section IV) suggested that a key theme of the dataset was an expectation of business partnership, the more formal notion of a partnership in business organisation was drawn upon [35]. Thus, a partnership arrangement requires that:

- individuals contribute to a common goal or enterprise;
- pool resources (e.g., skills, money, etc.);
- share profit and loss (in accordance with terms of the partnership agreement).

The workshop participants were asked to explain (by completing a questionnaire) if and why, as DSR service users, they agree/disagree to committing to the above three points, though no reference to a formal 'partnership agreement' was made in the questions (see Appendix A).

It should be noted that the theory itself was not shared either with the respondents, or with the broader community to which the respondents could have access. Only the small group of 3 researchers knew what the theory was and how the questionnaire was related to it. The respondents were simply told that findings from previous data collection activity are being validated and there are no right or wrong answers, as the key aim of the exercise is to find what the respondents, as potential users of DSR, think with respect to set questions.

C. Data Analysis

1) Use Case Elicitation: To elicit the relevant use cases, the interview transcripts were analysed to identify the actors and their interactions with the intended DSR software expressed by the interview participants [36]. These were aggregated and summarised into a use cases diagram.

2) GT Analysis: As previously noted, this study used the constructivist strand of the Grounded Theory (GT) analysis [5], as the initial (broad) research question was set for the study and the researchers could not expect to objectively forget their previous knowledge of the DSR literature. The line-by-line text analysis resulted in a set of codes, during the initial coding stage (e.g., wash for immediate use, noise from washing machine, etc.), which were then integrated into a set of 8 main categories during the *focused coding* activity (these are: Practices, Appliances, Data, DSR Automation, Motivations, Concerns, Knowledge, Smart). The *theoretical coding* then helped to establish relationships between these categories and formulate a cohesive theory. While the detailed description of the theory derivation is not presented in this paper, the overview of the process as well as a subset of sample codes are summarised in Table II; the code book for main categories is available at [37].

D. Validity and Limitations

Given that this is a qualitative study, based on data obtained through interviews and co-design workshops, we do not claim that the findings (either of the use cases, or of the adoption theory) are generalisble beyond the scope of this DSR case study. Given that a GT results are grounded within the studied context and collected data, this is an expected limitation.

Although qualitative studies can be designed to validate the obtained results for a more general population (as indeed is our intention for future work), findings form such additional studies will not change the validity of the study for the given context.

While we have made a best effort to engage with a representative sample of participants for both the interview study and the workshops, it is only representative to the community living in the Anonymous city.

In addition, the pool of participants was limited to those who responded to our invitation, and we note that this may imply a certain self-selection bias, with those interested in energy management and energy efficiency coming forward more prominently. This concern, however, is mitigated to some degree by the fact that these are also the very same households that would likely taken on the intended DSR service.

To further the validity of our findings, we draw on the notions of data, investigator, method and theory triangulation [38]:

- for data triangulation [38] we reached out across both the *space* (i.e. areas of the city) where ACC had initiated the activities related to demand-side response project (16 households) and to those areas that are completely independent of this ACC initiative (12 households). We also ensured that the participants of varying demographics were engaged (see Table I) across 6 months period (4 months of interviews and 2 of workshops).
- for investigator triangulation two researchers worked on the GT coding and analysis, continuously double-checking and varying each other's work, and discussing and resolving disagreements.
- for method triangulation we used interviews, GT analysis, co-design workshops and a questionnaire, ensuring that both sets of outputs (i.e., the use cases and the adoption theory) had been addressed through two methods each.

- Finally, for theory triangulation we compared the derived theory against the independently published related work (see section IV-C).

IV. STUDY FINDINGS

A. Addressing RQ1: Use Cases

Fig.1 presents the summary use-cases diagram[2].

As expected, the use cases depicted in Fig.1 seem to suggest that the prospective DSR clients are interested in practical management of their devices through DSR software. Furthermore, several somewhat unusual use case are also identified, such as *Foster Social Interaction*, which captures the respondents' desire to interact with like-minded individuals outside of the software sphere, or *Set Shared Goals* (a sub-goal of *Set Goals* not shown in Fig. 1).
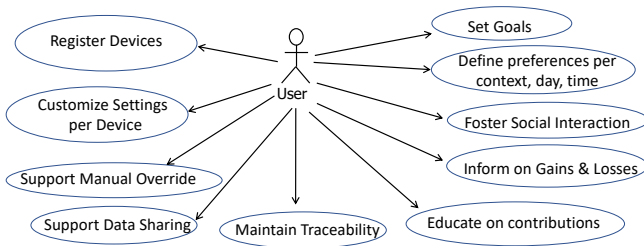

Fig. 1. DSR Use Cases.

