# Embedding IoT in Large-scale Socio-technical Systems: A Community-Oriented Design in Future Smart Grids

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**Abstract** In traditional engineering, technologies are viewed as the central piece of the engineering design, where the physical world consists of a large number of diverse technological artifacts. The real world, however, also comprises a huge amount of social components – people, communities, institutions, regulations and everything that exists in the human mind – that have shaped and been shaped by the technical components. Smart urban ecosystems are examples of such large-scale socio-technical systems that rely on technologies, particularly IoT, within a complex social context where the technologies are embedded. Despite that the two aspects are deeply intertwined, designing applications that embed IoT in large-scale socio-technical systems is slowly transitioning from a traditional engineering approach towards a socio-technical approach. The latter has not yet entered the mainstream of design practice. In this chapter, we present our experience of adopting a socio-technical approach in designing a community-oriented smart grid user application. The challenges, implications and lessons learned are discussed. The chapter is concluded by offering a set of good design principles derived from this experience, which are also relevant to the design of other smart urban ecosystems.

## 1 Introduction

The traditional science and engineering philosophy is dominated by technological determinism, the idea that technology determines societal development [15, 19, 23]. Within this reductionist view, technologies are the central piece of the engineering design, where the physical world consists of a large number of diverse technological

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artifacts. The plausibility of this view is challenged by the socio-technical systems view [24] which argues that technological and social development form a “seamless web” where there is no room for technological determinism or the autonomy of technological systems [5]. The latter view is premised on the interdependent and deeply linked relationships among the features of technological artifacts or systems and social systems (i.e. the mutual constitution) [19], since the man-made world also comprises a huge amount of social components – people, communities, institutions, regulations, policies and everything that exists in the human mind – that have shaped and been shaped by the technological components [8, 24]. Engineering design is hence identified as a process through which technologies materialize into products, a process that substantively shapes and reshapes our lives and societies and vice versa [11]. This focus on socio-technical interconnectedness becomes even more visible in designing new emerging technologies [11].

Smart cities, for example, use technologies such as Internet-of-Things (IoT) within a large complex social context where they are embedded. The goal is to facilitate the coordination of fragmented urban sub-systems and to improve urban life experience [6]. The rise of the IoT has important socio-technical implications for people, organizations and society – it is obvious that connecting devices is possible, we yet know little about its implications [21]. A socio-technical perspective can be insightful when looking at dynamic technological development and when considering sustainable development [21]. Although socio-technical systems have been studied for decades, socio-technical approaches are relatively new to the design and systems engineering communities [3, 17, 19]. Such approaches are not widely practised despite growing interests [3].

Through this chapter, we review the literature and present our experience of adopting a socio-technical approach in designing a community-oriented smart grid user application. We discuss the challenges, implications and lessons learned from this design experience, and conclude the chapter by offering a set of good design principles which are also relevant to the design of other smart urban ecosystems.

## 2 Designing in Large-scale Socio-technical Systems

The term “socio-technical” embodies both a research perspective and a subject matter [13]. The socio-technical systems view can be articulated as the recognition of three fundamental concepts [19] as follows. First, the *mutual constitution of people and technologies*. This mutual constitution generates complex and dynamic interactions among technological capacities, social norms, histories, situated context, human choices and actions, etc. Second, the *contextual embeddedness of the mutuality*, where the context is not taken as fixed or delineable. There are dynamic situational and temporal conditions that influence mutual adaptations throughout the course of design, development, deployment and uses of the system of interest. Third, the *importance of collective action*, the joint pursuit of one or more shared (potentially conflicting) goals by two or more interested parties such as problem owners, shareholders, users, communities affected (without implying positive or negative outcomes). The collective action shapes and is shaped by both the context and the technological components.

Researchers who hold a socio-technical systems view investigate more than just the technological system or just the social system or even the two side by side, but also the phenomena that emerge when the two interact [13]. A socio-technical approach tries to abstain from oversimplifications that seek a single or dominant cause of change, but studies the complexity, dynamic and uncertainty in the networks of institution, people and technological artifacts in the process of technologically involved change [19]. Taking a socio-technical approach towards design has a number of implications for (i) the formulation of the design problem, (ii) the products of the design process, and (iii) the design process itself (BootCamp, BC?).

