Citizen-centric Design of Consumable Services for Smart Cities

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The ongoing growth of city populations has brought new challenges and increased complexity to everyday city life. In response, numerous cities are making efforts to adopt new information technologies to become more efficient and transform themselves into smart cities. A large body of research has underlined that the success of these smart city initiatives depends on putting citizens at the center of the design process. In contrast to the techno-centric view applied in the past, citizen-centric approaches focus on prioritizing the needs of citizens over technology and aim at involving them directly in the development of smart city services. In this article, we describe this involvement as citizen development by introducing a model-based architecture that enables citizens to develop smart city services in a low-code fashion. Consequently, we focus on citizen developers, a group of citizens engaged with the technological development of services. Furthermore, the conceptualization of a citizen development architecture is discussed, as well as the ways citizens can interact with it. An important pillar in this approach are citizen workshops, which aim at stimulating innovative ideas and collaboration among stakeholders by using design thinking methodology. Our approach empowers citizens to become active producers within the smart city ecosystem, leading to more inclusive and citizen-centric smart cities.

CCS Concepts: • **Human-centered computing** → **User centered design**; **Collaborative interaction**; *Interaction design process and methods*; • **Networks** → Cyber-physical networks;

Additional Key Words and Phrases: Citizen-centricity, citizen development, smart city, conceptual modeling

ACM Reference format:
Alexander Voelz, Christian Muck, Danial M. Amlashi, and Dimitris Karagiannis. 2023. Citizen-centric Design of Consumable Services for Smart Cities. *Digit. Gov. Res. Pract.* 4, 3, Article 17 (September 2023), 18 pages.
https://doi.org/10.1145/3597420

1 INTRODUCTION

For several years now, cities around the world have been implementing novel technologies to offer new services that aim at improving citizens' lives. This includes purely digital services but also approaches that contain a combination of physical and digital assets. The resulting improvements manifest in a variety of different areas of life, and they range from providing basic services to enabling advanced process automation. In many cases, this trend towards the digitization of cities originates from the need to react to the challenges that emerge due to the continuous population growth and the resulting complexity of everyday life going along with it [34, 43].

As a result, more and more cities every year are coined as *Smart City* or are considered to be on their way to becoming one, even though the scientific community has not reached a consensus on what constitutes a city that is *smart*. On the contrary, a number of partially overlapping definitions have been proposed in the

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2639-0175/2023/09-ART17
https://doi.org/10.1145/3597420

literature, each of which puts a slightly different focus in regard to the relevant aspects that need to be taken into consideration [16, 21]. While the integration of novel ***Information and Communication Technologies*** (**ICTs**) often forms the underlying notion of these definitions, this focus is starting to shift towards seeing smart cities as a multi-stakeholder ecosystem, putting an emphasis on the needs of citizens. This new direction of research is often associated with the term *citizen-centricity*, which has become a new underlying design principle for the creation of smart city services and applications.

Several preconditions have to be met to enable such a citizen-centric design of smart city services or applications. Most importantly, the needs, as well as innovative ideas of citizens have to be identified and then integrated into the development process. This foundational first step of understanding citizens' needs already poses challenges because of the difficult communication between the involved stakeholder groups [59]. Furthermore, identifying the underlying problems during design and extracting relevant knowledge linked to it is essential for the development of adequate solutions [15, 59]. Hence, the article at hand aims at easing the communication between the involved stakeholders by better understanding their needs through the use of workshops and creative methods, where problems and possible solutions are discussed on a high abstraction level to facilitate understanding and communication (see Section 3.3).

Under ideal conditions, every citizen would have the possibility to transform their ideas on how to improve the smart city into real-world applications or services. Even though researchers report that, for example, the availability of open government data can foster innovations in smart cities [64], a big proportion of the population lacks the required skills and knowledge to implement solutions on their own. Considering these challenges, the main goal of this contribution is to enable citizens to design their own services in a low-code fashion by following the idea of citizen development. We propose to use conceptual modeling as a way for technically inexperienced citizens to describe their services and deploy them to an execution environment. For this purpose, conceptual modeling offers means of abstracting the complex ecosystem and thereby helps citizens to express their domain knowledge in a machine-understandable way, which can then be used to design citizen-centric services.

Besides understanding the citizens' needs, the requirements regarding city environments have to be considered to reach feasible solutions. The constant population growth, the increasing size of cities, and the aging infrastructure make it harder to satisfy the given requirements, which is why physical environments often need to be adapted accordingly.

The article at hand represents an extended version of [48], where we discussed the general idea of citizen development within the smart city setting. In this article, the notion of *citizen development* is utilized in order to propose a model-based architecture for involving citizens in the model-based design and creation of citizen-centric services. Following this objective, the remainder of the article is structured as follows: Section 2 describes the theoretical background, in which the most important elaborations from our previous work are recapped and extended by additional concepts relevant in the context of this contribution. Section 3 introduces the main contribution of our article in the form of a conceptual citizen development architecture. In Section 4, we discuss the proposed architecture with the help of a SWOT analysis before we conclude with the insights from our contribution in the last section.

2 THEORETICAL BACKGROUND AND RELATED WORKS

The following gives an overview of the theoretical background relevant to this contribution before the related works, encompassing existing model-based approaches and smart city conceptualization, are discussed in more detail.

2.1 Smart City Setting

For the general elaboration of the smart city setting, we first address that no universally used definition of the term *smart city* exists in the scientific literature before the importance of smart services within this setting is emphasized.

In general, a smart city is related to a set of approaches that use technologies to optimize existing or shape new city-related processes [9]. However, various terms (e.g., *Wired, Intelligent, Digital*, or *Knowledge City*) are used in the literature to describe different concepts of smart cities [16, 21], and definitions have also evolved over time, which might be explained through the effort of adapting them alongside the availability of novel ICT [62].