In *cycle 2* the above identified use cases were discussed with the prospective users as part of the co-design workshops. The users were asked to walk through their most recent instance of a smart appliance use as well as their customary use of appliances (which could differ from the last specific use instance). They were asked to explain why it was used at a particular time, in a particular way and how they would be able to manage their preferences and practices given the suggested outline DSR preference setting designs for automation. They also walked through the issues that either currently or potentially may prevent or complicate use of DSR for themselves; and discussed how DSR automation could support them.

The groups identified a number of relevant refinements to the proposed use cases (e.g., need to define more than one preferred slot for appliance use, need to differentiate between individual days of the week, ability to set default preferences, etc.), but the overall set of use cases was considered both relevant and appeared to cover all the expected needs. Thus, this addressed the RQ1 set out for the present study.

Yet, this view of the software system did not provide specific perspectives on whether or not the DSR service would be well adopted by the intended users.

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[2]Most of the use cases are to be refined into specific sub-use cases, e.g., *Inform on Gains and Losses* would include *Propose Alternative Settings*, and *Report Per-month Consumption*, *Set Goals* would include *Set Personal Goals*, and *Set Shared Goals*, etc.

B. Addressing RQ2: Theory for DSR Adoption

The theory derived from the users interview and feedback analysis suggests that the key theme that relates all other key categories is that of implied business *Partnership*, as illustrated in Fig. 2.
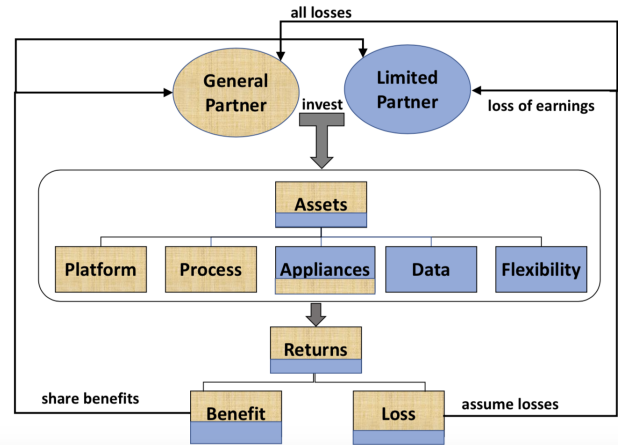

Fig. 2. Partnership Theory of DSR

The **Theory of DSR Partnership** suggests that: *The Prospective DSR-participant households have a set of Assets (such as appliances, data, flexibility of own practices/routines) which they could consider contributing towards the DSR Business, if a 3rd Party (which satisfies qualities and processes expected by the households) provides a DSR platform and a risk/benefit sharing agreement. In this agreement the selected 3rd party will act as a General Partner of a business, while each participating householder will be a Limited Partner.*

The *Assets* include both physical (e.g., energy generation and consumption appliances, such as PVs and washing machines) and non-tangible resources (such as data on energy use, processes to be followed, etc.). Thus, the concept of Assets integrates the categories of Appliances and Data, DSR Automation along with (sub-categories of) Smart (which together make up the Platform), as well as Practices (as the Flexibility of Practices is a necessary asset for feasibility of the DSR service). Furthermore, a number of sub-categories from Knowledge (e.g., provision of information), Concerns (e.g., loss of control; accountability), and Motivations (e.g., sharing information) form the Process category under the Assets group in the partnership theory, as processes would be expected to be put in place to address the issues raised by these sub-categories.

