DISDA: Digital Service Design Architecture for Smart City Ecosystems

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Abstract: Due to the interoperability difficulty and development bottleneck of various services in a city, the effective design of services has become a critical concern in smart city ecosystems. Based on the interconnection concept of Management by Competencies, this paper proposes an DISDA architecture to facilitate the digital service design in a smart city ecosystem. The DISDA architecture not only can guide the users to design the services with the defined processes but also can measure the maturity of the existing services and determine possible service improvements. Based on the proposed service design architecture, we conduct a case study to validate the usability and applicability of the proposed service design architecture.

1 INTRODUCTION

With the rapid growth of emerging smart technologies and services, smart city ecosystems have been extensively studied over the last decade (Gascó-Hernandez, 2018; Albino et al., 2015). From previous studies, it can be seen that digital services have been considered as one of the important components in a smart city ecosystem, since the digital service is capable of connecting service providers, users, infrastructures, and communities in a common ecosystem to support the value co-creation (Kashef et al., 2021; Salim et al., 2021).

On the other hand, digital service creation and delivery have become one of the strategic objectives in smart city ecosystems and can directly echo the stakeholders' concerns in a smart city (Oliveira and Campolargo, 2015; Buhnova et al., 2022). The importance of digital service has demonstrated that the capacity of smart city ecosystems to create and share value for stakeholders is directly related to new information technology, processes, services and associated business and information architectures (Silva et al., 2020). In this paper, we consider smart city as a typical ecosystem, and in turn the services are scoped as the digital services in a city.

While service-oriented initiatives have been developed in a variety of domains such as urban planning, mobility, transportation, smart living and community, smart environment, emergency, e-health, and government (Kashef et al., 2021; Ge et al., 2018), we found that the services in one domain are usually developed for some specific purpose or for this domain only. Therefore, the current services in the smart city ecosystem often encounter interoperability and development bottleneck issues (Koo and Kim, 2021). This results in that even similar services among different domains are isolated with each other. For example, the transportation IoT service in the mobility and transportation domain cannot be re-used for the urban road construction or emergency route planning (Bangui et al., 2020). Thus, urban planning and emergency domain have to develop their own services respectively to obtain the transportation information (Bangui et al., 2021).

As a result, it can increase the service creation cost, increase service incompatibility and possibly reduce the citizen's satisfaction. Furthermore, a large amount of the developed services are not aligned with the unified goal in smart city ecosystems and the service provider does not know how to improve an existing service, for example, (Kakarontzas et al., 2014) found that 44% of the services do not have a clear goal that can respond to the demands in a smart city ecosystem. One of the reasons is that there is a lack of systematic service design architecture in the smart city ecosystem. Service design, especially digital service design, is critical for building a smart city ecosystem.

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This paper, therefore, aims to develop a systematic service design architecture for the digital service developments in the smart city ecosystem. We have adapted the framework from Management by Competencies (Plamínek and Fišer, 2005) due to its interconnection nature and incorporated this framework with digital service design processes. Instead of developing a reference architecture like (Clement et al., 2017) to profile services in a smart city ecosystem, the proposed architecture focuses on facilitating the processes of digital service design in smart city ecosystems.

The contributions of the paper are accordingly two-fold: (1) a systematic service design architecture DISDA that can guide the users with a defined specification to design the digital services, (2) a maturity pyramid of the service design that can be used to define the goals of new service design, measure the service maturity and improve the existing services in smart city ecosystems.

The remainder of the paper is organized as follows. Section 2 revisits the related work on service development and service engineering for service design. Based on the review, Section 3 proposes a digital service design architecture, which is adapted from the framework of Management by Competence. Section 4 further describes the specifications of the architecture from four perspectives: usefulness, efficiency, stability and dynamics. In order to validate the architecture, section 5 conducts a case study in the context of smart transportation. Finally, section 6 concludes the paper and outlines future research for digital service design in smart city ecosystems.