The main focus of the study at hand are the services resulting from the utilization of technologies within the smart city setting. Such smart services form a core building block of a smart city and are often provided by the city administration to be consumed by other entities of the city [4]. The goal is that the life of citizens, administrative processes, and the overall quality of life in the city improve through the incorporation of ICT [4, 71].

Within our citizen-centric development approach (cf. Section 3), we highlight that the citizens' needs are of the highest priority when designing smart city services, as emphasized by other authors [62]. Moreover, a holistic view of the smart city is needed, in which citizens, technology, and the environment are treated as interacting concepts [49]. We, therefore, define a smart city in the following as a city, in which ICT is incorporated into the infrastructure and combined with existing technologies to generate benefits for the citizens in the form of smart services. Furthermore, the existing efforts in regard to smart city-related standardizations have to be acknowledged as a relevant factor for the design of smart city services. Such standards are created with the aim of providing guidelines for the consistent use of procedures across different smart city projects in order to ensure the interoperability of individual components [4, 35].

2.2 Citizen Centricity and Related Terms

The notion of citizen-centricity is nothing new and was first introduced in the context of web-based government services [37]. During this time, citizen-centricity was about identifying the needs of prospective website users and adjusting the provided services accordingly [68]. In the following years, the term's prevalence has developed alongside smart city research and often forms the foundation of related services. Nowadays, citizen-centric design is still about the assessment of the users' needs in the first place, to then incorporate those needs into the final solution.

At this point, it has to be mentioned that closely related terms, like *user-centric* [8], *human-centric* [11], or *people-centric* [27] are often used in the literature instead of citizen-centric. We argue that these terms are used synonymously to describe the same concept since humans, people, users, and citizens can be conceptualized as having different roles of the same entity in the smart city context (as will be shown in Section 3 and Figure 1). Hence, the term citizen-centric is deemed more suitable for the given context and used throughout the remainder of this article while still implying the inclusion of the mentioned related terms. Additionally, researchers suggest that the participation of citizens and public servants during the design of smart city projects has a crucial influence on the successful implementation of the respective project [61]. Consequently, two closely related terms are often used in the scientific literature and need to be emphasized in this context, namely, *citizen engagement* and *citizen participation*.

Early on, it was recognized that new technological capabilities could increase public engagement through political platforms [52]. At that time, the use of the terms *civic engagement* and *electronic democracy* was more widespread for describing the new ways of communication between citizens and their respective city administrations. These first ideas of political platforms that enable electronic democracy were mostly techno-centric oriented, meaning that technological capabilities were the subject of interest. Nevertheless, the proposed benefit of such platforms persists since participation platforms are still proposed as a potential solution to foster civic engagement [61]. In more recent contributions, the term citizen engagement has been brought into focus, and the concept of participatory or collaborative governance [38], for which citizen participation is seen as a crucial input [22], has mostly replaced electronic democracy.

Nowadays, the focus of citizen centricity and related concepts have shifted from a technological capability to a social necessity [11, 20]. This is partially the case because the elicitation of citizen engagement poses a major challenge to today's smart cities [13]. Furthermore, its importance for smart city development has been recognized in the literature [17], which can be explained through increased democratic participation by the population, leading to higher approval rates, trust, and also quality of life among citizens [22]. Other contributions even suggest that citizen engagement is linked to the development of so-called **sustainable-oriented innovations** (**SOIs**) [64].

Finally, the concept of *open data*, and specifically, *open government data*, is introduced in the context of citizen centricity and smart city development due to the numerous effects it is said to have on the related terms presented in this section. Before these effects are discussed, it is important to mention the different terminologies used in the literature that describe different elements of the same concept. Among them are open data [2] in combination with open data initiatives [51, 53, 69], open data portals [55], and open government data [1, 39, 72]. Open data includes all structured data that is publicly available in the respective city, while open government data describes all data made publicly available by the government or municipality. Open data platforms are essential for the management and publication of open data within cities, and all efforts towards establishing or improving such platforms form open data initiatives. Since open data platforms are usually operated by the government and can include data from open as well as governmental sources, it is hard to distinguish between open data and open government data in this context.

More importantly, open data initiatives are generally considered to be an essential building block of developing smart cities [51, 72]. The reasons for these effects are diverse, stating that open data can foster innovations [53, 69], citizen engagement [7], citizen participation [62], and even promote trust building between city municipalities and the respective citizens [51]. Increased trust in this relationship is especially important considering the movement in the opposite direction, resulting in citizens trusting the governmental institutions less and less [46]. Hence, another focus of most recent contributions has been the challenges connected to the publication of open data [55] and the assessment of the transparency of current open data initiatives [39].

2.3 Citizen Development in the Smart City Context

A *citizen developer* is considered a developer with little to no experience in software engineering or coding. Yet, they use so-called *low-code* or *no-code platforms* designed to enable fast, easy, and cost-efficient application development [57]. The idea behind citizen development originates from the problem of shadow IT systems within organizations where employees use applications not provided by the organization to compensate for specific shortcomings [24]. Consequently, employees have been encouraged to develop such workarounds through in-house low- or no-code platforms in order to distribute resulting applications within the whole organization. A similar approach is present in the smart city literature, namely, in the form of participation platforms [61]. In this study, we distinguish between citizens that use smart city services and those that produce them, although both roles can be occupied by the same entity. In the following, the first is referred to as *citizen as consumer* while the latter is referred to as *citizen as developer*.

The same notion of a citizen acting as both producer and consumer can be found in [1]. The authors use the term *prosumer* to describe the possibility of citizens both consuming data services and, at the same time, serving as providers of data for these services through their smartphones with the goal of generating citizen-centric applications. Nevertheless, it has to be mentioned that the term prosumer was originally coined by Alvin Toffler in 1980 [63] and used to describe the shift of companies outsourcing tasks to their customers (e.g., self-checkout systems and fast food restaurants). Later, the same approach was applied during the advancement of the web, where consumers suddenly became responsible for creating and maintaining the content they consume (e.g., YouTube and Wikipedia). Consequently, the term ***user-generated content*** (**UGC**) quickly established itself in this context as a competing concept to the prosumer.