The Assets are used by the General and Limited partners to generate Return upon their investment. The *Return* (which is differentiated as *Benefits*, constituted primarily from the sub-categories of the Motivations category, and *Losses* which includes many of the *Concerns* sub-categories) is shared by the partners, in accordance with the partnership agreement. However, the Limited Partner only incurs losses of prospective earnings, if the business fails to generate income (as his/her losses are limited to what she/he has invested and/or agreed to

TABLE II
GROUNDED THEORY ANALYSIS EXTRACT: DSR SYSTEM

Initial Coding Eg.	Focused Coding Eg.	Theoretical Coding Eg.
filling machine: "...we always try to pack it as full as possible..."; *wash for immediate use*: "There's some stuff in the laundry that I'd like to wear today or tomorrow";	**Appliances/**Washing machine/ Practices of washing/ filling machine **Appliances/**Washing machine/ Practices of washing/ wash for immediate use	Householders possess a set of appliances, which they have invested into both financially and in terms of learning and getting used to time and effort. They have developed a set of *Practices* around these *Appliances*. The *Appliances* can generate *Data*, which is also important to the Householders.
doing good: "if the main aim is to save energy, it's about doing something good"; *financial gain*: "And save me money."); *data ubiquity*: "...everybody has got our data anyway!"	**Data/**acceptance Data/acceptance/financial gain **Data/**acceptance/data ubiquity	Householders have *Appliances* which generate *Data*; the householders are supposed to be the owners of the data, but many are aware that their data is passed on and used by 3rd parties. Some householders are willing to share this data for common good (such as minimising environmental impact from energy use, but others are worried about privacy and security, and see use of data by *3rd party* as a *loss* to themselves.
loss of control: "...you're kind of losing control over what it's doing"; loss of convenience: "...would make life slightly less convenient or comfortable"; damage to appliances: "if I had sort of assurances that it wasn't going to wear out the appliances"	**Concerns/**loss of control **Concerns/**loss of convenience **Concerns/**damage to appliances	While considering use of automated control of their *Appliances* by a *3rd party*, the *householders* foresee a number of *losses* that they are likely to incur. The different types of losses are relevant to different degrees to different households, but they all would be deterred from engaging into the DSR if these perceived losses were not perceived to be compensated for by some *gains*.
reduced cognitive load: "just get it done at some point in the next few hours" *efficient use of resources*: "this is a more efficient use of energy. Can't really object to that."	**Automation/** acceptability/ benefits/convenience/ reduced cognitive load **Automation/** acceptability/ benefits/ efficient use of resources	Householders see *DSR automation* as a process that can lead to both *benefits* and *losses*.
energy consumption: "could do more awareness around you know, energy use on a machine" *personalised advice*: "maybe sort of tailored to you, rather than just random"	**Knowledge/** energy consumption **Knowledge/** personalised advice	Households would like to learn more about the impact (both in terms of *gains and losses*) that the *DSR Automation* would have on their activities, environment, grid as a whole and alike.
not technical: "I'm a bit more low tech man." *flexibility*: "I don't mind really as long as it's safe "	**Practices/** beliefs /energy consumption **Practices/** flexibility	Householders follow a number of own *Practices and routines* which are dictated by their work/life timeline, habits and preferences. Some of these cannot be changed, but some *Practices* can be adapted, if the householders are willing to do so. Change of *Practices* requires effort and sometimes investment

in accordance with the partnership contract), while the General Partner will assume all other losses. The gains from the DSR service are also shared by the partners, in proportion to the investment and risks assumed. Both the General Partner (i.e., the DSR service providing business) and the Limited Liability Partners (i.e., each household participating in the DSR service delivery/use) contribute their own assets. The assets can also be both separately and jointly owed. For instance a PV array can be owed by a group or households, or be co-invested into by a household and the DSR service providing business.

As noted above, this theory was checked for *resonance* through a dedicated questionnaire which asked the prospective DSR participants if they feel that the households and the DSR services providers:

- would be contributing to a common goal or enterprise, and
- would be pooling resources (e.g., skills, money, etc.)
- should be sharing profit and loss.

Table III summarises the responses (note, not all participants responded to all questions), demonstrating that at least two thirds of the prospective users would expect to have the partnership relationship with the DSR service providers, not

just act as simple service consumers. This demonstrates that the theory has a good resonance (i.e., makes good sense to the substantial majority of the study participants).

TABLE III
RESPONSES TO PARTNERSHIP THEORY VALIDATION

	Joint Goal	Pool Resources	Share Profit/Loss
Yes	8	8	7
No	4	3	3

The general sentiment of the respondents can be summarised by the statement of one respondent that "People buy ideas not products. So potential users need to have bought into the mission of the ... service provider".

This is in conformance with the theory itself, as participation in a DSR service does mean that the households:

- agree with the need to manage energy demand (either for financial, environmental, or other reasons);
- are willing to make some up-front investment, to either buy smart (i.e., externally controllable) appliances and/or generation/storage equipment, or invest time and effort

for setting up appliance user preferences, or adjusting own routines and practices etc.;

- are, at least implicitly, sharing in gains and losses of the DSR service provider, as if the service provider goes out of business, the (time or financial) investment that households planned to recoup through DSR savings will not materialise either.

