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Review

State of the art in open platforms for collaborative urban design and sharing of resources in districts and cities

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Abstract: This work discusses recent developments in sharing economy concepts and collaborative co-design technology platforms applied in districts and cities. These developments are being driven both by new technological advances and by increased environmental awareness. The paper begins by outlining the state of the art in smart technology platforms for collaborative urban design, highlighting a number of recent examples. The case of peer-to-peer trading platforms applied in the energy sector is then used to illustrate how sharing economy concepts and their enabling technologies can accelerate efforts towards more sustainable urban environments. It was found that smart technology platforms can encourage peer-to-peer and collaborative activity, and may have a profound influence on the future development of cities. Many of the research and development projects in this area to date have focused on demonstrations at the building, neighbourhood and local community scales. Scaling these sharing economy platforms up to the city scale and beyond has the potential to provide a number of positive environment impacts. However, significant technical and regulatory barriers to wider implementation exist, and realising this potential will require radical new approaches to the ownership and governance of urban infrastructure. This paper provides a concise overview of the state of the art in this emerging field, with the aim of identifying the most promising areas for further research.

Keywords: smart cities, sharing economy, peer to peer energy trading, collaborative urban design, co-design, smart platforms, urban energy infrastructure, scale jumping.

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1. Introduction

Recent years have seen increased interest in new sharing economy concepts in the design of urban infrastructures and in the sharing and utilization of resources. This has led to the development of various collaborative, community-based platforms and tools for urban co-design and resource sharing. These developments are motivated by several factors, which include:

- *Social and environmental factors:* Greater societal awareness of environmental issues, increased citizen commitment to sustainability, and higher levels of engagement with the local community in urban areas.
- *Technological factors:* Improved access to communications and computing technologies at all levels and scales in cities, massive interconnectivity with vast numbers of intelligent, internet-connected devices (Internet of Things (IoT)), advanced artificial intelligence, and distributed ledger technologies.

A range of new technology platforms provide opportunities for citizens to interact with the urban environment and with their local communities via intelligent, connected devices. Such platforms can have a significant role in enabling and scaling up restorative sustainability practices, through the application of new sharing economy concepts in the (co)-design of urban infrastructures and in the sharing and utilization of resources.

This paper examines the potential for smart, open technology platforms to enable the implementation of restorative sustainability practices on a large scale in urban environments [1]. The assessment of sustainability of the built environment is still in the majority of cases limited to the single buildings or their complexes, but in order to approach this in holistic way, it is necessary to move the scale to beyond the building, to district, city, or even regional scale [2]. It is no longer sufficient to implement smart solutions in single buildings; instead, it is necessary to consider the interoperability and interconnectivity of systems. Therefore this work is aimed at showing how smart open platforms can be employed to facilitate restorative sustainability practices at the urban scale.

Such an approach forms the basis for more holistic sustainability assessment, and enables the introduction of new regenerative solutions. There is a clear need to go beyond pilot and trial projects, towards the wide-scale roll out and implementation of smart regenerative solutions. Regenerative solutions are understood here as solutions that allow the establishment of a co-creative partnership of humans with the environment, by creating the needed conditions for not only guaranteeing a sustained development, but also a progressive positive contribution for co-evolution [3].

Many new smart solutions and smart city technologies are presently being tested through demonstration projects in order to show their operation and potential to citizens, public authorities, and other stakeholders [4]. This study analyses a number of demonstration projects, many of which introduce new open platforms designed to implement and test innovative solutions in urban environments.

We also discuss the strategic use of the results and outcomes obtained from such demonstration projects. The digital environment is crucial for this transformation, since digital tools can support decisions by providing data and allowing the exchange of information between relevant actors [5]. Technologies such as open data, Distributed Ledger Technology (DLT), IoT and artificial intelligence clearly have a key role to play in the widespread implementation of these regenerative solutions.

In this paper, we argue that open platforms for collaborative urban design and sharing of resources can be a supportive tool in this process. This paper contributes to existing knowledge by linking these open platforms to the concept of restorative sustainability in cities for the first time. We also discuss the main challenges and barriers to wider implementation of these technologies and identify the most promising areas for future research. The main contributions of this paper are:

- A description of the current state of the art in technology platforms for collaborative (co)-design and sharing of resources in districts and cities.
- An analysis of a number of recent demonstration projects in this area.
- An examination of the potential role and contribution of smart, open technology platforms in implementing restorative sustainability practices on a large scale.

The paper is structured as follows. Section 2 outlines the methodology used in this paper. Section 3 discusses recent developments in smart technology platform for collaborative urban design and details a number of relevant examples of projects implementing these platforms in districts and cities in Europe. Section 4 focuses on peer-to-peer sharing and trading of resources in the energy sector, as a case study of the potential for open technology platforms to facilitate sustainability energy practices in cities in the form of local energy markets, positive energy districts, and renewable energy communities. Section 5 concludes the paper.

2. Methodology

In this study, we conducted an extensive literature review allowing us to analyse recent developments in collaborative "sharing economy" concepts applied in districts and cities. These developments are driven by new technological advances, but also by social and political changes and increased environmental awareness. Based on this review of scientific studies of smart platforms and their drivers, we first discuss the state of the art in smart technology platforms for collaborative urban design. This part of the research was informed by a literature review of recent (post-2010) European projects that introduce or implement smart urban platforms. The relatively large number of European projects addressing these topics indicates strong international policy support for the development of these technologies. We have focused our study on the projects that propose the most innovative approaches, even though some of the platforms used are still only prototypes.