For our study, we deemed the term citizen developer to be most suitable in the smart city context for representing the underlying roles and relationships between them. Keeping the origin of the term in mind, we assume that a respective smart city is equivalent to the organizational environment mentioned above. Under these conditions, it can be argued that, instead of employees, citizens are looking for applications other than the ones provided by the city administration to compensate for specific shortcomings in the city. Such shortcomings could for example be the lack of a suitable platform to develop city tours. In this case, the city administration should aim at providing citizens with a development platform for the realization of their ideas in a low-code or no-code fashion (cf. [48]). The resulting applications and services can then be offered within the smart city environment to benefit all citizens. Hence, our interpretation of the term citizen developer not only ensures the incorporation of citizens' needs during the design of smart city services but also accounts for the responsibility of city administrations to ensure citizen-centricity.

2.4 Conceptual Modeling for Citizen Development

The aim of the citizen development approach is to ease the creation of smart city services for people with little to no software engineering skills. This aim requires a comprehensive specification of people's knowledge so it can be understood by humans and processed by machines. For this purpose, the use of computer-aided conceptual modeling is proposed, which implies that a modeling tool exists to create, digitally save, and process the models.

Conceptual models are abstractions of a domain under study, focusing on the representation of concepts and their relations within models [40]. Concepts form generalizations of objects, which are represented through their properties. Reducing concepts to these essential properties describes the abstraction process directed towards a specific purpose. Thereby, abstraction reduces the complexity of the system under study to make it manageable [40].

In computer science, conceptual models are used to describe information systems [40] with the goal of fostering communication and understanding between multiple stakeholders. To serve this goal, models are created as instances of modeling languages, which define the notation, syntax, and semantics of the models [30]. The benefit of using such modeling languages is that everyone familiar with their definition understands the created models. Furthermore, it is argued that the value of models is increased if they can be automatically processed by tools to put the captured knowledge to work [30]. Such capabilities distinguish the modeling language from the modeling method, as the latter also includes automated processing and guidelines for creating models in addition to the language itself.

Modeling methods should be designed in such a way that they can be interpreted by both humans and machines in the form of computers or other technologies. To make models readable for humans, they must be visualized through their notation. One way of doing so is diagrammatic visualizations, which have the benefit of encoding spatial information in the resulting models [25]. Additionally, computer-aided diagrammatic modeling can further facilitate human understanding if semantic-rich symbols are used to represent the concepts of the domain [44].

The interpretation of models by machines is enabled through the respective metamodel, which describes the underlying architecture of modeling methods in a machine-processable way so that every model instance can be interpreted [28, 30]. Metamodels are created for a specific purpose by applying abstraction to capture the main concepts relevant when creating models in a given domain. These abstractions are then enriched with semantic-rich notations to also foster the human understanding of the metamodel.

2.5 Technologies for Citizen Development

Certain technologies have to be offered and maintained by the city municipality to allow the creation of services in line with the proposed citizen development approach. In this context, technologies are not necessarily physical, meaning they can encompass any kind of applied knowledge used for a specific purpose [18]. Based on this understanding, two technologies relevant to our approach are introduced: microservices and multi-sided platforms. Additionally, we introduce the Scene2Model tool, which forms the foundation for the multi-stakeholder service model design proposed in Section 3.3.

Mircroservices. The development of ICT-based solutions in the smart city is closely associated with IoT, and open data [2, 71]. The resulting applications pose complex challenges for software systems as the interoperability of different technologies has to be ensured [35]. One way to tackle this complexity is the application of web services in the form of a microservice architecture [36]. The functionalities of a software system based on such an architecture are separated into decoupled services, each focusing on an independent functionality [19]. Every microservice is written in its own programming language and possesses its own technology stack. As a result, the microservice architecture reduces the dependency within the software system and supports individual deployment, maintenance, and replacement. Each service runs independently, and communication between services utilizes light-weighted communication protocols (e.g., REST-like interfaces). The workflows of the software system are then executed through the connection of different microservices. Two ways of accomplishing this execution are orchestration, and choreography [19]. Orchestration means that a centralized service exists, which handles the execution of the workflow. On the other hand, such a centralized service does not exist in choreography, and the workflow is embedded into the microservices. We assume that different services in a smart city are provided by multiple stakeholders, like other citizens, businesses, or the municipality (cf. Section 3). Stakeholders should thus be able to define their own services by orchestrating existing ones, as it is often done in microservice architectures. The logic of the created services is then described through conceptual models, which are executed in a microservice environment (cf. [66, 67]).

Multi-sided Platforms. Following the notion of citizen development, an ecosystem must be in place to enable citizen-centric service creation. The concept of multi-sided platforms is introduced in this context, as it offers a suitable orientation for a foundational architecture that supports such an ecosystem. Traditionally, one-sided platforms act as intermediaries that focus on connecting users with providers of specific products or services without an actual interaction between the two parties (e.g., online retailers or streaming services). In contrast to one-sided platforms, which only serve one specific group of users, two-sided platforms are based on generating value through interactions of users with compatible needs belonging to different user groups (e.g., ride-sharing or dating platforms). Multiple dependencies exist between the involved parties in an ecosystem like the latter, as everyone needs to participate in creating value for the other parties [56]. Namely, the provision of offerings, the satisfaction of user needs, and matching the two in a suitable way through an intermediary platform form the underlying prerequisites that have to be fulfilled for a functional multi-sided ecosystem [58]. The platform provider has a special role in this context. They must mediate the interaction between the involved parties and ensure a balance between demand and offerings to foster the value exchange [12]. A foundational architecture for the proposed citizen development approach is oriented on multi-sided platforms, therefore, has to contain at least a platform provider that acts as an intermediary between the involved parties. Notably, these parties of consumers trying to satisfy their needs and providers offering services on the platform can be the same entity, as in the case of AirBnB.