We must underline that the questionnaire respondents that did not say "yes" to the resource and profit sharing options of the partnership theory, did not actively disagree with these premises. Instead they pointed out that the set questions were somewhat simplistic since:

- a service user is likely to have more than one goal (while the question in the set questionnaire was formulated in terms of one single goal);
- any sharing needs to be guarded by privacy concerns;
- the service users must be protected against the service provider passing his/her losses onto the citizens.

These points were integrated into the *theory review*, which was updated to account for the *"limited liability partnership"* type (as presented in Fig. 2), instead of the full partnership theory where equal liability would be normally expected. The privacy concern, as well as ethical behaviour, accountability and other principles of behaviour that the households expect of the prospective service provider partner, had previously been identified to be a part of the theory. However, for the sake of keeping the key message of the validation exercise simple, these additional parts, were not integrated into the questions asked for theory validation.

C. Comparison to Related Work

Though, to our knowledge, no previous research has undertaken a study of a DSR adoption with grounded theory analysis, others have trialled DSR services.

For instance, Buryk et al. [39] worked on a 3-week trial to determine whether disclosing the environmental and system benefits of dynamic tariffs to residential customers could potentially increase their adoption, thus, helping to shift consumption to more opportune times. The trial included 160 residents in US and EU out of which 88 received information on environmental and systems benefits from dynamic tariff use, while the rest did not. They found that the respondents strongly preferred environmentally-friendly energy consumption and supply mix, and were willing to switch to a cleaner supply, even if it was up to 10% more costly.

These findings are in line with the sentiments categorised under the Motivations/environmental theme in our study. Indeed, many study participants observed that their interest in DSR is driven by the environmental concerns. Yet, we also observe that the socio-economic circumstances of the respondents have a significant impact on their willingness to take on additional costs. Participants with lower annual incomes were unwilling and unable to incur additional costs. Thus, we consider that the limited liability partnership, which guards those most stressed financially against any losses, while allowing those more able to assume financial risks to take additional challenges on, is well suited to these circumstances.

Buchanan and colleagues [40] first ran a workshop to develop concepts for smart meter enabled services and then conducted focus groups to explore consumers' perceptions of how smart meter data can be used to provide services. They considered 3 options: automation of appliance use, community rewards for disciplined use of appliances, and gamification as motivators for peak avoidance and use reduction. They found that automation was consistently the most preferred concept. Participants realised that the proposed system offered them different choices about if and when they would like the system to control their household appliances. Community reward schemes were not very liked, participants stated they would rather receive money off their energy bills than contribute toward paying for a collective benefit. Gamification was not popular, as participants did not have the time to commit.

Our findings concur that automation is a preferred solution to DSR service provision (as indicated by the DSR Automation and Smart themes of our GT analysis, and the Assets category within the Partnership theory). While we did not address the notion of gamificaiton at all, we did observe the concerns about additional cognitive load and time requirements emerging from our respondents as well. Automation, however, was considered as a viable and necessary solution for handling the additional complexities of the DSR service use. With respect to community vs. individual rewards, we observed a split, whereby 2/3 of respondents were willing to fully or partially contribute their gains to the community cause (e.g., a common battery storage, a community playground, etc.), while 1/3 preferred to keep the additional income to themselves. We noted that the requirements that emerge from the proposed Partnership theory (see section D) advocate for goal setting, allowing each limited liability partner to choose which goal he/she will aim for: from own income maximisation, to environmental impact reduction. Thus, we consider that our findings are aligned with those of Buchanan et al. [40].

Customer experience of demand side response with smart appliances and heat pumps is studied in the trial by Capova and Lynch [41] for a small sample of houses in Durham. Here none of the participants believed that the direct control of the service provider over the appliances had any influence on their decisions about when to do the laundry. All participants thought that they had not changed any of their previous washing regimes.

These findings, again, are compliant with our proposed Partnership theory, which suggests that the DSR model would be successfully adopted if the contributions of the Limited Liability Partners are acknowledged, supported, and appropriately rewarded. The DSR provider simply is not able to take a direct control over the necessary Assets for the successful operation of the DSR service, as the Flexibility, Appliances, and Data remain under the householders control. Thus, unless the householders are motivated to participate in the DSR business venture, the venture cannot succeed.