2 SERVICE DEVELOPMENT AND SERVICE ENGINEERING

Service development research is directly related to service design. The early research works regarding service development can be traced back to the 1970s, and at that time, new service research streams have appeared (Moradi et al., 2020), such as *New Service Development*, *Service Design*, *Service Engineering* (Dragoicea et al., 2020). Over the last decade, integrating physical products and various services has become a crucial strategy for many companies (Pirola et al., 2020). However, designing and developing a Product-Service System (PSS) is a complex task due to a long-term relationship among different actors in the system (Song et al., 2021). In order to cope with the complexity in service design and development, researchers proposed a large number of models and methods to design a PSS. However, most of these models and methods lack evaluations in practice (Pirola et al., 2020). Therefore, the design of services is still on the theoretical level as seen in (Janácek and Fabricius, 2021), and service development is less efficient than the development of physical products (Froehle et al., 2016). This motivates us to further conduct research on the service design and carry out the design in practice such as Smart City context. In this paper, we define the digital service design process by adopting the concept of New Service Development, which is defined as a process of developing a new service from initiating an idea for a service to the service market launch (Lin and Hsieh, 2011). As such, the process of digital service design starts from service idea initiation and ends with realizing the service in the smart ecosystem.

Another research stream dealing with design and development of services is the service engineering. It approaches the service design challenge in a systematic and methodological way using engineering know-how. It is, therefore, a rational and heuristic approach based on the discussion of alternatives, goals, constraints, and procedures, through the adoption of modeling and prototyping methods, aiming to increase the value of service offering by improving the service conception, service delivery and service consumption (Shimomura and Tomiyama, 2005; Chohan and Hu, 2020; Holmlid and Evenson, 2008). Most renowned service engineering process models are based on the following three classical models. (1) Waterfall model, a linear, sequential design process following phases of requirements analysis, design, implementation, testing, integration, and maintenance. It is a simple model, not recommended for complex development. (2) V-model, a linear product-development process in shape of a letter V. The left side of the V describes a decomposition of requirements and a creation of system specification, while the right side stands for integration of decomposed parts and their verification. (3) Spiral model, a model with a cyclic approach for improving the precision of definition and implementation of the system in several increments (cycles) for a decrease of a risk degree.

In (Pezzotta et al., 2014), the authors conducted a detailed analysis of the literature on service engineering process models and derived four main common phases, (1) customer analysis, (2) requirements analysis, (3) PSS design, (4) PSS test and implementation. They argue, as well as some others (Bertot et al., 2016), that a customer is an important element of a service design since they co-design the service, but there is another important factor, which is the company itself. It needs to standardize and optimize its processes for it to remain competitive. Based on this idea, they propose Service Engineering Methodology that is aligned with other service engineering process models in terms of the four phases. In this paper, we consider service engineering models as a development base for designing the digital services in smart ecosystems (Walletzký et al., 2019).

3 DISDA: DIGITAL SERVICE DESIGN ARCHITECTURE

DISDA is a digital service design architecture inspired by the Management by Competencies (MbC) that was developed as a holistic guideline for the companies and intended to solve problems from root cause instead of patching from where the service pitfalls take place. MbC is a systematic method for company management. It is based on a harmonic development of competitive and soft aspects of business environment. The main rationale behind MbC is to interconnect the discrete company segments, performance *requirements* and company *competences*. It is based on several well-known theories such as Theory of constraints (Goldratt, 1990), Theory of vitality (Plamínek, 2006), Person-centered approach (Rogers, 1979), Learning organization (Senge., 1994), Scientific management (Taylor, 1911), Re-engineering (Hammer and Champy, 2001), as well as Balanced scorecard (Kaplan and Norton, 1996).

The goal of MbC is to help the company achieve *vitality*, which is a status of the company can be continuously successful, not restricting the possibility of being successful in a shot time. In other words, not exhausting its own resources just for one-time success. MbC defines competence as an ability to use human resources of a personnel (such as knowledge, skills, qualities) on a specific task in order to fulfill the task's requirements, whereby, the competencies and tasks help interconnect the performance requirements of a company with possibilities it has. MbC helps to reach vitality by developing the relationships among its requirements and possibilities using employee's *competencies*.

The strategy of developing requirements is described by one of the MbC tools, the pyramid of vitality, see Figure 1. It states that every service design can start from thinking about usefulness. That is, which product or service from the company can be delivered and useful to the stakeholders. The process goes from identifying stakeholders, their needs and defining a service that satisfies the needs of stakeholders. In the next step, it comes to level of the efficiency, where the specified service is decomposed to processes and activities with necessary resources that are gathered into appropriate structures to ensure proper distribution of resources for the processes and activities.