Design Thinking and the Scene2Model Tool. The design and creation of services in complex environments, such as smart cities, often require the collaboration of multiple stakeholders. To address the challenges present during such collaborations, design thinking has been shown as an effective approach (cf. [14]). One way of utilizing this approach are physical workshops that bring together domain experts and employ creative methods to address communication and coordination issues resulting from the presence of diverse stakeholder interests [59]. The results of such workshops aim at capturing the externalized knowledge of the workshop's participants in the form of physical representation, e.g., through paper figures on a table. Scene2Model addresses the challenge of capturing and distributing the externalized knowledge by offering a physical and digital modeling environment that allows an automated digitalization of physical storyboards created during the workshops [41, 42]. The physical storyboard approach uses paper figures to represent stories of users designed in the workshop and is based on SAP Scenes™.[*] These storyboards are then automatically transformed into digital models, which contain not only the graphical representation of the physical scenes but also each of the paper figures as its own object that

[*] https://apphaus.sap.com/resource/scenes.

can be enriched with information or changed individually [47]. The automatic transformation is an essential feature, as it removes the cumbersome task of creating documentation (e.g., the models) for users, allowing them to focus on creating and representing the idea in the workshop. Moreover, the knowledge represented in this way is computer-processable and, therefore, improves its utilization by easing the adding of information to the storyboards as a whole or to its individual concepts.

2.6 Related Works

2.6.1 Conceptual Modeling and Citizen Development. To enable citizen development as described in Section 2.3, citizens have to make their knowledge explicit using models, which can then be executed within smart cities. A similar approach has shown that conceptual models can be used to control ***Cyber-Physical Systems*** (**CPS**) [66, 67]. In both contributions, models capture the domain knowledge and the tasks to be executed within a given environment. In the remainder of this article, we build upon this idea by highlighting how models can be used as means for humans to interact with the smart city environment. Nevertheless, it needs to be emphasized that we do not aim at designing a new modeling method for these interactions. Instead, the objective is to analyze which conceptual components are needed within a smart city to realize a model-based citizen development architecture. We chose the model-based approach as domain-specific conceptual modeling methods have been proven suitable for solving complex domain problems [31, 32].

2.6.2 Smart City-related Conceptualizations. Within the literature, several efforts have been made to conceptualize the smart city as a whole or a partial aspect of it. As this research aims at contributing to these research efforts, an overview of existing approaches is given. Early on, technology factors encompassing both the physical city infrastructure and virtual technologies present in it, as well as human and institutional factors, were identified as fundamental smart city components [50]. Other contributions further differentiate between technology and the physical environment while maintaining the other factors in the form of society and government [23]. Concentrating on open data use, research has been conducted to uncover which components need to be considered in a conceptual framework assessing citizen participation [26]. Beyond the conceptualizations of the smart city, authors have investigated the interaction of service consumers and service providers within the context of a smart service system while highlighting the value co-creation generated through this interaction [10]. In order to support the development of smart city services, existing research proposes a conceptual architecture for data integration and distribution through dedicated smart city APIs [6].

3 CITIZEN DEVELOPMENT ARCHITECTURE: CITIZENS AS DEVELOPERS AND CONSUMERS

In this section, we present a model-based citizen development architecture, which includes the conceptualization of the system and the different roles present in it. The underlying structure of the architecture was derived from multi-side platforms (cf. Section 2.5). Our approach aims at achieving citizen-centric design by enabling citizens to create their own services without requiring sophisticated software engineering skills. Modeling is used to reduce the complexity so that citizens can better understand and design their own services. This reduction in complexity is achieved through the abstraction of technical details by focusing on the utilization of the relevant domain knowledge of citizens and how it can improve the services offered within smart cities. Moreover, we present a specific drone tour guide instance to foster understanding and conclude by arguing how design thinking can further complement citizen-centric design. The latter aims at identifying innovative ideas and corresponding design requirements for new service applications

3.1 Conceptualization of the Model-based Citizen Development Architecture

The architecture for our proposed citizen development system must account for the different entities and technology-enabled interactions that exist within (cf. Section 2.6.2). For this purpose, the interdependence model from our previous work was extended to account for all entities and components relevant to the functionality of

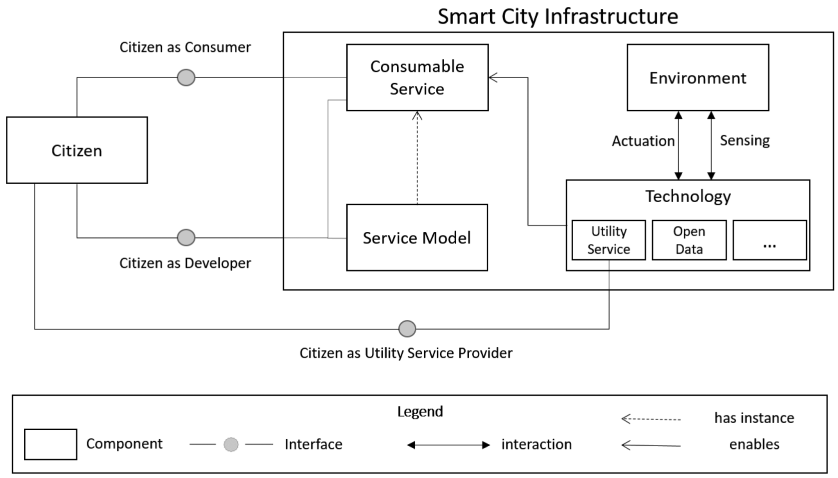

Fig. 1. Citizen development architecture: An extended interdependence model (based on [48, p. 5]).

an interconnected system in which value is created through the exchange of resources in the form of knowledge or services [3, 65]. In this context, interactions enabled by technologies play a crucial role [45]. Hence, different entities, digital as well as physical technologies, and their various interactions are involved and therefore have to be considered in this value-creating system. The resulting abstraction in the form of a conceptualization is displayed in Figure 1.