Another factor that influenced our selection of example projects was the accordance of project goals with sustainability principles, as it allow us to study whether platforms based on these principles can enhance sustainable urban development. The expected results of applying these new technologies and innovative approaches is going beyond sustainability towards a regenerative sustainability, and enabling the larger-scale application of sharing economy concepts.

The case study of peer-to-peer approaches applied in the energy sector is analysed in detail in Section 4 of the paper. The results of this practical application allow us to evaluate the potential, as well as technical and regulatory barriers, to wider implementation of such platforms. In the conclusions, we try to evaluate based on literature review conducted in previous sections, how sharing economy concepts and their associated technologies can accelerate efforts towards more sustainable and regenerative urban environments. We assess their potential for enabling scale jumping to the city/region and societal level, and some of the barriers and challenges to this are then discussed.

Finally, it should be mentioned that this study is a research output from the European COST Action called RESTORE ("REthink Sustainability Towards a Regenerative Economy"), [1]. The authors are all members of the RESTORE project, and have taken advantage of the knowledge gained from this COST Action and its network of researchers across Europe. In particular, the involvement of the authors in RESTORE Working Group 5 "Scale Jumping" [1] has been key for identifying scale-jumping potentials for society-wide level regenerative sustainability, guiding the authors in the selection of the technologies explored in the paper.

3. Smart Platforms for Collaborative Urban Design and Sharing Economy

3.1. Co-design and Sharing Economy in the Smart City

The smart city concept has proliferated since the late 2000s, while urban areas ever more dependent on Information and Communication Technologies (ICTs) for management and service provision [6]. The introduction of new tools for open collaboration in smart cities is rapidly changing the way collaborative action is organized. There is a need to move from government-centricity to citizen-centricity [7]. In the context of a smart city, stakeholder participation and actors' involvement are of paramount importance since their operation does not follow a top-down pattern [7]. The individual citizen does not only become a contributor to policy but constructs his/her own forms of governance through individual networks [8].

Policy formation, implementation and service delivery happens in a network of interdependent actors, which are predominantly autonomous organizations [9]. Those networks define in new way interactions, power relationships, and patterns of rules that regulate behaviour within the network, reduce transaction costs and influence network performance [10]. By doing this, it is anticipated that the overall energy and resource efficiency of cities can be increased [4].

3.2. Urban Platforms as Tools of the Sharing Economy

Multi-stakeholder collaboration is influencing complex value networks these stakeholders need to navigate. Inviting users to participate, connect, and "co-create" indicate shift from a more closed production, service provision and innovation model to a more open, distributed and modular one [11]. The exemplification of this phenomenon are urban platforms. The digital revolution in contemporary society provides smart technologies and digital platforms that, if based on principles of restorative development, can support the transition towards regenerative buildings, regenerative cities and a regenerative society [12]. Urban platforms have emerged as a vision of what smart city could be like if it is built on co-creation and network of social relations, as it creates intersections between local policy-making, urban activism and digital living [13]. The platforms allow to consider the interrelationships and interoperability of urban systems by enhancing co-operation mechanisms and exchanging information between users and providers, co-creating better solutions [6]. Such platforms can provide a strong support and can have a profound impact onto ongoing and evolving urban processes by supporting the sharing economy and stimulating collaboration in the urban design processes. As it has been stressed by the European Commission in its roadmap for making the EU's economy sustainable- 'European Green Deal' there is a need for a "comprehensive assessment of the role of (online) platforms, including in the sharing economy" and in that view, the future direction of development of such platforms is of crucial importance [14].

In recent years, open, peer-to-peer (P2P) "sharing economy" platforms, such as AirBnB in the hospitality sector and Uber in the transport sector, have experienced massive growth. Advocates claim that these technologies enable citizen empowerment, improvements in efficiency, and reduced environmental impact, while critics have argued that the true nature of these platforms is centred on economic self-interest and exploitation, rather than any utopian "sharing economy" ideal. However, if they are owned and governed in a fair and democratic manner, these tools can create new possibilities for cooperation in the production and consumption of goods and services [15].

Digital technologies are the essence of the sharing economy, where the sharing economy system is based on efficient, scalable technology that brings large networks of people together and matches them to the goods or services they need [16], [17], [18]. In the sharing economy, 'technology' can be viewed from the perspective of interactions between human strategies and goals. In this view, we can identify a set of six attributes (affordances) that empower stakeholders in terms of organization, hierarchy, transactions, which are: generating flexibility, match-making, extending reach, managing transactions, trust building, and facilitating collectivity. Strong public interest has been noted regarding joining in a collaborative urban design while providing benefits for all of the stakeholders. The sharing of goods has sustainable and regenerative implication, as it reduces carbon footprints in both household economies and urban economies in CO_2 emissions [19].

From the literature review in [20], it can be concluded that there is a strong public interest in joining in a collaborative urban design with benefits for all of the stakeholders. GIS formats are already common methods used by public administrations to collect data and gather buildings information [21]. The sharing of goods has sustainable and regenerative implication, as it reduces carbon footprints in both household economies and urban economies in carbon emissions [19].