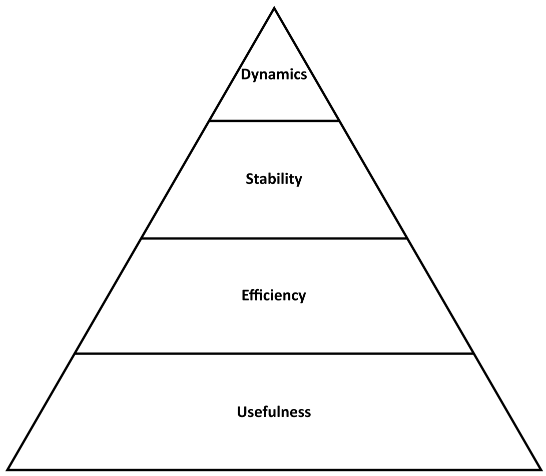

Figure 1: Pyramid of Vitality adopted from MbC.

Nevertheless, creating a service and receiving a temporary profit in return can be not stable. For example, the company can be negatively affected by business or requirement change, which is a critical part of the business environment. The company needs to be able to react quickly to those changes. Thus, the third level is the continuous improvement in the company such as process optimization and conforming market trends e.g. based on the customer research. Hence, the stability level is about company's improvement based on customer feedback and people who is willing to react to changes in the company and quickly allow the changes.

Finally, the strategic step to vitality is called dynamics. It should not only be just reactive for the company, it should be also proactive, such as predicting the future and being prepared for market trends, or even influencing the future. For this objective, the people who are involved in a company should actively search for new opportunities and ideas. MbC approaches the development of a company in a meaningful and logical way from the fundamental step of finding stakeholders, for whom the company aims to provide useful products or services, through the efficiency of a company processes, till predicting and creating new areas for business. We found that the rationale of MbC is in line with our perception of digital service development in smart ecosystems such as smart cities. Therefore, we adopt the four maturity levels from MbC to develop the following digital service architecture.

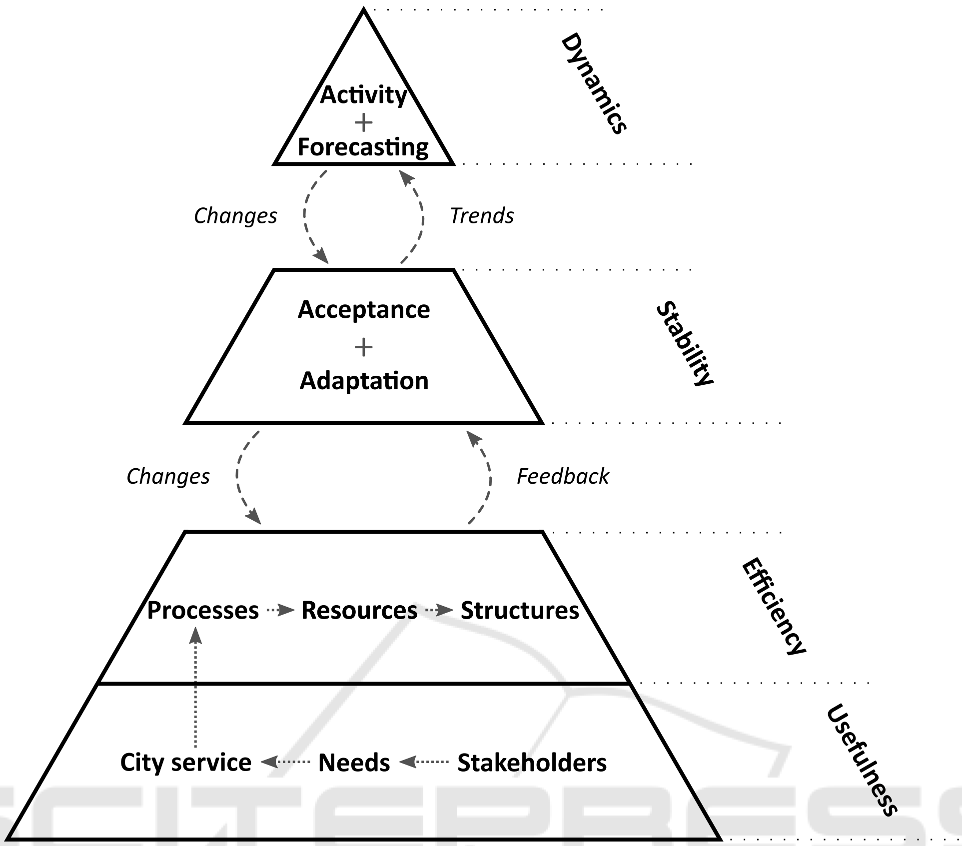

Figure 2: DISDA: Digital Service Design Architecture.