The *smart city infrastructure* contains *consumable services*, *services models*, its *environment*, and *technologies*, with utility services being part of the latter. In reference to Section 2.5, the city infrastructure and the respective city administration governing it can be defined as the platform provider, that enables the interaction of users with compatible needs.

The *environment* component represents the physical attributes and properties of the respective city, which include static attributes (e.g., location of roads and buildings) and dynamic properties (e.g., weather, live data on traffic or public transport). The term *technology* has been defined in various ways, depending on the historical period (e.g., prehistoric and modern), the underlying perspective, and several other factors. To be suited for the context of this study, the high-level definition presented in [18] is adapted, which entails that technology stems from the application of derived knowledge that is used for a specific purpose while the output does not necessarily have to be something physical. The technology component thus encompasses not only physical objects but also digital applications offered within the smart city infrastructure. One example would be an endpoint that provides open data access (cf. Section 2.2), which can support the creation of services through citizen developers [53, 69].

Nevertheless, technology cannot directly interact with the physical environment, which is why a technology-enabled interaction must be established. This interaction is represented in Figure 1 through the relations between environment and technology, namely, *actuation* and *sensing*. These ways of interaction can be provided by incorporating CPS into smart cities [33], which allows the physical components to be enhanced and made accessible to the services.

In this architecture, the entity *citizen* can interact with the smart city infrastructure by taking on different roles. As a result, the term citizen describes not only a person living in the respective city but also all entities that interact with its infrastructure through varying roles, depending on their respective goal. Citizens either consume already available services, which lets them take the role *citizen as a consumer*, or they provide their domain knowledge for the creation of services, which lets them take the role of *citizen as a developer*.

Consumers interact with the smart city infrastructure through the consumption of *consumable services* to achieve a certain goal. Although consumers don't provide services themselves, they still generate value for the system by paying a price or creating demand, which attracts new providers. Furthermore, the consumers trying to satisfy their needs form another prerequisite defined in the context of multi-sided platforms (cf. Section 2.5).

The interaction as citizen developer happens through the creation of consumable services, and their domain knowledge qualifies them to solve problems they experience themselves. In this context, the citizen development approach employed in this study (cf. Section 2.3) supports citizens in creating solutions in a low-code fashion without the need for sophisticated software development skills. This is achieved through the application of domain-specific modeling methods that provide the means of defining the solution in an executable way. Citizen developers then share their consumable services with other participants on the platform and thereby form the second party of providers offering services (cf. Section 2.5). Their motivation can range from altruistic acts of helping other citizens to monetary compensations they receive from consumers of their services or through agreements with the municipality.

To reduce the complexity of the creation process and support citizen development even further, a consumable service makes use of different available utility services and other technologies from the smart city with the goal of combining existing functionalities. An example of a utility service is the offering of a payment service, which citizen developers can easily reuse and integrate into their respective design of a service. Consequently, citizens or the city municipality can act as a *utility service provider*, which forms an extension to the roles introduced in our previous work (cf. [48]). The motivation for providing utility services can again be monetary value for citizens, as they can offer their services to a broader audience on a pay-per-use basis. Municipalities or governments, on the other hand, can stimulate the system by providing their own foundation of utility services as part of an open government initiative while also offering incentives for every contribution to the resulting multi-sided ecosystem.

The reusability of existing functionalities in the form of utility services is enabled through their microservice architecture as described in Section 2.5. That implies that the utility services are developed independently from each other and run on their own, requiring utility service providers to have software engineering skills, in contrast to the citizen developers. To enable such a combination of services, we follow an orchestration approach [19], where a central unit coordinates all microservices. Within our conceptualization, the orchestrator is represented by a consumable service, which is defined through an individual diagrammatic model (cf. Section 2.4) that can be directly executed within the proposed architecture [67]. Each citizen-developed service forms its own orchestrator of selected utility services which require an interface that is compatible with the citizen-developer platform to enable seamless integration.

Service models form the final component within Figure 1, which represent the abstract specification of citizen developers' domain knowledge lying at the heart of each consumable service. As visualized in Figure 1, the service model alone cannot be executed or consumed as it only forms the specification of the domain knowledge. Hence, it must be configured within the modeling environment to allocate the right interface of utility services and other technologies. This enhanced specification of a service must then be adapted to the respective city infrastructure in order to transform a service model into an executable instance of a consumable service. One essential part of such a transformation is the incorporation of suitable utility services and other technologies to provide the functionalities needed for the execution.

To allow for a separation of the service model and its executable instance, the defined tasks are not directly linked to the interfaces, as this makes the services dependent on the respective smart city technology. The additional abstraction between the technology interfaces and the service model through capabilities, as displayed on a conceptual level in Figure 2, is thus proposed. Capabilities represent an abstraction of the tasks that are needed to execute services within a given infrastructure. In the case of a specific executable instance, the capabilities are allocated to the required technology interfaces of the city infrastructure. Furthermore, if the technology within a smart city changes, a limited number of interfaces have to be reconfigured so that consumable services can be executed within the new infrastructure. This adaptability requires that the technologies are based on a microservice architecture that separates the abilities of the smart city into independent and reusable components offered through a defined interface.

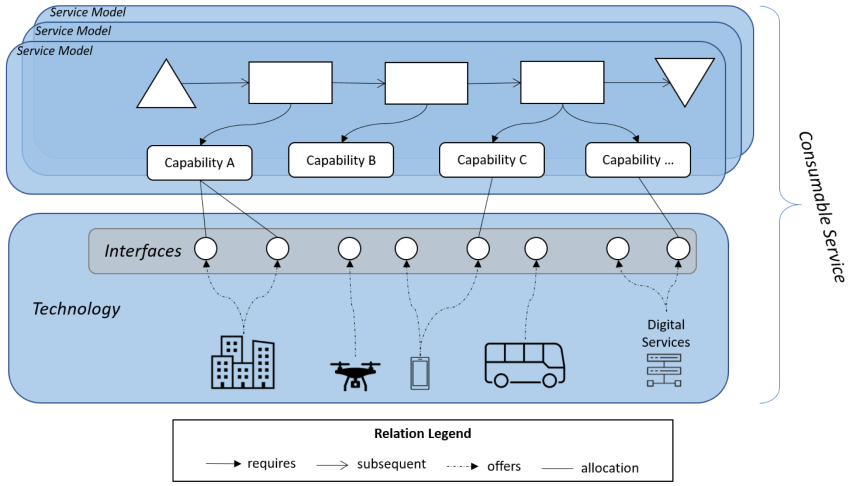

Fig. 2. Composition of consumable services.