3.3. Review of Collaborative Urban Platforms

The review of platforms for collaborative design shows that they can be organized in a decentralized manner, and there are also brave visions for a self-governance and bottom-up organizing, which can provide a citizen-led future. Regarding energy efficiency, the optimisation of the energy demand has usually done in isolation, that is, without considering neither the urban and surrounding environments nor their interactions [4], but it can be changed by implementing these new platforms. The use of the living lab method has increased as a way to implement participatory design and test the solutions applied. They differ in the approach to the issues of control, surveillance, and algorithmic management, as well as the decision-making process in the design, stakeholder involvement and task organization. Therefore, the success of a collaborative design platform is strongly correlated to an underlying decision-making system during the design process and assigning appropriate weight to the voice of different stakeholders.

The collaborative platforms enable scale jumping in solving urban issues by empowering residents in cooperating in a decentralised manner at a local, district, neighbourhood, city level. This experience and knowledge can be replicated at an inter-city level.

Several authors have examined sharing economy platforms [22]. Some relevant examples include:

- Almanac project [23] developed a service deliver platform integrating Smart City information System for green and sustainable Smart City applications;
- Butterfly effect project [24] which focuses on developing prototypes that enable cooperative design through location-based social media (however, participation is limited to reporting);
- JPI Urban Europe SubUrbanLab [25] has developed tools for urban living labs that enable different stakeholders to participate in urban development and the accent is on improvement of energy-efficiency in less-valued sub urban areas;
- Urban IxD project [26] that has defined a coherent multidisciplinary research community working within the context of city/urban design;
- POLDER project [27], which aims to design, develop and deploy a software tool-suite to support government, city councils and related organisations in the elicitation, design, application and validation of policymaking;
- C3PO platform [28], which is based on utilizing participative urban planning and it is focused on tackling urban design challenges through a cloud collaborative and semantic platform for city co-design. In targeting the growing market of smart cities, the C3PO solution covers the whole urban project development process and involves citizens, decision makers, architects, etc;
- Open Cities [29], which is oriented towards creating and managing smart urban ecosystems based on an open innovation approach, as it was established to alleviate and stimulate the interaction between the residents and the local governments.

As indicated above, there are several large-scale collaborative projects in Europe aimed at supporting collaborative design through urban platforms. The U_CODE project [30] aims to create a co-design platform for urban design that allows participation for a large number of (simultaneous) participants. Another example is Smarticipate [31] which is a project similar to C3PO comprising the delivery of a web platform which will enable citizens to support decision making processes in the city's development. The platform is based on use of open data to enable co-creation by giving the citizens possibility to shape their cities. In general, data are essential for these innovative platforms and systems, being the specific datasets of paramount importance for developing and managing new urban energy models [21]. Moreover, political leadership is essential for guiding toward the implementation of smart grids and sustainable cities, allocating recourses to make it happen. It has been highlighted the importance of a triple helix model (cooperation between academia, industry and government) to promote innovation, being crucial in the case of smart city solutions the involvement of citizens (quadruple helix) [4].

In the frame of the Espresso project [32], a conceptual Smart City Information Framework based on open standards, which consist of: A Smart City platform and number of data provision and processing services to integrate relevant data, workflows, and processes, has been developed. It allows to create a people based network between cities and research centres aimed to develop better eServices to citizens. The ROCK project [33] at its core is based on knowledge transfer and sharing technology from several "role model" cities across Europe, to, among others, the city replicators, among which is the city of Skopje. The transfer is related to the Athens-based platform called SynAthina [34]. Established in 2013, SynAthina is the common space which brings together, supports and facilitates citizens' groups engaged in improving the quality of life in the city. The transfer involves replicating a collaborative platform for delivering sustainable urban design solutions, monitoring of city districts for improving the outdoor comfort, walkability etc. The project focuses on historic city centres with an aim to demonstrate how the built Cultural Heritage can be a unique and powerful engine of regeneration, sustainable development and economic growth for the whole city. The topics being `replicated` in this project are shown in Fig. 1, involving collaborative online practices among others. The outcomes of the project have delivered several online tools so far, among which is an interoperable platform, providing generated data freely and easily available, dashboards, related to project activities, city assets, data collected by environmental and visitor flow sensors etc., thus supporting the collaborative aspect for improvement of the city. Additionally, an interoperable platform collection and management of data sets on cultural heritage facilitating communication and relationships between different information sources.