4 ARCHITECTURE SPECIFICATIONS

In this section, we specify our DISDA digital service design architecture as Figure 2, which is inspired by MbC, specifically the pyramid of vitality based on the Theory of Vitality. The pyramidal shape illustrates the strategy of digital service development and consists of four levels as the pyramid of vitality and maturity. We describe each level from bottom to top as follows.

4.1 Usefulness

The goal of the first level of the DISDA architecture is to find out which services a city ecosystem needs to be created, for example, the city can choose and define city service that will fulfill the specific needs of the stakeholders. In this stage, the city needs to follow a definition scheme, which has reversed order. It means that the city should at first focus on determining the stakeholders (e.g., commuting citizens), then identify stakeholders' needs (e.g., to travel efficiently throughout the city) and finally propose a service that fulfills identified needs (e.g., intelligent traffic control service). The service of intelligent traffic control should be described as precisely as possible at this stage to define measures of the service success. Thus, usefulness level specifies a relevant city service by choosing the stakeholders to whom a city will offer values in term of appropriating city services that can address their needs.

Table 1: Usefulness properties.

Property	Definition
Goal	choose and define relevant digital services
Input	information about stakeholders and their needs
Process	stakeholders need city service
Output	service specification

Usefulness: Efficiency Relation. The service specification in the usefulness level is then transferred to the efficiency level for further optimization.

4.2 Efficiency

In this phase, the efficiency level is to define the service development and creation. It starts with an elaboration of the service (e.g., intelligent traffic lights in our case) into a process map describing a service creation process (e.g. simulate different traffic lights distributions, changing traffic lights for intelligent ones), followed by resources identification and assignment (e.g. storage, computers, traffic lights, engineers, laborers). And arranging this complex into appropriate structures (e.g., simulation can run in parallel with finding more information about possible providers and precede the change of current traffic lights) to supply the resources for respective processes. Efficiency level ensures an efficient creation of the city services by defining the processes and their resources organized into structures in order to provide a proper amount of quality resources to the right object and on time.

Table 2: Efficiency properties.

Property	Definition
Goal	improve or optimize service process
Input	service specification from the usefulness level
Process	city service specification → processes → resources → structures
Output	process definitions with required resources, organization structure definition, role specification
Output	service specification

Efficiency: Stability Relation. The relation between these two levels is recurrent, while the stability level acquires feedback from the efficiency level and translates them into change actions for efficiency level.

4.3 Stability

In order to adapt and enhance the service (functionality, efficiency, reducing costs, etc.), the city needs to get the feedback by using the service. Feedback can be automatically acquired in the form of sensed and evaluated data (e.g., service response time, service malfunction reports) as well as in the way of users' opinions (e.g., what they like, what they are missing). Stakeholders' involvement is needed to evolve the service, e.g., service users need to be willing to share feedback, the city needs to manage the service, and the service provider should upgrade the service efficiently based on the feedback. The stability level helps a company to quickly react and adapt itself using feedback and stakeholders' cooperation.

Table 3: Stability properties.

Property	Definition
Goal	obtain and evaluate relevant data and information about service and service context to confirm current approach or to propose a service change
Input	service data & stakeholders' information
Process	get data → evaluate by goals → confirm current approach | propose service changes
Output	service confirmation | service change proposal

Stability: Dynamics Relation. Dynamics gathers relevant data from the stability level to predict the trends and proposes possible changes back to the stability level. The relation is also rotative, but the duration of one execution cycle is usually longer than the efficiency – stability relation.

4.4 Dynamics

The dynamics level proactively prepares possible changes and predicts the future state in parallel with the service adaptation. Forecasting as well as influencing the future is a challenging task that needs the active participation of stakeholders. Therefore, even more demanding personnel management is necessary for enabling stakeholders' pro-activity. The dynamics level proposes service changes based on forecasts and estimations of the future allowed by stakeholders activity achieved by personnel management. With the recent development of machine learning and big data technologies (Macák et al., 2020), the predication function can be more integrated to services. It also reflects the "smartness" of service, which is in the city ecosystems called as smart services.