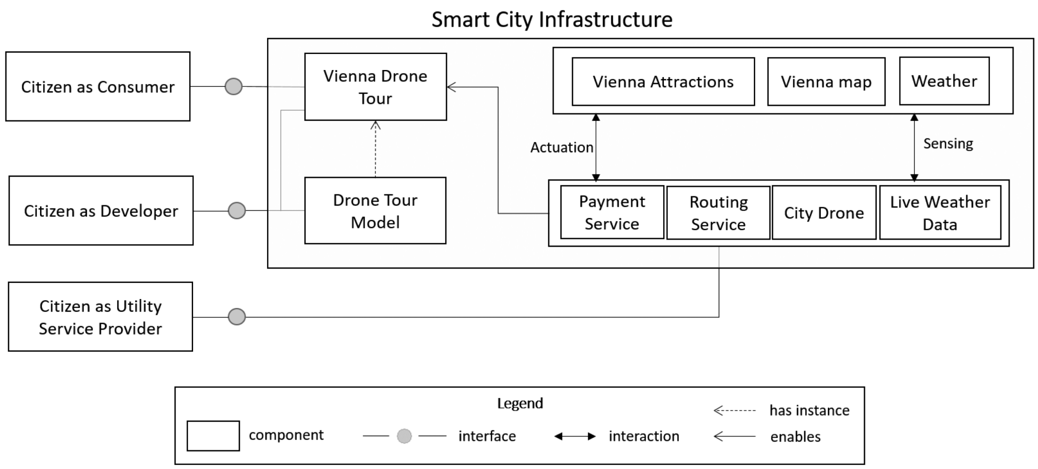

Fig. 3. Citizen development architecture: A drone tour guide instance.

3.2 Citizen Development Architecture: A Drone Tour Guide Instance

When describing a specific scenario within the citizen development architecture, the relevant components of the smart city infrastructure have to be instantiated. An instantiation of the drone tour guide case is displayed in Figure 3, which is reduced to exemplary environment and technology components.

The drone tour guide scenario takes place in the smart city environment of Vienna. The environment contains both static (e.g., *Vienna Attractions* and *Vienna Map*) as well as dynamic properties (e.g., *Weather*) and interacts with the present technologies through actuation and sensing. This technology-based interaction is enabled through both static and dynamic CPSs organized in a microservice architecture that are incorporated into the city infrastructure. Static CPSs like sensor networks are strategically placed in defined locations. In contrast, dynamic CPSs, such as flying drones, gather and use information on weather and traffic conditions while moving through the city.

Additionally, the technology component also contains digital applications that are represented in Figure 3 by selected utility services considered helpful in the context of the scenario (e.g., *Payment Service*, *Routing Service*

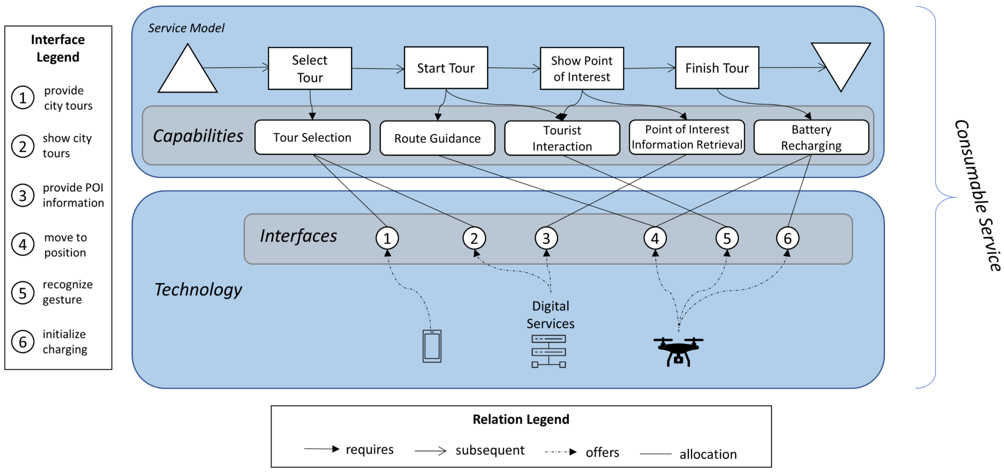

Fig. 4. Composition of consumable services: A drone tour guide instance.

and *Live Weather Data*). Such services are provided by citizens acting as utility service providers. As elaborated before, this role can be occupied by both citizens and organizations which are motivated through monetary incentives, or the city municipality offers the services as part of a government-supported initiative (cf. Section 3.1).

Assuming that the described environment and technology in the infrastructure of Vienna are in place, citizens can interact with the smart city as citizen developers by creating service models that are later transformed into consumable services to satisfy a consumer's needs. Within the presented instance of the drone scenario, this can be citizens of Vienna that decide to use their knowledge about the city to create a tour designed for a specific purpose. The citizen developer benefits from the microservice architecture of the utility services, which enables easy integration of different capabilities provided by the available technologies into the resulting consumable service (cf. Figure 2).

An exemplary instantiation of the composed consumable service in the context of the tour guide scenario is represented in Figure 4. In this representation, the citizen utilizes the benefits of the microservice architecture by designing the respective tour as a process within a dedicated modeling environment. The different tasks contained in the tour require specific capabilities, like the selection of a tour from an existing database. To execute the defined tour in a real environment, these capabilities must be allocated to the technologies present in the respective smart city environment. This allocation process is enabled through interfaces, which abstract the functionality that the technology components (e.g., users' smartphone, drone as a tour guide, and available smart services) offer to the environment. For example, the tour selection needs to retrieve a list of all city tours and provide them to the interface of the user's smartphone.