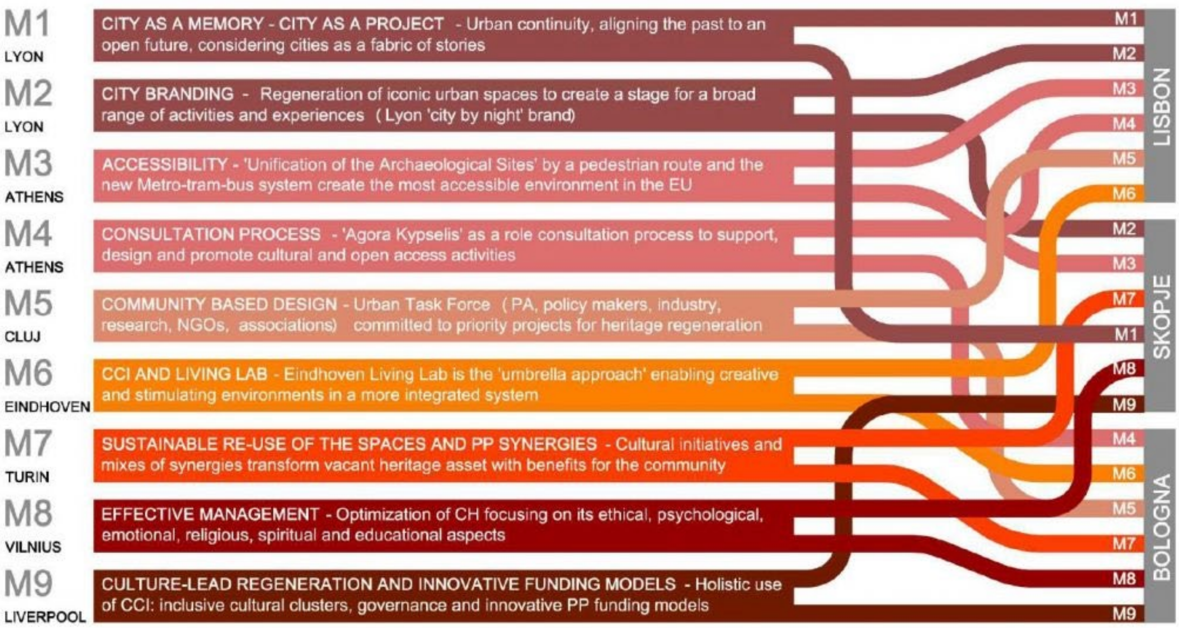


Figure 1. ROCK project topics flow chart [33].

The enhancement of city planning by co-design and collaborative platforms demands access to different information, requires visualisation of relevant information, etc. It has become evident the need for modelling tools to help manage and plan cities, allowing for instance the evaluation of different energy scenarios [21]. There has been considerable development of various methodologies, tools and complex platforms that integrate a multitude of novel technologies, such as: Big Data analytics, Geographic Information Systems (GIS), Building Information Modelling (BIM), open Application Programming Interface

(API), 3D modelling and visualisation (3D, Augmented Reality and Virtual Reality), gaming tools, etc.

3.4. Boundary Conditions for the Efficiency of Urban Platforms

The theoretical establishment of collaborative platforms for urban design can be based on the concept of the 'smart cities', meaning harnessing smart technology to an agenda of sharing and solidarity (rather) than one of "competition, enclosure, deepening inequality and division" [35]. If based on those principles collaborative platforms can support shift towards regenerative development of the cities. However, regenerative measures and their impacts on urban environments need to be evaluated by using the proper tools and clear parameters [5]. One of the key issues for the efficiency and efficacy of the collaborative platforms for urban design is the setup of the communication, coordination and organizational management while establishing a proper decision-making process in a highly dynamic participatory setting with pool of urban data.

Sharing platforms often raise legal issues and demand certain degree of municipal/city governance. Sharing economy platforms in certain cases operate legally even without legislative reform, while other sharing platforms operate illegally—or arguably illegally. For example, short-term rentals (fewer than 30 days) as well as ride-sharing are prohibited in many jurisdictions, and while some are choosing to apply the existing laws to prohibit them, other cities chose to "silently" approve them [36], [37], [38]. Those that chose to regulate them, were either revising existing ordinances, while others have created new legislation [39]. Certain cities recognize the sharing economy in their municipality and engage with their local sharing economies as direct providers of full sharing services while simultaneously they experiment with such practices (e.g. Santander, Lyon [15], [40]). Other municipalities choose either to proactively utilize sharing economy platforms (e.g. Berlin, New Orleans [40], [41]) or to apply measures to prevent the negative implications they produce to the neighbourhoods/cities (such as Barcelona or Amsterdam [37]). These distinctions are not always clear, as many of those cities employ more them one strategy at the same time.

One aspect that influences the effectiveness of peer-to-peer platforms is the governance model. Five models of sharing economy platforms have been discussed in [42]. Self-governing relates to the municipalities' capacity to govern their own activities or when it shares its own assets [43]. Governing by authority involves the use of traditional forms, such as regulations [36]. It is argued that Sharing Economy Organisations (SEOs) could be given regulatory responsibility such as self-regulation or be involved to certain extent in developing regulatory framework [44]. By employing various regulatory strategies, such as enforcement and sanctions, municipalities may constrain the emergence and spread of SEOs or support them. Researchers conclude that municipalities primarily regulate ride-hailing services and short-term accommodation rentals. Governing by provision refers to the shaping of practice through delivery of particular forms of service and resource. In this case municipalities may supply SEOs with services, material and infrastructural means, or withdraw them. Additionally, municipalities may also engage with SEOs in partnerships in which both parties play active roles in the governance process, or in negotiation processes with SEOs to support their policy making [42]. Governing through enabling refers to the role of municipalities in facilitating and coordinating action via partnerships with agencies in the private and voluntary sectors, with a focus on community engagement. This suggests that municipalities may govern SEOs by enabling or disabling them through intangible means such as persuasion, argument and incentives [45]. There is a need to choose an appropriate governance model, which is the most suitable one for local actors involved, and which allows to share risks and use local assets in the most efficient way.