Then the section proceeds with discussing the three implications (1) making relation to the three fundamental concepts (2) using the literature mentioned (can be expanded) in the next grey box

**Understanding and formulation of the design problem or situation** The understanding and formulation of the design problem

It is not straightforward what needs to be taken into consideration in relation to the design. What systems boundaries to choose. the question of systems boundaries is an issue for technical systems and even becomes more difficult for social technical systems what are the issues to be addressed.[BC]

Ill-structured problem

**Products of the design process** these not only consists of technological artifacts but also may include rules for behaviour, policies, etc. through which the designer wish to intervene in social-technical systems. what is it that we are designing?

**Design process** The design process can be seen as a decision-making process where the problem owners, shareholders, users, etc. participate to represent their interests. It is often conceived and implemented in participatory decision-making processes actively involving stakeholders

Large-scale socio-technical systems are often not designed as a whole but incrementally "piece by piece" evolving from legacy systems (BC). Designers are therefore working *in* the context of some socio-technical system with the intention of changing or improving some part of that system [BC]. This means that what matters more in the design is the design process itself, more than the "final status" of the system [21, **?**] because the socio-technical system keeps evolving and exhibits emergent behaviour [16]. An important goal of the design process is to make the design (a product or system) relevant to the evolving context [21, **?**] as social and technical artifacts exist within their socio-technical context [BC].

can be put in the discussion: acontextual and detemporalized perspective approaches , general solution ., is self-limiting focus on situating work and seek to examine all contextual factors , this types of inquiry attempt to construct a holistic view of context: one that does not diminish or remove contextual elements, even those with limited influence. paying little attention to the environment of the organization and temporal dimension of technological innovation [19]

Use and combine content in: (the literature can be connected, e.g. problems mentioned in Norman and Baxter can be mapped to the four layers in Whitworth )

1. [17] (design problems in large-scale socio-technical systems) and
2. [3] (socio-technical approach to systems engineering)
3. [28] (four system levels of Socio-tehnical systems);
4. [21] (a very good article about IoT, socio-technical perspective )
5. see also https://medium.com/rettigs-notes/notes-on-sociotechnical-systems-design-178f161bc9e8

## 3 IoT for the Smart Grid

The term Internet of Things (IoT) was coined by Ashton in 1999 [2] while introducing RFID technology in the context of supply-chain management. The meaning has evolved during the past years. International Telecommunication Union (ITU) defines IoT as the worldwide network of interconnected objects uniquely addressable based on standard communication protocols. While the Internet has led to the interconnection of people at an unprecedented scale, the IoT is expected to interconnect also the objects around us, leading to a smart environment [7].

On the most general level the IoT can be divided into three following layers:

- comprehensive sensing (perception layer),
- reliable transmission (network layer), and
- intelligent processing (application layer).

Another term that is often used interchangeably with IoT is *ubiquitous computing* coined by Weiser [27]. Ubiquitous computing is defined as “the physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network" (ibid.). While the IoT describes connected devices, ubiquitous computing focuses on the smart environment in which computing is pervasive. Hence, the two terms take a different stance and focus on different aspects of what is envisioned to become the Future Internet. The vision put forward by Weiser [27] led to a fruitful new field within computer science (ubiquitous computing). However, 15 years later, Rogers [18] offered a constructive critique of this vision. Namely, Rogers argued that we should switch from a computing approach to a human approach in developing the smart environment. In particular, the original vision suggested that ubiquitous computing can lead to an environment that is predicting and adapting to the people's needs, while the people were considered passive elements. Rogers argues the opposite: "To make this happen, however, requires moving from a mindset that wants to make the environment smart and proactive to one that enables people, themselves, to be smarter and proactive in their everyday and working practices."

Yun and Yuxin [1] discuss the possibilities of the IoT to bring about the *smart grid* through sensors, novel telecommunications and computing technologies. The sensors, such as smart, temperature, and illumination meters, collect energy and environmental data. They can also form a high-speed, real-time and bidirectional connection between the consumers, utilities and the electrical grid. It is envisioned that such an improved data collection and communication can support the decision making and in turn improve the overall efficiency of the grid. Interestingly, the technology at the heart of the IoT, the Internet itself, consumes up to 5% of the total energy spent today in the world. Given the expectation of connecting billions of new devices, this consumption is expected to go up [7].

One of the key application areas of IoT is envisioned to be in the smart residential buildings [20]. Among a number of smart devices that are interconnected and installed in such buildings, the devices that support the smart grid development, such as smart energy, temperature, illumination and other types of environmental meters, will also be present. According to Zygiaris' Smart City Reference Model [30], there are different innovation layers that can be used to describe the smart innovation and development characteristics within the smart cities. IoT should play an important role in several of those layers: from the interconnection layer with a number of sensors and actuators, through the integration layer monitoring those smart devices, to the intelligent applications layer making use of the real-time data. In China, in particular, among the largest portions of the IoT market is envisioned for the development of the smart grid [22].