Through the allocation of capabilities to concrete interfaces, the drone tour model from the example is transformed into a consumable service within the Vienna infrastructure that can be used by citizens acting as consumers. Although this service model is specified for a drone, the microservice architecture allows for the reallocation of utility services so that the tour can be adapted for the execution by different technologies available in the infrastructure.

3.3 Multi-stakeholder Service Model Design

Previous elaborations on the smart city setting (see Section 2.1) did not cover the fact that multiple stakeholders are usually involved during the design implementation of smart city services, which further complicates the process [5]. Relevant stakeholders could potentially include city planners and technicians to implement necessary

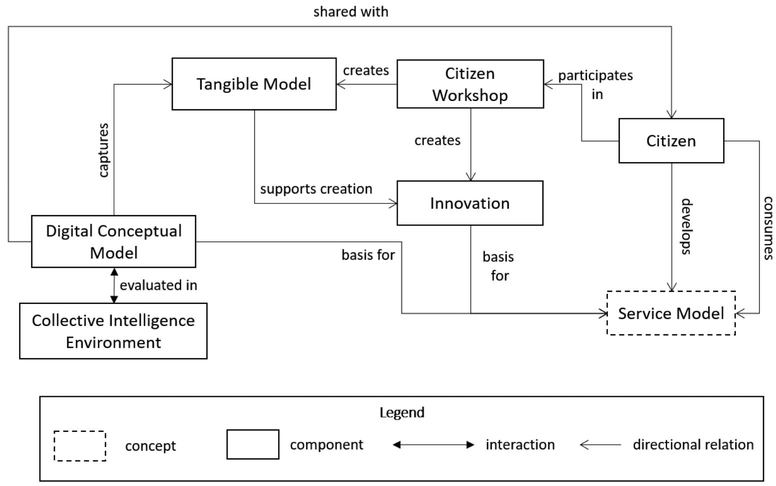

Fig. 5. Components of the multi-stakeholder service model design approach.

infrastructure changes, citizens influenced by the service, and representatives of the city municipality. Furthermore, citizen developers and utility service providers should also be considered relevant stakeholders in the smart city context.

We argue that the initial phase of the innovation process and identification of requirements for future service models can be supported through both creative workshops and conceptual modeling. The goal is to identify citizens' problems and needs and capture them so that they can be understood and shared with involved stakeholders. In Figure 5, an overview of the most relevant concepts in our multi-stakeholder design approach is visualized.

The central component of our idea is the use of *citizen workshops* to bring multiple stakeholders together and allow the exchange of ideas in a comprehensive manner. Citizen workshops are inspired by creative workshops used in design thinking, whereas the name itself highlights the crucial role of *citizens* participating in the workshops. The physical design thinking workshops are used within our approach to facilitate the co-creation of multiple stakeholders, and the resulting knowledge in the form of *tangible models* can be digitized as *digital conceptual models* through the Scene2Model tool (cf. Section 2.5). Therefore, the knowledge itself is created through creative methods in the workshop, and Scene2Model is used to capture this knowledge in digital models to support its utilization and distribution.

Digital conceptual models are a known tool used for describing information in a comprehensible way and are thus suitable to serve as the medium for knowledge exchange between stakeholders (cf. Section 2.4). In this article, the focus lies on diagrammatic models since graphical visualization significantly improves comprehensibility for humans.

The digital models resulting from a workshop can thus be used to communicate innovative ideas between stakeholders by sharing them directly with other citizens or evaluating them in a collective intelligence environment. This entails sharing enhanced models with a large group of people to gather feedback, for example, through social media. The modeling environment of Scene2Model enables the automated publication on such a platform and later gathers the feedback, automatically processes it, and saves it with the model. In this context, sentiment analysis can be used to analyze the mood of people replying to social media posts and assess if the general idea is well received by a broader audience [70]. The created innovative idea and the evaluated digital conceptual model (representing the results from the citizen workshop) can then be used as the basis for the development of service models as described in Section 3.1.

4 DISCUSSION

In order to evaluate the proposed citizen development architecture, we present a SWOT analysis combined with insights from the tour guide instance to assess our idea not only on an abstract level but also in a case-specific context.

Strengths. The main strength of the proposed architecture is the abstraction through conceptual modeling and the execution in an underlying microservice architecture of utility services that form the basis of the low-code development approach. It is intended to serve as motivation for citizens without technical skills to interact with the smart city and make good use of their domain knowledge by developing consumable services. Incorporating the citizen perspective directly into the development process of smart city services in this way follows the notion of citizen-centric design.

Furthermore, the separation of consumable service and service model supports the design of the latter independent of specific technologies. This separation of the service workflow and its execution facilitates adaptation to changing technologies, as existing capabilities can be allocated to new services, while the defined workflow stays the same.

Modeling not only supports the definition and execution of services but also improves communication between multiple stakeholders. Here conceptual modeling with tool support helps citizens by digitally capturing knowledge from physical citizen workshops for automated processing. This can be the transformation from a physical to a digital knowledge representation or an evaluation within a collective intelligence environment.

Weaknesses. Implementing and operating the proposed system is inherently complex. Therefore, the effort must justify the expended means, inferring that the value generated for the smart city is big enough. We have applied the proposed modeling and execution approach in our teaching and in the OMiLAB experimentation environment (cf. [29]). An implementation for the proposed approach of Section 3.3 is the Scene2Model tool [41]. Still, there is no functional system in the real world that can be used to explore our proposed architecture. Therefore, the difficulty in estimating the effort needed and the potential success of this implementation stands out as our main internal weakness.

The creation of consumable services enables citizens without technical skills to interact with the smart city as developers while, at the same time, the overall functionality of the resulting services is limited by the available technologies and the modeling environment. Existing utility services have an especially strong influence on the number of distinct consumable services that can be created. Within the example from the drone tour guide instance, the tour could not be developed in a low-code fashion if the needed capabilities are not provided upfront.