4. Peer-to-Peer Technology. A case study of application in the Energy Sector

4.1. The Potential of Peer-to-Peer Trading Platforms in the Energy Sector

This section examines P2P platforms for energy trading and sharing in detail. The example of P2P energy trading and sharing platforms is used as a case study in order to demonstrate the potential of open technology platforms to enable more sustainable use of resources in districts and cities.

A number of fundamental changes are taking place in the energy sector and more specifically, in electricity grids. This can be attributed to three major technology trends:

(i) The massive integration of distributed renewable energy sources;

(ii) The increasing electrification of the transport and heating sectors;

(iii) The extension of communications and control technology down to the level of individual users via smart metering and building energy management systems [46].

Many countries and regions worldwide are no longer investing in conventional, centralised, carbon-intensive generation such as coal, oil, and gas, and are instead moving towards the large-scale integration of electricity generators, based on solar, wind and other renewable sources. Often these renewable resources are located far from the demand centres of the electricity grid and are highly-dispersed geographically. This presents significant challenges to conventional approaches for electricity grid operation and planning

In addition, renewable generation and microgrid technologies are moving towards grid parity (i.e. the point where they can directly compete with existing grid energy sources without subsidy). Renewable energy sources are often considered "zero marginal cost", due to fact that have no fuel costs associated with them. These factors are changing the economics of the electrical energy system, and many researchers have argued that the existing, centralized electricity market is no longer fit for purpose in this context, and new electricity markets designs are now required [47].

The concepts of "energy communities" and "peer-to-peer" electricity trading and sharing have received much attention in recent years [48]. These efforts have been boosted by new energy policies initiatives at the national and international level, which encourage community energy as an important step towards reaching climate objectives (e.g. the European Union's Green New Deal [49]).

This has led to research in creating new approaches to the design of energy systems and markets that are more "consumer-centric", and some have discussed this as the application of an "Uber" or "AirBnB" sharing economy model in the energy sector [50]. Rather than traditional, top-down energy systems with "vertical" transactions between individuals and various upstream grid entities, "horizontal" or peer-to-peer energy transactions between citizens in the same community or local area may provide significant benefits to individuals, communities and the system as a whole.

Due to the economies of scale, electricity markets have traditionally been either monopolies (e.g. in countries with a single state-owned electricity supply company) or in more recent times, oligopolies (e.g. liberalised electricity markets implemented since the 1990's in most developed countries). In contrast, P2P or community energy markets may be considered as an application of "sharing economy" concepts in the energy sector [51]. For instance, Uber is a technology platform designed to share under-utilised cars, and AirBnB is designed to share underutilized houses. Similarly, P2P energy trading is intended to allow citizens to share and trade microgeneration and energy demand flexibility with others in their community [52].

There is a growing body of academic research into future "decentralised" electricity market designs, which are fundamentally different from the traditional "centralised" electricity markets. Despite the economies of scale offered by large, centralised generation and conventional energy markets, it is theoretically possible to trade electrical energy in a P2P or community market with electricity rates than are more favourable for individual citizens than the electricity rates available from the main grid. This could be achievable because in P2P and community energy markets, the costs of transmission, distribution, and taxes are greatly reduced, and intermediaries such as banks, energy traders and energy supply companies may no longer be required.

Figure 2 illustrates a "centralised" electricity market arrangement, which is typical in that most developed Western countries, where liberalised electricity markets have been implemented for several decades. The is a "top-down" market design, with users in the residential, commercial, and industrial sectors assumed to be price-takers, purchasing electricity from energy supply companies or retailers, Figure 2. The retailers then interact with various other entities in order to trade electricity in a centralised pool market.