When it comes to the smart grid, there are the dimensions of demand and supply of energy that can be tackled. Tackling the demand should involve the users [25]. While the focus on technology is still too strong and some smart grid players still perceive the users themselves as the barriers to the smart grid development process, we instead need to understand to what extent the users can act as solution to the sustainability pathway. IoT is predicted to enable transparent energy consumption information of different services in cities, from lighting, through public transport, to heating and air conditioning of public spaces [29]. Moreover, the real-time, bidirectional connectivity between the utilities, grid and the users is suggested to lead to the improved overall efficiency of the grid [1, 14]. Finally, in the future smart homes, devices are expected to cooperate, actively share their energy and participate in building wide energy management systems [10]. It is apparent how in such a context, where IoT meets the smart grid, innovative services and business applications emerge, but also security, privacy and trust gain novel importance.

Through this chapter, we review the literature on applying IoT to support the design and development of the smart grid.

## 4 CIVIS: A Community-Oriented Design in Future Smart Grids

Discuss the CIVIS project making relation to the previous theory section.

The discussion shall not be limited to the app YouPower, but also the other efforts made around it (if they are related to the discussions in the previous section), e.g. the user stories, focus groups workshops, interviews, participatory budgeting, etc.

Use the YouPower paper as much as possible.

### *4.1 Understanding and Formulation of the Design Situation*

[note by GP] Giacomo can write this part. To be expanded/integrated by all.

It will focus on CIVIS project by outlining its foundations (as fp7 R&I project) and approach (interaction with local stakeholders + incremental design & development of platform architecture). It will describe the inital, explicit objectives (+ simple rationale/roadmapp to achieve them) and it will provide an overview of the local contexts (from social, technical and energy point of view), in order to make clearer who are the involved stakeholders and their context.

Since more than two decades the ongoing and long-term energy transition process is shifting the energy domain towards decentralization, distributed production and renewable sources [**?**]. Several general and intertwined aspects contribute to this transition: (*i*) the awareness of the inherent complexities that exist among energy systems, societies and the environment [**?**]; (*ii*) the widespread diffusion of new, enhanced technologies and their hybridization with contemporary ICTs [**?**]; (*iii*) the pursuit of national and supranational energy policies around energy efficiency, sustainability and low carbon emissions [4]; and (*iv*) the emergence of new actors in the energy value chain, such as energy cooperatives and energy communities [26], or the transformation of old ones, such as housing associations, and amateur energy managers [9].

CIVIS work took place under European Unions interest to foster energy transition by tackling the so called societal challenge of efficient energy. This was pursued the vision of a smart grid and, basically, the use of ICTs as main driver for the reconfiguration of relationships among traditional and emerging actors in the energy value chain *i.e.* distributors, producers, retailers and prosumers, cooperatives. In particular, CIVIS was a three year, EU project[1] funded under the *FP7 Smart Cities* framework, that pursued the design, prototyping and real-life testing of a platform for the improvement of energy behaviours in the domestic sector. The project was structured around three main areas of interest *i.e.* energy, ICT, social innovation and business and organized into three broad phases that roughly overlapped with the project years and that ensured a close interaction with the local realities and contexts of the pilots: (*i*) an exploratory phase, used to align CIVIS overarching objectives with the local contexts needs; (*ii*) a prototyping one, which concerned the actual design and development of the platform (from data monitoring devices to the front-end applications); and (*iii*) a final testing phase which included the full scale deployment of the platform in the pilots for usage and assessment purposes.

Italy and Sweden hosted two pilots each. The two municipality areas of Storo and San Lorenzo, in Trentino Alto-Adige (a region in north-west Italy), included the Italian pilots. Here, two electric cooperatives, producing and selling 100% renewable energy to their associate members, together with two samples of recruited associate member households acted as the main stakeholders. The regional distribution system operator (DSO), the institutional representatives of the two municipalities and two local cultural associations participated as stakeholders in various phases of the project, by providing knowledge and support for technical aspects related to energy and households engagement. The area of Stockholm hosted the two Swedish pilots. One involved the residential and central neighbourhood of Hammarby Sjöstad, which included apartment buildings owned by housing cooperatives[2]. Recruited households from the cooperatives and cooperatives' board members acted as key stakeholders here. ***[NOTE: Do we want to include Fardala?]*** The other pilot concerned a townhouse area in the outskirts of Stockholm: Fårdala. In this townhouse area the local residents association and some of its member households participated to CIVIS.