The microservice architecture of the utility services requires the corresponding interfaces to be standardized, which limits their capabilities and efficiency, especially since the interfaces should be usable through configuration by non-experts, who allocate the interfaces to service models. If new technologies should be implemented for utility services, it can come to a delay in the adaptation, as people without technical skills may not grasp the capabilities and benefits. In this regard, it is important to consider the existing smart city-related standardization efforts (cf. Section 2.1, or [4]) when implementing the proposed citizen development architecture in an existing smart city.

Opportunities. If the citizen development architecture is assumed to be established, the most promising opportunities encompass the adaptability of service models, the development of new innovations through the use of design thinking, and the positive effects of a government-supported ecosystem. The adaptability of service models is enabled through the separation of services, which are described using abstract capabilities. Since they are only afterward transformed into a consumable service and instantiated to the respective city infrastructure, service models can be easily adapted to different smart cities by reallocating the respective interfaces, assuming the same capabilities are available.

The previously mentioned strength of easing the communication between citizens through design thinking turns into an opportunity for the future if a feasible number of useful innovations can be derived from citizen workshops. The feasibility is especially important in case a city commits to building up a government-supported ecosystem as described in Section 3.1, in which smart city standards can be established to. This includes the provision of necessary technologies in the form of utility services, open data endpoints, and physical technologies like sensors or even drones. Hence, the utilization of existing smart city standards can facilitate the seamless integration of new utility services to be used in various service models. At the same time, such a government-supported ecosystem promotes the opportunity of developing more sophisticated innovations that can increase participation, trust, and the quality of life among citizens with the overall goal of advancing smart city development. Investigating such effects can offer interesting new research possibilities to the already existing contributions (cf. 2.2).

Threats. Finally, a number of threats must be considered in the context of our citizen development architecture. First, the potential lack of governmental support for establishing a citizen development architecture could be a major threat since providing an equipped environment and suitable technologies might require major initial investments and adaptations in the city. Furthermore, the utilization of open data as part of the technologies brings along an increased risk of cyber-attacks [54], which must be considered as a serious threat to the architecture, even more so if fundamental services relevant to everyday governmental interactions are organized within it. Appropriate measures to minimize such risks of cyber-attacks and potential far-reaching problems need to be implemented to protect the system.

The general premise of the proposed model-based citizen development architecture is that citizens interact with the smart city assuming different roles. However, all the different roles must be fulfilled to enable value creation. If one of the roles is under-occupied, the system cannot work, as often is the case with multi-sided platforms (cf. Section 2.5).

Lastly, the threat of increasing the digital divide among a city's population has to be addressed. The digital divide describes the gap between individuals regarding their access to modern ICT (e.g., internet and smartphones), which might be explained by socio-demographic factors like age, income, and geographical location [60]. Therefore, efforts have to be made so that the benefits provided by establishing a citizen development architecture are available to all citizens. Providing physical spaces in affected areas to access the ecosystem is one of the possibilities to meet this challenge.

5 CONCLUSION

The central claim of our contribution is that the low-code-enabled citizen development approach ensures the citizen-centric design of service in the smart city by directly involving citizens in the innovation and development process. The underlying notion of citizen centricity has evolved over time from the early techno-centric view to now being an essential building block of smart cities [17]. Several closely related terms are discussed in the literature, among them citizen engagement and citizen participation, which are considered prerequisites for citizen centricity and smart city development (cf. Section 2.2). Nevertheless, the elicitation of citizen engagement still is a major challenge for today's smart cities [13], and the interaction with governmental institutions is still seen as a problem-solving process [68].

As the main contribution of our article, we present a citizen development architecture intended to foster citizen centricity and participation by easing the development of smart city services for citizens that would otherwise not be engaged due to a lack of technical skills. We propose a modeling-based low-code approach to allow a wide range of citizens to create such services. This enables citizens to make use of their domain knowledge regarding shortcomings or problem-based potentials within the respective city, as they are the ones who face and understand them. Conceptual models are used to define the domain knowledge in an abstract way while specifying the necessary capabilities to make the resulting models machine-processable and executable within the smart city infrastructure. In this context, we separate service models, which are high-level representations of the service without an allocated execution environment, and consumable services, which are service models instantiated to a specific smart city infrastructure. The last element of importance from the architecture are utility services, which provide the reusability and easy integration of existing functionalities, such as retrieving city-related information from open data endpoints. The drone tour guide case was presented as an exemplary instantiation within the smart city to better understand this abstract system.

By combining the methodology of design thinking with conceptual modeling, we provide a simple way to help citizens express their innovative ideas communicated in citizen workshops. These ideas are evaluated in collective intelligence environments and can be enhanced with information or shared with other stakeholders. If sophisticated modeling tools are available, these approaches can accelerate the communication and evaluation process.

As this approach aims at improving citizen-centricity in smart cities, there are still questions to answer before the whole architecture can be used. For example, it is important to identify concrete technologies that can be employed for its implementation on a scale suitable for a smart city. Furthermore, it will be necessary to understand how such an architecture can be managed by the municipality. Enabling citizens to directly provide their knowledge, and thereby create innovative services used by others, could facilitate new opportunities in smart cities. However, more research is needed to ensure such an architecture will be functional. Since no architecture of this kind exists in the real world, a future research possibility will be a prototypical implementation on a smaller scale within a smart city to assess the necessary effort and the created value for involved citizens. Once such an architecture is implemented, it has the potential to grow gradually and offer more and more services over time. One intriguing idea is that this way of fostering the development of smart cities could become a standard in the future, especially when assuming the involvement of governments. It is, therefore, crucial to elucidate the real value of the proposed architecture. The next step in this regard will be to identify smart cities with an infrastructure that can support a corresponding implementation.

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Received 20 December 2022; revised 20 March 2023; accepted 10 May 2023