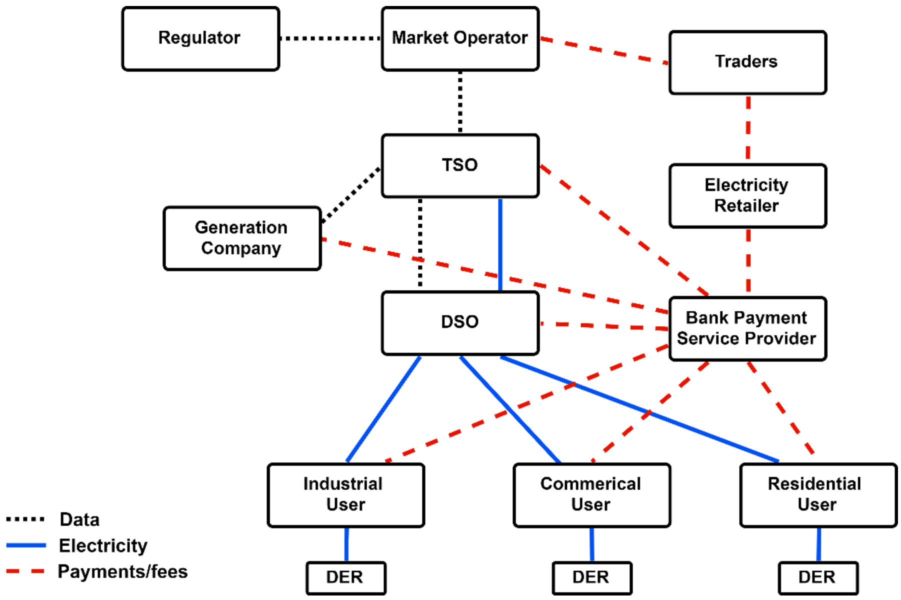


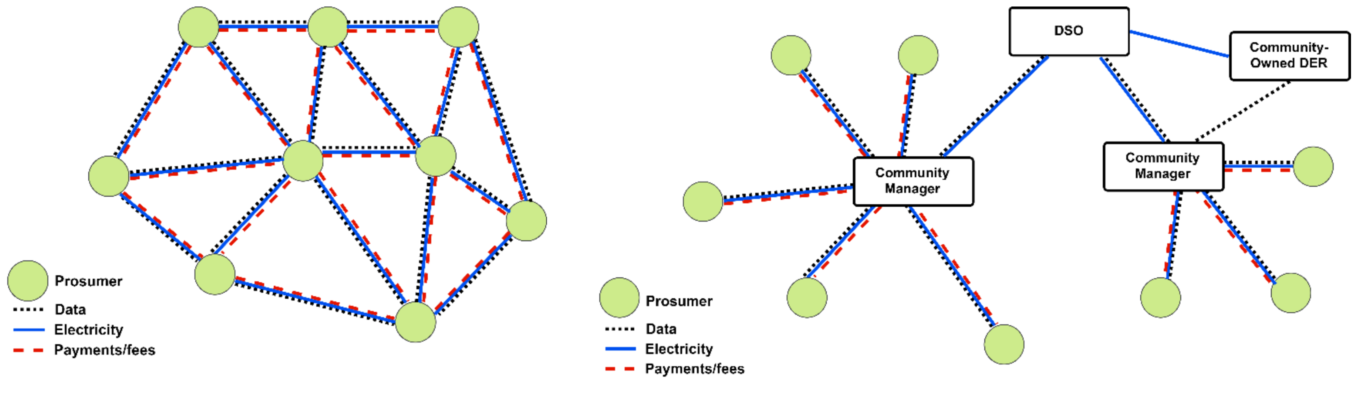
Figure 2. Centralised electricity market design typical in most developed countries (TSO = Transmission System Operator, DSO = Distribution System Operator, DER = Distributed Energy Resources).

This type of centralised electricity market model has been effective in many countries to date, driving competition amongst electricity generators and retailers, and in many cases delivering relatively low electricity rates for consumers. However, the centralised model is fundamentally incompatible with the future vision of a sustainable, net zero-emissions energy system in several regards. The centralised market assumes that large, generating plant is dispatched centrally under the control of network and market operators. However, in an electricity system based mostly on renewable energy sources, there may be millions of energy resources distributed throughout the network, and often connected at the end-user level (e.g. rooftop photovoltaics).

This creates challenges for controlling and operating the system, since there are major technical difficulties in coordinating vast numbers of highly dispersed energy resources, such as receiving and sending vast numbers of heterogeneous control signals from and to a central point. In addition, a highly centralised system is more vulnerable to cyber and/or physical attacks on the central control infrastructure.

Centralised power systems have also not been successful enough in providing market access and economic incentives for microgeneration and the participation of active energy citizens. Centralised electricity markets typically have minimum entry size requirements, and are by their nature biased towards larger market participants [53].

This has led many researchers to investigate the potential for future grids with "horizontal" transactions (e.g. P2P or local community markets) either instead of, or in addition to the traditional, "vertical" transactions shown above in Figure 2. This approach could provide benefits by removing many of the intermediaries in the centralized model and allowing individuals and communities to share and trade energy directly with each other. This may provide stronger incentives for individuals and communities to install renewable microgeneration and microgrid technologies.



(a) **(b)**

Figure 3. Decentralised "prosumer" electricity market designs: (a) "full P2P" market; (b) local community-based market structure.

Decentralised market architectures can be in the form of a "full P2P" design (each peer in the network is capable of directly trading with any other peer, Figure 3a). Alternatively, they may have a more structured "community-based" design (each local area has a community manager that manages transactions within the local community and interactions with the rest of the electricity system, Figure 3b). The "prosumer" indicated in Figure 3 refers to an active energy citizen who may be both a consumer and producer of electrical energy, subject to the availability of local renewable energy resources and energy flexibility [54].

4.2. The Role of Distributed Ledger Technology (DLT)

In recent years, Distributed Ledger Technology (DLT) has attracted interest from researchers, energy suppliers, and start-up companies for new applications in the energy sector [54]. Many have envisioned a future with prosumer-based, decentralised electricity markets, where there is a requirement for a system that that can manage and settle prosumer transactions from thousands, or even millions, of Distributed Energy Resources (DER). In order to accommodate new market entrants and new DER technologies quickly and easily, such a prosumer transaction management system should be based on an open architecture. It also needs to be resilient and secure from cyber-attacks.

Distributed Ledger Technology (DLT) such as blockchain may provide an appropriate solution that meets the above criteria. DLT systems are considered to be inherently decentralised and secure, and can be configured to manage very large numbers of micro-energy transactions securely [55]. One possible future scenario is multiple interconnected local electricity markets, each with fully decentralised control and no central authority (i.e. a trustless system), where all of the market participants (i.e. prosumers) take decisions on a consensus basis using DLT. However, the difficulty in applying a fully decentralised, trustless system to electricity grids arises around responsibility maintaining the network infrastructure and reliability of supply, since in such a system it is unclear where the responsibility for maintaining security and quality of supply lies, and how the risk associated with reliability issues are distributed along the supply chain.