V. Implications for Requirements

Thus, as previously discussed, both the use cases and the partnership theory for the DSR system were found relevant and valid by the validation workshop participants. What then does this imply for requirements of our DSR system?

Clearly, the set of use cases reflects the core functions of practical utility that the DSR system should deliver. Yet, the relevance of the partnership theory to the prospective DSR system users implies that a number of **new requirements must also be considered**, if the DSR service is to be widely adopted by these prospective users. Such requirements would be motivated by the theory, such as, for instance:

- *Support setting of shared goals between the DSR service providers and the service subscribers*. There could be several goals set (such as Maximise financial return, Maximise use of renewable energy, or Minimise environmental impact, etc.). A participant could choose to join and support one or many of these goals. Each such goal will require a particular DSR scheme design.
  Also, the shared goals between the service provides and the citizens could differ from the goals that the citizens want to set and share with other users (e.g., local or other communities), as noted in the elicited use cases (see Fig. 1). Thus, an additional consideration is to be given to the way that these groups of goals would coexist within the DSR system.
- *Explicitly acknowledge, support and encourage various modes of resource sharing*. E.g., A prospective DSR customer may not have an own smart device, but may be willing to contribute own Data and Flexibility, should the service provider (as a general partner) (co-)invest into a smart device with this customer. Similarly, the appliances (e.g., PV arrays, batteries, etc.) that participate in a DSR may be a shared resource of a number of customers (e.g., common investment by a block of flats in a given building). Sharing of other (non-tangible) assets, such as good practice, tips and success/failure stories should also be recognised, attributed and supported across the DSR user communities and with the service provider.
- *Integrate profit and loss sharing scheme into the DSR service provision contract*. This should recognise that prospective customers will undertake varying degrees of risk (e.g., relying on service provider's funds for devices, vs. investing own funds into device purchase, etc.) and so should receive varying degrees of return to investment.

More importantly, this partnership theory not only brings up a number of new requirements to the software system, but also **changes the framework** within which the DSR service provision business would successfully operate. For such a business to align with the expectations of the partnership theme, it would need to consider a new legal framework, a fresh process for customer relationships management (as what traditionally was a customer now becomes a business partner), and a rather different business model for service provision as well. All in all, the business and the software system that would deliver DSR service and comply with the partnership theory would hardly be confused with the one that would be delivered only with the use cases functionality of in Fig. 1.

Thus, our two research questions, while separately addressed, must be integrated from which new requirements must arise for the success of a DSR system.

VI. Lessons Learned

A. Interdependence of theory and software requirements

We commenced this study expecting to report on requirements for a DSR system design (as per RQ1, for which use case elicitation was to be carried out), and suggest strategies for fostering adoption of this system by the prospective users (as per RQ2, for which a theory of adoption was to be derived). Yet, as we progressed with the study, it became apparent that these two objectives (and research questions) are closely interdependent, and one cannot be addressed without the other. In particular, adoption success not only depends on the useful functionality delivered though the system, but also imposes a set of deeply transformational functional and non-functional requirements upon the target socio-technical system (as discussed in section V).

Furthermore, we note that this observation is not unique to the adoption question which happened to be posed in our case, but is equally relevant to other issues related to the broader socio-technical system within which the intended software system is to be situated.

B. Integrated RE process

We further observe that the process used for our study is well suited for constructing theories for explanation and understanding of various socio-technical concerns, as well as informing the relevant software system's requirements and constraints. This process is therefore represented in Fig. 3. The process starts with **selection of a key question** to address, which is deemed relevant to (most) stakeholder groups. For instance, in our study of demand-side response energy management system, the question of adoption was set as the key issue to be studied. This is because successful adoption (i.e., widespread acceptance and use of the system) is dependant on the majority of all kinds of intended users taking the system up, which still remains a challenge for DSR systems.

In order to address the key question, a set of input data is to be collected, for which a suitable **data collection instrument** needs to be designed. The instruments will vary depending on the set question. For instance, to collect the data for the above set question, we could undertake interviews with the intended system users, and/or run focus group, co-design workshops, user observations, and so on.