5 CASE STUDY

In order to validate the DISDA architecture, we have conducted a case study in the context of smart transportation for a metropolitan city in Czech Republic. The case study is targeting on the traffic control service that is designed for more than 700 000 inhabitants in this city. The city aims to design a smart

Table 4: Dynamics properties.

Property	Definition
Goal	forecast future trends and possibilities in a larger context and be prepared for them
Input	data and information from the context
Process	get data → find trends → propose service changes
Output	service change proposal

transportation service for its citizens. We will use the DISDA architecture to design smart transportation service in the city.

As shown in Figure 2, the DISDA architecture is developed to guide the practitioners to design services in a smart city ecosystem. In our context, we focus on the transportation service design. In the initial usefulness level, a smart transportation service firstly has to be useful and meet the user's requirements. Therefore, this service needs to provide a safe and reliable service for the citizens to travel around the city. This can meet the basic requirement of citizens.

Afterwards, the service design enters to the second level that focuses on the efficiency. In this level, the processes and structures of services can be improved to more efficient. For example, with limited resources how to cover the most inhabited locations by the public transportation network, also how to make the travels from A to B more smooth by reducing the transition time. The DISDA architecture can effectively indicate the service design objectives when the service can meet the basic needs of the citizens.

In the stability level, the service design begins to involve the feedback from the citizens. This is featured by a feedback and changes loop. This loop is expected to make the magnitude of changes in a convergent way, in turn it can reach the stability status of a service. In order to consider one concrete transportation service in our case study, we have scoped down the traffic control service as a sequence of the traffic lights in the roads. For example, the light iteration can be optimized to allow traffics to wait for less red lights.

Furthermore, the smart transportation service provides a channel to collect feedback from the citizens as well as adapt the service to address the new or changed requirements. For example, if citizens provide the feedback that at the rush hours some traffic lights in the main roads can be optimized. This can on one hand reduce the possibility of traffic jam and on the other hand increase the citizen's service satisfaction. The feedback channel in this phase is important as the service stakeholders are usually do not know how to quickly send feedback to a public service. Assuming the well-known and easy-to-use feedback channel, the feedback is expected to be converged to a stabilized limited amount.

Therefore, the stability phase is expected to balance the adaptation of the service, acceptance and satisfaction of citizens. Also in this phase, the service can handle the interoperability across different services. For example, traffic control service can also cooperate with the school service, some traffic light near school can be adjusted based on the school-off time.

Finally, the service is expected to have the ability of predicting and preparing to react to possible or unexpected situations. For example, if there is some special event or celebration in the city, traffic control service can predict other possible routes based on the constraint of expected blocking roads, and meanwhile make clear detour for the citizens.

Consider that when different services in a city are designed with the DISDA architecture, we are able to interlink and connect the services in the same level. This is especially important when different service have reached the stability level. The changes in the level should also include the interoperability improvements across different stable services. For example, a stable transportation service can be interconnected to the healthcare services in the city. By using the DISDA architecture, when designing the smart services, we can easily identify the level of a smart service, and the goal of reaching to the next level. Thus, the usability and applicability have been verified during this case study.

6 CONCLUSIONS

This paper proposes an architecture, named DISDA, to help the users to design new digital services and improve existing digital services in smart city ecosystems. The DISDA architecture is adapted from the essence of Management by Competencies, which contains four maturity levels: usefulness, efficiency, stability, and dynamics. In each level, the service design processes are specified to illustrate how to design the service in order to achieve the maturity level of the service. Among the levels, the relations are described to guide the service designers to walk from one level to another. More importantly, different smart services can be inter-connected with each other for each level.

In order to validate the proposed architecture, we have conducted a case study on smart transportation service in a metropolitan city. The results of the case study have indicated the usability and applicability of the DISDA architecture. Furthermore, it can be seen that DISDA architecture can facilitate the service design, service improvement as well as handling the interoperability across different services so that to formulate a smart city ecosystem.

As future works, we plan to refine further the service design processes and conduct more case studies in different application domains to verify the validity and reliability of the proposed digital service design architecture. We will also deepen the architecture into a technical design and further show the how different services can be connected in each DISDA service maturity level.

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