In another potential future scenario, traditional centralised databases could be used to manage new local electricity markets. If it is assumed that the users in the local market trust the network operators and that network operator databases are maintained securely, then it could be argued that there are no advantages in employing DLT in implementing local electricity markets. The optimal future solution may be a "hybrid" scenario, where the ultimate responsibility for reliability and security of supply still lies with the traditional network operator, but a significant amount of system supply-demand balancing is distributed via local P2P and community energy markets [50].

Local markets could be used to carry out a significant portion of system supply-demand balancing at the local level, and provide new means of procuring system flexibility. In order to achieve this, national electricity regulations will need to allow network operators to have a role in operating local energy and ancillary services markets [46]. This arrangement is expected to take advantage of the potential offered by decentralised electricity markets (creating new opportunities for DER participation, increasing renewable hosting capacity, reducing technical losses, deferring network infrastructure upgrades), while keeping the reliability benefits of a centralised "pool" market structure in ensuring security of supply. DLT could have an important role in such a hybrid system in managing and securing automated smart contracts using lightweight, permissioned blockchains. There are potential issues with DLT around scalability, excessive transaction verification times and excessive energy consumption, however, it is expected that these issues will be avoided to a large degree by future developments in the technology, e.g. carrying out smaller transactions offline or using side channels [56], and only including aggregated financial transactions in the final ledger.

4.3. Multi-agent Systems and Advanced Computing Techniques

Advanced computing techniques, such machine learning and multi-agent simulation are also expected to have significant influence in future decentralised energy systems. For instance, a local P2P energy market can be characterised and analysed as a collection of multi-bilateral trading agreements between multiple agents. Several research efforts have formulated local electricity markets with multiple DER as a distributed optimisation problem, which are solved using iterative techniques [57]. However, computational complexity and convergence can become a significant challenge when dealing with large-scale energy system. Multi-agent systems approaches may be more appropriate for the modelling and simulation of prosumer-based markets, in order to provide tractable solutions that can be scaled up to very large systems, as well as to test the resilience of the system. Multi-agent systems modelling has been demonstrated to provide flexible, scalable and fault-tolerant solutions to a number of power engineering problems in previous work, e.g. [58].

Other authors have also investigated the potential of technologies such as Digital Twins (DT), Urban Building Energy Modelling (UBEM) and Urban System Energy Modeling (USEM) as enabling technologies for prosumer markets and energy communities [48]. DT refers to digital duplicates of the physical objects or environment and processes. The DT concept entails a holistic socio-technical characterisation of the objects and a process-oriented approach that can be used for a continuous assessment [59]. Similarly, UBEM and USEM tools allow modelling of buildings and energy systems respectively, to simulate the operation and energy performance of buildings and energy networks at large scales. According to [21], the latest tools show an increasing trend towards approaching UBEM and USEM together. This holistic approach could contribute to accelerating the transformation of urban environments.

4.4. Scale Jumping to District and City Level and Beyond

The majority of trial and demonstration projects for P2P and community-based markets have focused on demonstrating P2P and local community energy markets at the neighbourhood level, e.g. [60] and [61]. Demonstration projects to date have generally involved energy trading and exchange in small, localised areas, e.g.:

(i) in microgrids, where the local energy community is isolated from the main grid;

(ii) “behind the meter”, e.g. energy exchange between households in the same apartment block; or

(iii) other “private wire” arrangements, such as a small section of the electricity grid dedicated as a “sandbox” for research activity.

These approaches have allowed P2P and community energy demonstration projects to avoid regulatory problems, such as non-compliance with national grid codes and electricity market legislation [62].

However, in order to scale up P2P and community energy exchange to the district and city level and beyond, it will become necessary to carry out trading over the main electricity grid, i.e. using utility-owned network infrastructure.

Presently, it is still unclear what impacts on system-level operation and planning would result from the large-scale implementation P2P and community energy trading platforms [63]. A major research gap exists in integrating P2P and community energy exchange platforms into exiting grid operational practices and centralised wholesale electricity marketplaces. There are also open questions around how citizens and communities involved in P2P and community energy should contribute to maintenance of the grid infrastructure (e.g. if they are not contributing through traditional electricity rates). It is necessary to socialise the costs of managing the electricity networks fairly in order to ensure security and quality of power supply into the future, e.g. through re-designing regulation around “use of network” charges. The technologies mentioned above (DLT, IoT, Multi-agent Systems, DT, UBEM and USEM) will all have a role to play in this scale jumping

4.5. Cooperative Models and Co-Design Approaches for Urban Energy Infrastructure

This discussion has focused on the potential of new energy trading platforms and local energy communities to enable decentralised, flexible, and sustainable approach to energy management at the urban scale. If successful, the possible benefits include:

(i) Empowerment of individual citizens and local communities.

(ii) Reduction in losses resulting from increased local self-consumptions and reduced long-distance transmission of electrical energy.

(iii) Grid-scale benefits from increased balancing of energy demand and generation at the local level (increased capacity for new renewable energy connections, and reduced need for grid flexibility services)

(iv) Environmental benefits resulting from the deferral or the removal of the need to build new grid infrastructure.