Once the instruments are designed, **data collection** would take place. After which, the collected **data** would be **analysed** using the integrative GT process of data coding. As part of the analysis, the initial theories about how the set question can be addressed would be formed. This could then necessitate new data collection and analysis cycles, as additional data collection instruments would need to be designed and new data
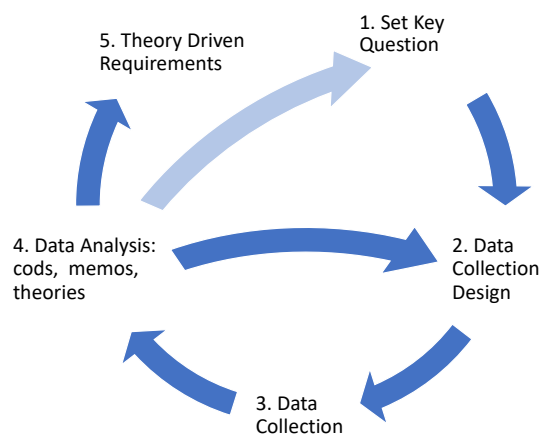
Fig. 3. Method Used

collected in order to provide the missing information and/or validate or refute the initial theories.

As a satisfactory theory is developed, the theory will then serve as the basis for new **theory-driven requirements elicitation**.

It must be noted that the theory building, or the theory-driven requirements do not replace the "usual" requirements engineering process, but only augment it with an additional activity, aimed to identify the additional requirements for the noted key question.

Moreover, given the integrative, cyclical nature of data collection, analysis and theory development/refinement, we propose that this version of GT analysis could align well with some agile development cycles. Study of such an integration is one of the main directions of our future work.

C. Cost of Theory Development

The overall process of integrated use case and theory development which serves as a new source of requirements was outlined in section VI-B. While this paper presents a theory of a DSR adoption, the process is not restricted to addressing this specific question. Any other question pertinent to the concerns of the socio-technical system can be posed and addressed through the same process. Yet, as addressing a set question requires both data collection and analysis, the value of the answers expected from this process must compensate the committed effort.

VII. CONCLUSIONS

In this paper we report on our experience of a DSR system requirements elicitation and socio-technical theory development, which led us to recognition that a theory itself must serve as a source of (software) system requirements.

Charmaz [5] suggests that to evaluate the developed theory, one should consider

- *credibility*, e.g., has sufficient data been collected, was the appropriate process followed, etc.?
- *originality*, i.e., does the theory offer any new insights?

- *resonance*, i.e., does the theory make sense to participants?
- *usefulness*: does the theory offer useful interpretations?

We addressed the *credibility* criterion by undertaking data collection until the theoretical saturation of category generation was observed, and followed the good practice guidelines [16] in undertaking and presenting the study process and product (see section V).

We address the *resonance* criterion by validating the developed theory with participants (see section IV-B), as well as comparing the findings with the related work reported in literature (see section IV-C). In both cases, we find that the Partnership theory is both acknowledged as relevant by the prospective DSR participants, and that it also aligns with the findings of researchers working in the DSR domain.

We address the *originality* criterion by considering whether the developed theory noticeably changes the requirements of the socio-technical and software systems-to-be (see section V). Here we find that integration of the requirements driven by the Partnership theory not only substantially expands the software system requirements, but also completely re-shapes the socio-technical system within which the DSR software-to-be would operate. To point out just one of the change impacts: here the notion of DSR customer is completely changed, with each household acting as a business partner within this massively distributed, multiparty DSR business model.

Finally, to consider *usefulness*, we ask if the proposed theory proposes a useful answer to the question set forth for its development, i.e., *What could foster better adoption of the intended system by the households?*. On one hand, this theory can be seen as very useful indeed, as it provides a set of actionable requirements that drive a new kind of socio-technical system; also our partner energy companies are very interested in it. On the other hand, real usefulness of this theory can be observed only when the socio-technical system emerging from its operationalisation is implemented, and its results compared to those of more traditional DSR systems. This, however, is presently a long way away.

As it is, we summarise that a good theory (in terms of the above evolution criteria) will, likely, also be a good source of new requirements for the relevant socio-technical system.

VIII. ACKNOWLEDGEMENTS

APPENDIX

Questionnaire to validate the Partnership Theory

In order for this energy management system to function well, do you think...

- You/households need to have any common purpose with the energy management service provider? (Yes/No) What is the common purpose?
- You/households need to share skills (e.g., how to optimise time management of own devices) / resources (e.g.,

access to devices) with the energy management service provider? (Yes/No)

What are the skills/resources?

- You/households need to share in the ups and downs of profit/loss from the energy management service? (Yes/No)

Please explain: why?

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