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[1] http://cordis.europa.eu/project/rcn/110429_en.html

[2] In Sweden, those who buy a home officially own the right to inhabit the estate and must join a corresponding *housing cooperative* that owns and maintains the estates. The members of a cooperative annually elect a board that makes energy related decisions on behalf of the members.

### 4.2 Products of the Design Process

TODO

Evaluation

After a successful deployment, YouPower was evaluated in the test sites in Sweden and Italy. We collected in parallel, the data on user engagement with the app and on energy prosumption. The initial evaluation revealed how the Trentino residents engaged with a weather feature that predicts the solar energy production levels, while the Stockholm housing association managers used the community features to engage with the residents and connect with other managers.

Some of the tangible results in the Italian test site include the savings in the electricity and heating energy spent or produced [12]:

- percent of self-consumption of the PV self-produced energy is increased for more than 50% of the users comparing to the period before CIVIS;
- electricity consumption from the grid is reduced for the same period for more than 50% of the consumers;
- total electricity consumption (including both, from the grid and the PV self-consumption) is reduced for the same period for more than 50% of the consumers;
- the users spent less than 11% of hours in overheating their spaces.[3]

The housing cooperatives (BRF; bostadsrättsförening in Swedish) in Stockholm conducted following actions as a result of the YouPower use [12]:

- BRF Grynnan: adjustments of ventilation system and turning off the outdoor ice melting system (resulting in reductions in heating);
- BRF Sjöstaden 1: extra insulation added to the roofs in May 2015 (lead to a decrease in heating consumption); installation of heat recovery heat pumps in February 2016 (lead to some increase in electricity consumption but the overall savings);
- BRF Älven: ventilation optimization due to lower thermal comfort, however the energy use went up;
- BRF Seglatsen: installation of recovery heat pumps in the building (reduction in the heating consumption by around 60%, and since electrcitiy consumption increased, overall savings are about 40%).
- BRF Hammarby Kanal: ventilation optimization;
- BRF Hammarby Ekbacke: a goal based energy reduction in a new business model for the housing associations where they do not have to pay upfront costs for the energy actions, and then part of the savings goes to the ESCO (European Skills, Competences, Qualifications and Occupations) for a fixed time period.

[3] The heating behaviour of CIVIS users (control of space heating), met the recommended standard values.

To assess the long term effectiveness of the CIVIS social energy intervention, after a certain period of time, it would be beneficial to fuse the collected data from the app with those about the consumption/prosumption.

Limitations

The initial lack of data due to acquisition and privacy issues in the residential setting was among the main limitation in this project. We installed the IoT sensors to collect additionally needed data for using the introduced app.

### *4.3 Design Process (or participatory design?)*

[note by GP] Giacomo can write this part.

## 5 Discussions

Lessons Learned? / Design Guidelines?

## 6 Conclusions

*Run-in Heading Italic Version* Use the LaTeX automatism for all your cross-references and citations as has already been described in Sect. **??**.

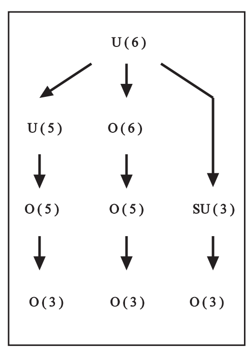


**Fig. 1** If the width of the figure is less than 7.8 cm use the `sidecapion` command to flush the caption on the left side of the page. If the figure is positioned at the top of the page, align the sidecaption with the top of the figure – to achieve this you simply need to use the optional argument `[t]` with the `sidecaption` command

**Table 1** Please write your table caption here

| Classes | Subclass | Length | Action Mechanism |
|---|---|---|---|
| Translation | mRNA[a] | 22 (19–25) | Translation repression, mRNA cleavage |
| Translation | mRNA cleavage | 21 | mRNA cleavage |
| Translation | mRNA | 21–22 | mRNA cleavage |
| Translation | mRNA | 24–26 | Histone and DNA Modification |

[a] Table foot note (with superscript)

Type 1 That addresses central themes pertainng to migration, health, and disease. Blablabla

Type 2 That addresses central themes pertainng to migration, health, and disease. Blablabla

**Acknowledgements** If you want to include acknowledgments of assistance and the like at the end of an individual chapter please use the `acknowledgement` environment – it will automatically render Springer's preferred layout.

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