New technologies such as DLT that can electronically trace supply chains all the way from source to consumption may also influence the future development of other utilities such as gas, water, and waste. Some have envisaged future “citizen utilities”, new utility models based on economic localism and on the democratisation of ownership and governance [64].

In the energy sector of many developed countries, community ownership of renewable generation is already well-established, and there is growing trend towards community-owned energy storage. In a future prosumer-based energy system, these co-ownership models may become much more commonplace. Co-ownership could also be extended to a much wider range of microgrid and physical network assets, even including power distribution lines and cables, as community energy models become more economically viable and socially accepted as a means to achieve greater levels of energy independence and sustainability.

This raises questions around the design of urban infrastructure in an energy system based almost entirely on distributed, renewable energy sources. It also raises questions in relation to how adaptable are the existing building stock and existing urban fabric to accommodate these changes. To do that, the amended Directive 2018/844/EU [65] introduced a "Smart Readiness Indicator" (Article 8 (10) and (11)), which will contribute to evaluate the preparedness buildings for integrating smart technologies and for interacting with energy grids [28]. This new concept of 'smart readiness' aims to promote smart-ready systems and digital solutions (e.g. building automation and control), taking on board key advances in several technologies applicable not only to single buildings, but also to the built environment. It presents challenges to the present model where energy infrastructure such as transmission and distribution networks are considered natural monopolies from a regulatory perspective, and fully owned and managed by network operators. Future urban energy systems may benefit from a "bottom-up" co-design model, where citizens have a central role in the planning and ownership of energy infrastructures, and where the grid infrastructure is viewed as a common, shared asset, rather than owned by the network operators.

This discussion, along with much of the literature in this field, has focused on urban areas in the developed world, and the potential applications for new concepts and technologies in this context. However, it is interesting to note the considerable progress made in microgrids and community ownership of energy infrastructure in developing countries. In many developing countries, grid access is not available to large numbers of citizens, particularly those located in isolated and remote communities. For many remote communities, building renewable energy-based microgrids is the most practical and economically-viable solution to their energy needs [66]. The electrification of these areas of developing countries could leapfrog the traditional centralised utility grid model and the inefficient, carbon-intensive technologies associated with it, by developing community microgrids based on solar or wind energy instead. These experiences can provide significant learnings for scaling up of community energy projects in urban areas of developed countries.

In summary, this section of the paper outlines a detailed case study of one application of open technology platforms for sharing economy (peer-to-peer electricity trading in the energy sector). This is intended to provide a real-world example of the potential of open technology platforms applied in districts and cities. This case study illustrates the potential for such platforms to contribute to district, city, and region sustainability goals, but also highlights the technical and regulatory barriers to wider implementation of such technologies and the changes in governance models that are necessary in order to implement sharing economy concepts at scale.

5. Conclusions

This work discussed the state of the art in sharing economy concepts and collaborative co-design technology platforms applied in districts and cities, and their potential to enable more sustainable and regenerative urban environments. It outlined recent development in technology platforms applied in collaborative urban design, discussing a number of recent examples from cities and districts around Europe. The collaborative platforms for urban design studied in this paper create dynamic participatory settings that encourage citizen involvement. In order for these platforms to be effective there is a need to establish suitable decision-making processes. Moreover, as these platforms deal with very large volumes of urban data, efficient communications, management and organisation of data is crucial for platforms to become tools that support real-time data-driven decision-making and evidence-based sustainable urban development.

The case study of P2P and community approaches to energy trading and exchange in the electricity sector is described in Section 4 as an example of how sharing economy concepts and their enabling technology platforms can accelerate efforts towards more sustainable urban environments. Recent work suggests that these platforms can provide strong incentives for citizens to share and trade locally-generated renewable energy, and achieve greater energy independence.

New platforms designed to facilitate of peer-to-peer economic activity have already had significant impacts on the transport and housing sectors in many cities, and may have a significant influence on energy systems of districts and cities, including the further development of zero- and positive-energy districts. Such technology platforms may also have a profound influence the future development of other utilities including gas, water, and waste.

These platforms, if implemented with accordance to regenerative sustainability principles, may become a tool supporting:

(1) environmentally enhancing of the restorative relationship between cities and the natural systems for a sustained and positive evolution,
(2) the mainstreaming of efficient renewable energy systems for human settlements across the world, and
(3) new lifestyle choices and economic opportunities which will encourage people to participate in this transformation process, towards co-creative partnership between humans and natural environment.

These concepts and their associated smart technology platforms studied in this paper could be harnessed to effect positive changes in the built environment and its transformation towards regenerative sustainability. However, the concepts around P2P trading and exchange of resources discussed in this paper have been demonstrated only at the building and neighbourhood scales to date.

More research and political support is needed to overcome the significant technical and regulatory barriers identified in this paper in order to enable wider implementation across a range of jurisdictions. This paper has identified that scaling these technologies up to the district and/or city scale and beyond could provide significant positive environmental impacts. However, realising this potential may require radical new approaches to the ownership and governance of urban infrastructure. In order to change the status quo there is a need to encourage active roles in the governance process for public, private and voluntary-sector agencies as well as to give Sharing Economy Organisations (SEOs) regulatory responsibility and/or allow them to be fully involved in developing regulatory frameworks. At the same time, these changes need to be implemented very carefully in order to avoid negative impacts from market driven-decisions on urban development.

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